EVALUATION OF GROUTING AS A MEASURE FOR CONTROLLING GULLY EROSION IN NANKA SANDS GEOLOGIC UNIT IN ANAMBRA STATE. NIGERIA

BY

ONUOHA DAVID CHIJIOKE

NAU/PG/PhD/ 2014347001F

DEPARTMENT OF ENVIRONMENTAL MANAGEMENT,

FACULTY OF ENVIRONMENTAL SCIENCES,

NNAMDI AZIKIWE UNIVERSITY, AWKA

MARCH, 2018.

EVALUATION OF GROUTING AS A MEASURE FOR CONTROLLING GULLY EROSION IN NANKA SANDS GEOLOGIC UNIT IN ANAMBRA STATE, NIGERIA

A DISSERTATION PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY (PhD) DEGREE IN ENVIRONMENTAL MANAGEMENT

BY

ONUOHA DAVID CHIJIOKE

NAU/PG/PhD/ 2014347001F

TO

THE DEPARTMENT OF ENVIRONMENTAL MANAGEMENT,

FACULTY OF ENVIRONMENTAL SCIENCES,

NNAMDI AZIKIWE UNIVERSITY, AWKA

SUPERVISOR: DR. ONWUKA, S. U.

MARCH, 2018.

CERTIFICATION

This is to certify that this project report has been carried out by Onuoha, David Chijioke in the Department of Environmental Management. The work embodied in this project is original, and to the best of my knowledge, has not been submitted in part or full for any other degree of this or any other University.

------------------------------ ----------------

Onuoha, David Chijioke Date

(Student)

Reg No.: NAU/PG/PhD/ 2014347001F

APPROVAL PAGE

This is to certify that this dissertation"**Evaluation of Grouting as a Measure for Controlling Gully Erosion in Nanka Sands Geologic Unit in Anambra State, Nigeria**" has been supervised, examined and approved for the award of **Doctor of Philosophy (PhD) in Environmental Management,** in the Department of Environmental Management, Faculty of Environmental Sciences, Nnamdi Azikiwe University, Awka.

To the best of my knowledge, the work embodied in this dissertation is original and has not been submitted in part or full for any other degree of this or any other University.

----------------------------- ------------------------

DR. S. U. ONWUKA Date

Dissertation Supervisor

----------------------------- ------------------------

DR. C.O. OKOYE Date

HOD Environmental Management

----------------------------- ------------------------

PROF. P. A. O. ODJUGO Date

External Examiner

----------------------------- ------------------------

PROF.(MRS.) V. C. NNODU Date

Dean Faculty of Environmental Sciences

----------------------------- ------------------------

PROF. IKE ODIMEGWU Date

Dean of Post Graduate Studies

ACKNOWLEDGEMENT

I am very grateful to Almighty God for the inspiration, life, health, provision and the enablement of the Holy Spirit that was instrumental to the reality of this work. May His name ever be praised.

May I acknowledge Dr. S. U. Onwuka, my amiable and indefatigable supervisor, who play

ed the role of a teacher, a director, a companion and most of all a father to me while this work lasted. I appreciate your stimulating advice, meaningful suggestions and constructive criticisms which led to the actualization of this vision. God will continue to bless you.

I am highly indebted to Prof. (Mrs) V. C. Nnodu, my Faculty Dean and Academic mother, for her assistance and corrections most importantly in suggesting a befitting topic to picture the vision of this research work. I appreciate the support of my able Head of Department Dr. C. O. Okoye for his approvals, corrections, attestations and timely response to my needs in the course of this work. My special thanks go to Dr. B. O. Uwadiegwu, my Departmental PG Coordinator for his advice, training, timing and co-ordination during the research. I also thank Prof. S. Uchegbu, Dr. A. C. Okoye, Mr. E. Anyaeze, and other lecturers who took it upon themselves to read through my work and make all the reasonable corrections which brought the work this far, may God reward you all.

I appreciate the assistance of Mr. Chigozie of Statistics Department Unizik, Awka, who helped me in the statistical computation of my data. I also appreciate the assistance of Engr. Chinedu Anyanwu, the Laboratory Technologist at Civil Engineering Department University of Nigeria Nsukka who designed the equipment and rainfall simulator for my erodibility analyses.Mr. David Okechukwu Okeke, the Chief Analyst of Spring Board Laboratories Udoka Housing Estate Awka, for helping me with the Laboratory analyses and some essential materials. I am indebted to Mrs. Ibekwe of EVM Department for helping me in the area of information making me aware of the happenings in the Department whenever there was need. To my colleagues Mr. Anyasie, Obibuzor, and Uzomba for your helpful discussions and suggestions I say a big thank you and pray the Almighty God to reward you all bountifully in Jesus name. Amen.

DEDICATION

I dedicate this work to my beloved wife Esther, who took the pains of covering me up while this work lasted. You took my place in the house and supported me in the work, while I was away in the field, in the laboratory and in school my house was in order because you were home. To my beautiful daughter, Adaeze who always call me back to the work table with her midnight cry, I love you so much.

TABLE OF CONTENTS

CHAPTER TWO: CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

CHAPTER THREE: THE STUDY AREA

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

AAS:	Atomic Absorption Spectrometer's
ANOVA:	Analysis of Variance
APHA:	American Public Health Association
CaCl:	Calcium Chloride
CaOH:	Calcium Hydroxide
CEC:	Cation Exchange Capacity
DMM:	Deep Mixing Method
FMoF:	Federal Ministry of Finance
GPS:	Geographic Positioning System
H_2S0_4:	Tetraoxosulphate VI Acid
HCL:	Hydrochloric Acid
KCL:	Potassium Chloride
LGA:	Local Government Area
NaOH:	Sodium Hydroxide
$NaSi0_4$:	Sodium Silicate
NEWMAP:	Nigeria Erosion and Watershed Management Project
NTA:	Nigerian Television Authority
ODW:	Oven Dry sample Weight

PAP: Project Affected Persons

pH: Potential of Hydrogen

SPSS: Statistical Package of Social Science

WHO: World Health Organization

LIST OF APPENDICES

ABSTRACT

Sequel to the persistence of the problem of gully erosion in Anambra State despite all control efforts, the untimely failure of most of the control measures put in place and the unfair consideration of geology as a very critical factor of gullying in Anambra State; this study was conceived with the aim of evaluating grouting as an effective measure for controlling gully erosion in Nanka Sands geologic unit in Anambra State with a view to identifying the best chemical(s) to be adopted for the grouting/stabilization of the Nanka Sands formation. The study adopted a laboratory and field survey design, judgementally selecting to sample Nanka sand underlain part of Anambra State as it has been proven by literature to be the geologic unit that is mostly troubled by gully within the state. Four chemicals ($AlFeSiO_4$, $NaSiO_4$, CaOH, and CaCl) were purposively adopted for the grouting experiment considering their availability, gumming ability, cost and complimentary role they may play to the elemental composition of the soils. Six hypotheses were postulated and tested using appropriate statistical tools; while hypotheses 1 and 2 were tested with one way ANOVA, 3 was tested with paired sample T-Test while 4, 5 and 6 were tested using one sample T-Test. The entire parameters were subjected to univariate analysis to determination of the overall best among the grouting chemicals. The hypotheses tests results shows that: There is no significant difference in the chemical composition of the soils of the gully erosion sites in the study area; There is no significant difference in the physical characteristics of the soils of the gully erosion sites in the study area; There is significant difference between the pre-grouting porosity and permeability and the post grouting porosity and permeability of the soils of the study area; There is significant difference between the pre-grouting and the post grouting erodibilities of the samples collected; There is significant difference between the water samples collected before and after grouting; the grouting chemicals impacts the water significantly. The study found $NaSiO_4$ to be the best amongst the four grouting chemicals used. Inline with these findings, the study concluded that chemical grouting increases soil resistance, reduces erodibility and should be encouraged in the study area to better manage gully erosion problems. The study recommended that chemical grouting be adopted as a gully control measure in the State, timely information of the development of new gullies be given, quick response to gully development alerts and immediate commencement of an advancement in the research to model the stabilization of the Nanka Sand geologic unit. The study also developed a project management framework for execution of grouting as a gully erosion control measure in Anambra State.

CHAPTER ONE
INTRODUCTION

1.1 Background to the Study

Soil erosion is the physical movement of soil particles from one location to another, primarily due to forces of water or wind. It is defined as the wearing away of the land surface by running water, wind, ice or other geological agents, including such processes as gravitational creep. The most common types include sheet, rill and gully erosion. Gully erosion is an advanced stage of rill erosion much as rill erosion is an advanced stage of sheet erosion (Izinyon, Ehiorobo and Adedeji, 2013). Gully erosion occurs when water concentrates to form big furrows with a steep head-cut wall. They may also occur when run-off volume from a sloppy terrain increases sufficiently or increase in flow velocity as to cut deep holes along its path (Ehiorobo and Izinyon, 2011).

Gully Erosion is an obvious and clear form of soil degradation consisting of an open incised and unstable channel generally more than 30 centimeters deep. It occurs where surface water flow has become trapped in a small concentrated stream, and begins to erode channels in the ground surface, making it wider and deeper. Uncontrolled progress of gullies results in 'bad land' topography and destroys the ecology and economy of the affected areas, (Cavey, 2006).

This gives rise to different hazards to lives and properties of the communities and states of Nigeria. Among these are:

- reduced access to lands and other properties,
- a reduction in the area of arable and other agricultural land, which become divided into smaller parcels and leads to increased farming cost,
- major changes to the patterns of overland flow causing sedimentation in watercourses and leading to bank erosion problems,
- increased rates of erosion where more subsoil material is exposed, further economic losses from soil erosion are incurred by landholders and the wider community from

off-site effects such as: sedimentation and increased flooding affecting fences, farms and public roadways, railways, culverts and bridges; sedimentation of water ways and water supplies; and increased pollution from agricultural and chemicals and animal effluent in incised water ways.

Gully erosion is generally most highly developed where the contributing agents of land use, climate and slope interact. High rainfall also contributes to the development of many serious gullies on the eastern slopes.

In Nigeria, gullies are quite frequent in lower foothills and in valleys inside the mountains. Gullies are extended by back scouring, an active process during heavy rainstorms. Lateral and bottom erosion in the gullies may occur every time the gully is carrying water, and is not necessarily associated with heavy rains. Most gullies extend upslope as a result of the head of the gully being continually undercut and collapsing. However, collapse and slumping of sidewalls usually contribute a greater proportion of soil loss. Gully erosion occurs virtually in all parts of the country but it is most devastating in south eastern states of Anambra, Imo, Enugu, and Abia, but with less effect in areas like Auchi in Edo state (Izinyon *et al,* (2013). Ajaero and Mozie (2011) also stated that the most devastating gully erosion in Nigeria is found in South-eastern Nigeria. Available literature on gullying in Nigeria, shows that this menace is more predominant in the eastern half of the country compared to the western half. Soil erosion has been identified as the most threatened environmental hazards in the country with the South-eastern part of Nigeria being more affected than its north-eastern counterpart (Albert, Samson, Peter and Olufunmilayo, 2006). Anambra State is the most affected of all the states in Nigeria where Agulu, Nanka and Oko communities of the state are the worst hit. Available literature has also clearly reiterated the fact that the underlying geology exerts a major of control on gully development and, more often than not, the process is rock type dependent as some rocks are more susceptible to erosion than the others (Abdulfatai, Okunlola, Akande, Momoh and Ibrahim, 2014). Considering the rate of occurrence and the increased level of negative impacts on the environment, there is need to drill more into the best ways of managing and controlling this unavoidable natural disaster in Nigeria, especially within the Southeastern States like Anambra which are most vulnerable.In the bid to find a better way to handle this situation, grouting which is a proven method of soil stabilization was considered.

According to Reuben (2003), in the book titled: "Chemical Grouting and Soil Stabilization", the 1974 edition extends the definition o of Webster's Dictionary defined grout as a ''thin mortar used for filling spaces (as the joints in masonry); also, any of various other materials (as a mixture of cement and water or chemicals that solidify) used for a similar purpose.'' The grouter, however, defines what he/she does as the practice of filling the fissures, pores, and voids in natural or synthetic materials in order to alter the physical properties of the treated mass. A grout may then be simply defined as a material used for grouting.

The Grouting Committee (1980), Geotechnical Engineering Division of the American Society of Civil Engineers, in her ''Glossary of Terms Related to Grouting,'' defines grout as a material injected into a soil or rock formation to change the physical characteristics of the formation.'' Chemical grout is defined as any grouting material characterized by being a pure solution; no particles in suspension''. The key phrase in the definition is,"altering the physical properties.'' This is the purpose of grouting. However, for a material to qualify for this, it must have that capability- altering the physical properties.

This definition is actually very encompassing. The formation changes desired are always related to strength and/or permeability of that formation. Virtually, any solid has the capability of plugging formation voids under some conditions Reuben (2003). Materials such as bran, oat hulls, straw, and sawdust have been used as grouts (primarily by drilling crews trying to plug a zone in a hole and recover drill water circulation). More common materials include sand, clay, and cement.

All the specific materials mentioned so far are solids that do not dissolve in water. When used as grouting materials, they are mixed with water to form a suspension. The water acts as the moving vehicle which carries the solid particles into the formation until the solids drop out of suspension. All these materials fall into the category of suspended-solids or particulate grouts, often referred to as suspension grouts.

The other broad category of grouts comprises those composed of solids which are soluble in water and are handled as solutions, and other materials that may naturally be liquids. These materials, which in themselves contain no suspended solid particles, are called chemical grouts. (In practice, suspended solids are often added to chemical grouts to modify the solution properties, but these materials are considered additives, and the operation is still considered to be chemical grouting.) Although chemical grouts are often referred to in terms of the solids content, this is generally understood to mean the percent solids in the solution.

The major functional difference between particulate grouts and chemical grouts is that penetrability of the former is a function of particle size, while for the latter it is a function of solution viscosity (Reuben, 2003). Grouting, being a new concept in Nigeria has little or no empirical evidence to prove its adoption, thus making this study justified. Moreover, considering that a lot of control measures adopted to manage gully erosion problems in Anambra State, especially those on the Nanka Sands, has proved abortive, this work is really timely and of great importance in the area.

1.2 Statement of the Research Problem

The greatest threat to the environmental settings of theSoutheastern Nigeria is the gradual but constant dissection of the landscape by soil erosion, mainly by water. Although the incipient stages of soil erosion through rill and interrill are common and easily managed by people through recommended soil conservation practices, the gully forms have assumed a different dimension such that settlements and scarce arable land are threatened. Therefore, gully erosion problems in Nigeria have become a subject of discussion among soil scientists, geographers, geologists, engineers, environmental managers and even social scientists.

From literature, it is crystal clear that soil erosion remains the world's biggest environmental problem threatening sustainability of both plant and animal in the world (Abegunde *et al* 2006). Soil erosion increment results in an unsustainable development of the living standard of the people. Sustainable development is the positive socio-economic change that does not undermine the ecological and social systems upon which communities and social systems are dependent.

According to Izinyon, Ehiorobo and Adedeji (2013), there have been numerous attempts to curb the advancement of the gully erosion in Nigeria using structural approaches, but these have been with limited success. They noted that the formation of gullies have become one of the greatest environmental disasters facing many towns and villages in southeastern Nigeria. Hundreds of people are directly affected every year within towns and villages and have to be re-located, and yet the rate of increase in gully erosion has continued unabated with no suitable solution. The economic cost of managing gully erosion in Southeastern Nigeria is devastating. Gully erosions lead to great losses of land every year. Large sections of land have been destroyed in recent years in towns such as Ekwulobia and Nanka. In addition, highways are ruined due to gullies, leading to numerous vehicle accidents and deaths.

According to Okoye, Emengini and Onwuzuligbo (2014), lives and properties are regularly lost. Houses with the entire families living in them have often been swallowed by landslides in Nanka, Agulu, Nnewi, Ekwulumili, Obosi etc. Sometimes, major landslides carry along many houses, trees, roads, all standing as they were, into loose flood plains or wide deep gully bottoms. Several properties whose value cannot be quantified accurately here have been destroyed and others are under treat by this menace especially houses and other properties located on the floodplains. About 10 houses have been lost in a single event of gully erosion in Auchi area of Edo State (Izinyon *et al*, 2013). Besides, it was reported recently that over 450 buildings are lost in Edo State of Nigeria as a result of erosion (NTA News, Sunday 6th July 2013). On a separate note, Committee on Erosion and Ecological Matter recently discovered 15 gully sites in Bida, Niger State of Nigeria (NTA Minna News, Wednesday 17th July 2013). Apart from untimely evacuation from these gully sites, infrastructural facilities such as pipelines, utility cables, roads and houses also suffer from these hazardous events.

Gully erosion has given rise to infertile and barren land that may need to be reclaimed. This usually brings untold hardship to the inhabitants if the land is still inhabitable but has been severely affected. Anambra State has lost over 30 percent of her land, and over 40 percent of the total area of land and homes are being threatened by the menace according to the Anambra State Ministry of Environment (Abdulfatai *et al*, 2014).

Many lives have been lost as a result of the problem of gully erosion. Some either fell into these gullies and sustained various degrees of injury or died. Some instances have also been reported where people were drowned in some of the gully sites. According to Abdulfatai *et al* (2014), about 23 people have been reported in the past few years to have lost their lives in a single event of gullying activities inIbori, Ugbalo, Ewu-Eguare, Idogalo and Oludide communities of Edo State, Nigeria. Millions of people have been displaced and evacuated their homes following the gully incidences. The gully erosion in Oko and Nanka communities in Anambra State has created a deep gully and wide crater, threatening to sweep away the homes of over 826 families as this channel is continuously expanding at an alarming rate (Abdulfatai *et al*, 2014).

Upon all the numerous research findings being applied, government, NGOs and community interventions, this cankerworm is eating deeper by the day. Although some success has been recorded in some cases, but in many others none, some implementation of control measures were done haphazardly such that the sites were left worse than they were before the remedial action started. A personal observation from visits made to some sites within the study area showed failure of the adopted control measures within a short time after application. At Oraukwu, Neni and Nnewichi, the civil engineering channelization and bioremediation methods adopted failed; while in Awka, the drainage channels failed at Ekwueme Square Gully Site and Agu Awka, although the newly constructed Amachalla channel is still stable. The worst is the very large Nanka Gully where the gabions and sandbag check dams constructed by Rhino Maritime and Construction Company for over one billion naira (David-Chiddy, 2016), has started failing in less than one year of its construction.It becomes necessary to advance in research to come up with more effective and efficient preventive and control measures. In line with this, the need to harness new areas in the advancement of this fight to better control gully erosion in Anambra State becomes expedient.

From literature (Egboka et al, 2006 & Igbokwe et al, 2008); the outcome of reconnaissance survey and personal interview with the geologist at Geohazard Centre Awka, it is clear that the main geologic unit responsible for gullying in Anambra State is the Nanka Sands which is a geologic unit occurring within the Ameki Formation of the stratigraphic sequence of the Southeastern Nigeria.

It is note worthy that geology as a major causative factor of gullying in Anambra State has been partially overlooked, as there has not been any in-depth study on it. Also,the nature of Nanka Sands, a major geologic unit hosting more than 80% of the gullies in the State due to its friable and unconsolidated nature has received little or no attention by research works as evident from the review. Also, grouting which is one of the best methods of chemical stabilization of soils practiced in the western world has not been studied or tried in this region at all.

To better address the problem of gullying and land sliding in Anambra State due to the geology and soil characteristics, a solution which will be structured must be one that will strengthen the resistance and resilience of the soil, thus the reason for consideration of grouting as the right option. This work therefore evaluates grouting to ascertain its workability as a gully erosion control measure on the Nanka Sands geologic formation of Anambra State.

1.3 Aim and Objectives

The aim of this study is to evaluate grouting as an effective measure forcontrolling gully erosion in Nanka Sands geologic unit in Anambra State with a view to identifying the best chemicals to be adopted for the stabilization of the Nanka Sands formation.

To achieve this aim, the following objectives were pursued; to:

1. Identify and sample the active gully sites on the Nanka Sands geologic unit of Anambra State;
2. Determine the chemical composition of soil samples from Nanka Sands geologic unit;
3. Compare the chemical composition of all the analyzed samples in the study sites;
4. Compare the physical characteristics (porosity and permeability) of all the analyzed samples in the study sites;
5. Determine the relationship between pre-grouting and post-grouting porosities and permeabilities of the rocks samples collected;

6. Compare the pre-grouting and post-grouting erodibilities of the rock samples collected;

7. Examine the impact of the grouting chemicals on water quality; and

8. Develop a project management framework for execution of grouting as a gully erosion control measure in Anambra State.

1.4 Research Questions

This study answered the following questions:

1. Where are the active gully erosion sites located in the areas underlain by Nanka Sands?

2. What is the chemical composition of the rock samples collected from the various gully erosion sites underlain by Nanka Sands within Anambra State?

3. How do the chemical compositions of the various samples compare?

4. What is the relationship between the physical characteristics of all the samples obtained as analysed?

5. What is the relationship between pre-grouting and post-grouting porosities and permeabilities of the formation?

6. What is the comparison between pre-grouting and post-grouting erodibilities of rock samples in the study area?

7. What is the impact of the grouting chemicals on water quality?

8. What project management framework can be adopted for execution of grouting as a gully erosion control measure in Anambra State?

1.5 Research Hypotheses

The study postulated and tested the following hypotheses:

1. H_0: There is no significant difference in the chemical composition of the soils of the gully erosion sites sampled within Nanka Sands geologic unit in Anambra State.

2. H_0: There is no significant difference in the physical characteristics of the soils of the gully erosion sites sampled within Nanka Sands geologic unit in Anambra State.

3. H_0: There is no significant difference between the pre-grouting porosity and permeability and the post grouting porosity and permeability of the rock of the area.

4. H_0: There is no significant difference between the pre-grouting and the post grouting erodibilities of the samples collected.

5. H_0: There is no significant difference between the water samples collected before and after grouting exercise.

6. H_1: The effects of the grouting chemicals on water vary significantly.

1.6 Significance of Study

This study was designed to create a new outlook to the gully erosion control practices within Anambra State and it should be of immense benefits in the following ways:

1. The outcome of the execution of this study should add to the existing body of knowledge in the issue at stake.

2. The findings of this study should provide information to students and other researchers in advancing the knowledge base on gully erosion control in Anambra State and other States within the Southeastern part of Nigeria and should create new areas of research for students as it is not a terminal study.

3. The government agencies in-charge of combating gully erosion and other non-governmental agencies who are in the field of environmental hazards management should benefit from the findings of this study.

4. The policy makers in the field of environmental management should find the findings of this study very useful in choosing the best approach to combating gully erosion and its negative impacts on the environment.

1.7 Scope of Study

This study concentrated on gully sites in Anambra State that are underlain by the Nanka Sand geologic unit of the Ameki Formation, which is the main geologic unit hosting majority of the gullies within the study area. The samples were analyzed in the laboratory for their chemical composition and subsequently four complimentary chemicals for stabilization of the soil were selected and tested to determine their impact on water quality as compared with a know water quality and WHO standard, afterwhich the study recommended the best chemical for grouting in the study area. The study also interviewed at least one inhabitant of each of the sampled gully sites and one professional from two agencies working in the study area on erosion control, just to gather information to buttress literature facts on the origin, causes and effects of the gullies; and empirical facts on the feasibility of adopting chemical grouting as a control measure. The study lasted for 18 months, starting from December 2015 to May 2017.

1.8 Limitations of Study

The study has the followinglimitations:

1. For this type of study, the application of the chemicals for stabilization ought to be done on site and in-situ with samples undisturbed for best results, but this study made use of inference from the tests in the laboratory alone.

2. The test for portability of groundwater after the grouting/stabilization process was simulated in the laboratory, not on site. Thus, there is need for an insitu field analysis to buttress the findings.

3. The budget of this research accommodated few samples, which were judgmentally selected on purpose to represent all the gullies underlain by Nanka Sands in Anambra State, but it is incontrovertible that the more the samples, the more real the results and findings should be.

4. The challenge of limited accessibility, constrained the sampling to spots that are stable and easily accessible by the researcher as certain depths of the gully sites could

not be reached especially at Nnewichi site. Hence some of the gully depths were estimated by throwing down the tape from the top of the gully to wherever it can stop and adding up the estimated values for the rest.

1.9 Plan of Study

This work wass arranged in six chapters. Each chapter reported an aspect of the whole research as stated below:

Chapter One introduced the work. That is a general overview of what the research work is all about. It discussed the background to the study, described the problem at stake, the aim and objectives actualized in the study, the research hypotheses tested and stated the significance of the study. It also detailed the scope of the study and the constraints limiting the scope.

Chapter Two discussed the concepts upon which the work is based and reviewed the previous and current studies done on the subject matter and other works related to the issues of gully erosion control.

Chapter Three discussed the study area, detailing its geographical location, climate, geology, population and economic activities.

Chapter Four detailed the research methodology employed, the data source, design of the experiment, procedure for sample collection and analyses,also detailed the statistical techniques employed in the work to analyze and test the hypotheses.

Chapter Five presented the data obtained from the research and the analyses using various statisticaltechniques. It also discussed the findings of the research.

Chapter Six summarized the findings of the study, noted the contributions to knowledge, recommendations and conclusions drawn from the study.

Appendix displayedthe tables and graphs generated from the result of laboratory analyses and statistical results, with pictures of onsite investigation of the various sampling stations.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

This chapter discussed the conceptual framework on which the paper is based, and also the review of empirical works on the subject matter.

2.1 Conceptual Framework

Soil erodibility and rainfall erosivity are two important physical factors that affect the magnitude of soil erosion (Lal and Elliot, 1994). Soil erodibility, the resistance of the soil to both detachment and transport, is a function of soil texture, structure, permeability, organic matter content and also the management of the soil (Hudson, 1995; Morgan, 1995). Rainfall erosivity is the aggressiveness of the rain to cause erosion and is a function of the physical characteristics of rainfall (Morgan, 1995). It has been established that a few, very intense rainfall events are responsible for the largest part of the soil erosion and sediment delivery (Gonz´alez-Hidalgo et al., 2007). It is also an established fact that soil erodibility represents the effects of soil properties and soil profile characteristics on soil loss by erosion (Romkens et al., 1996 cited in Fufa et al., 2002). However, the quantification of these two factors stated earlier is the basis to an understanding of soil erosion. To tackle the problem of gully erosion, the concept of rainfall erosivity as an erosion catalyst and predictor of erosion risk has been applied in some parts of Ghana (Baffour et al, 2012), in the Africa continent by Vrieling et al (2014) and in Europe by Panagos et al, (2015).

Soil erodibility is an estimate of the ability of a soil to resist erosion based on the physical and chemical characteristics of that soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved structure have a greater resistance to erosion (Wall *etal*.1987). Sometimes a soil with relatively low erodibility factor may show signs of serious erosion, yet a soil could be highly erodible and suffer little erosion (Nyakatawa *et al.* 2001). This is because soil erosion is a function of many factors as stated in the universal soil loss equation (USLE). These factors include rainfall factor (R), soil erodibility factor (K), slope length (LS), crop factor (C) and control practice factor (P). This is represented in the universal soil loss equation as (Renard *et al*. 1997); $A = R\ K\ LS\ C\ P$.

According to Morgan (2001), one of the importance of quantifying the erodibility of soil materials is the prediction of the possible occurrence of gully erosion. The depth of erosion is very often determined by the soil depth. Soils below the plough layers are often compact and less erodible. Rills will develop in areas where the bedrock close to the surface is not resistant and if the parent material is unconsolidated such as sands and gravel (Morgan, 2001). Also erodibility is influenced by the organic and chemical constituents of the soil / rock as this determines the stability of the aggregates (Relf, 2001 and Morgan 2001). On the other hand, erosivity is a function of rainfall, a natural phenomenon which is outside human control and manipulation. Rainfall intensities can be high in Southeast Nigeria, thus the high incidence of gullies in this part of the country. Erodibility and erosivity are indispensable factors of soil loss (Bryan, 2000; Singh and Khera, 2009) as can be clearly seen in the USLE.

The interest of this study is on the stabilization of the soils / rocks prone to gullying in order to reduce their detachability (erodibility) and reduce the impact of the rainfall intensity (erosivity) on them. Therefore two major aspects of soil loss were harnessed and used as foundation concepts for this study, the concept of resistance and resilience.

Soil Resilience

Soil resilience has been defined as the capacity of a soil to recover its functional and structural integrity after a disturbance (Herrick and Wander 1998; see also Pimm 1984; Lal 1993a, 1993b, & 1994; Blum and Santelises 1994; Sombroek 1994; Blum 1998). This definition is consistent with the broader use of resilience as defined by Webster, which is "the capability of a strained body to recover its size and shape after deformation caused especially by compressive stress." However, others have defined soil resilience as the capacity of a soil to resist change caused by a disturbance (Rozanov 1994; Lang 1994). This concept of "resistance to change," which differs from resilience, is an important component of ecosystem stability (Tilman and Downing 1994) and will be defined as a separate concept in this paper.

Functional and structural integrity are defined as a soil's capacity to perform vital soil functions such as those proposed by Karlen *et al*. (1997):

(i) Sustaining biological activity, diversity, and productivity;

(ii) Regulating and partitioning water and solute flow;

(iii) Filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition;

(iv) storing and cycling nutrients and other elements within the Earth's biosphere; and

(v) Providing support of socioeconomic structures and protection for archeological treasures associated with human habitation. Structural integrity is linked to soil function and deals with the physical arrangement of primary soil particles and their aggregation.

Walker et al (2004) describe four critical aspects of resilience: latitude, resistance, precariousness, and panarchy. The first three can apply both to a whole system or the sub-systems that make it up.

1. Latitude: the maximum amount a system can be changed before losing its ability to recover (before crossing a threshold which, if breached, makes recovery difficult or impossible).

2. Resistance: the ease or difficulty of changing the system; how “resistant” it is to being changed (Walker *et al*, 2004).

3. Precariousness: how close the current state of the system is to a limit or “threshold” (Peterson *et al,* 1998).

4. Panarchy: the degree to which a certain hierarchical level of an ecosystem is influenced by other levels. For example, organisms living in communities that are in isolation from one another may be organized differently from the same type of organism living in a large continuous population, thus the community-level structure is influenced by population-level interactions.

Closely linked to resilience is *adaptive capacity*, which is the property of an ecosystem that describes change in stability landscapes and resilience (Gunderson, 2000). Adaptive capacity in socio-ecological systems refers to the ability of humans to deal with change in their environment by observation, learning and altering their interactions (Folke *et al*, 2002).

A disturbance is broadly defined as any event that causes a significant change from the normal pattern or functioning of an ecosystem (Forman and Godron, 1986). Whether an event is considered to "cause a significant change from the normal pattern or functioning" depends on the temporal and spatial scale of interest. At geologic time scales, nearly every event can be considered to contribute to normal functioning. Many types of perturbations are actually necessary for ecosystem function. For example, formation of a single earthworm burrow is clearly a disturbance at the scale of the root system of a grass tussock when considered in terms of the lifespan of the plant. But, it may be considered part of the "normal pattern" at the field scale. A wide variety of disturbances are included in this broad definition, including those that are primarily natural in origin and others that are largely or wholly anthropogenic. Natural disturbances and causes of disturbance include fires, earthquakes, floods, landslides, and high-intensity storms. Nearly all human activities associated with land management and use can be classified as "disturbances," including logging, grazing, urban and industrial development, recreation, and annual cropping. Agriculture itself is one of the greatest sources of stress and disturbance to the environment (Brussaard 1994). Common disturbances or stresses associated with agriculture include heavy load as a result of vehicular traffic; tillage; application of fertilizers and pesticides; and removal or exclusion of competing plant species (Bezdicek *et al*. 1996).

Soil Resistance

Soil resistance, which is distinguished from soil resilience, has been defined as the capacity of a soil to continue to function without change throughout a disturbance (Herrick and Wander 1998; Pimm 1984). The magnitude of decline in the capacity to function defines the degree of resistance to change. A small decline indicates a high resistance, whereas a relatively large decline indicates a low resistance to change throughout a disturbance. Williams and Chartres (1991) distinguish the difference between the resilience and resistance concepts with respect to soils: "The magnitude of the decline in the capacity of the soil to function (resistance) and the rate of recovery or the elasticity (resilience) are two key measures of sustainability."

The distinction between resistance and resilience can be illustrated further in an example using soil functions related to soil physical properties on an annual time scale. In temperate regions, many surface soils are resilient with respect to porosity changes following compaction. Frost action may serve as a recovery process. However, some soils are inherently resistant to porosity changes following compaction. These resistant soils can maintain their functioning capacity (e.g., hydrologic functions) at a higher level throughout the year than those that have a lower resistance but are resilient on an annual time scale.

The distinction between soil resistance and soil resilience also depends on the temporal scale of interest. For example, the capacity of soil to supply nutrients to plants (a soil function) can be degraded by nutrient removal through plant uptake into biomass. For short periods of time, the soil solution near the root surface can be replenished from supplies on exchange surfaces and through diffusion. Temporary reductions in nutrient availability may result. However, because these reductions are generally undetectable in plant growth measurements, the soil is perceived to be resistant from a functional perspective. As exchangeable nutrients decline and diffusion distances increase, resistance to nutrient depletion processes decline and the importance of mineralization (recovery mechanism) increases. If mineralization rates are high, measurements made on an annual basis may indicate little or no change in nutrient availability, again suggesting high resistance, even though nutrients were limiting at one or more times during the year. The proportion of the year during which nutrients are limiting, then, depends on the rate of recovery or resilience.

The importance of soil resistance in sustainable management was demonstrated by Davenport *et al*. (1998) for Pinyon-Juniper (*Pinus edulis, P. monophylla, P. cembroides-Juniperus monosperma, J. osterosperma, J. Occidentialis, J. scopulorum, J. deppeana*) ecosystems in the western U.S. They found dramatic variation in the capacity of pinyon-juniper ecosystems to resist soil erosion as a result of reductions in ground cover. In sites that exhibited low resistance, a small reduction in ground cover was needed before a threshold was reached and soil erosion increased dramatically. In sites with high resistance, thresholds sometimes did not exist, and if one existed, a large reduction in ground cover was needed before the threshold was reached.

Soil stabilization is a means of upgrading the engineering properties of soils to provide maximum return on investment in road construction or improvement. Although there is no precise definition of stabilization, a soil is said to be stable

when it resists change, particularly mechanical change, over long periods of time. Conversely, an unstable soil is one that breaks up, shifts, or sinks when acted upon by the normal forces of load in an unfavorable slope (topography), under a critical climate or agent of erosion or mass movement, resulting in a premature deterioration of the surface area. Three mechanical aspects are critical to a soil's ability towithstand loads: {a) cohesion, {b) friction, and (c) density.Cohesion refers to the ability of soil particles to stick together.Friction refers to the ability of particles to resist shifting oftheir position relative to each other. Density is the weight ofa material to its bulk. These three aspects when improved in a soil, improves the soil's resistance thus making the soil more stable.

The understanding of these concepts brings to mind the mechanism of the strength and weakness of a soil and how the soil can respond to erosion forces, thus creating a strong background to the actual exploration of the issues of grouting and soil stabilization as measure to control gully erosion through the improvement of the soil's resistance to erosion forces.

2.2 Literature Review

The related literature were reviewed under the following sub-headings:

- causes of gully erosion
- effects of gully erosion
- gully erosion control measures
- Efforts of NEWMAP

- Grouting as a Method of Soil Stabilization

2.2.1 Causes of Gully Erosion

2.2.1.1 Nature of Topography:

Renard *et al*. (1997) and Igwe *et al*. (1999), among others who went into classical modeling research works on soil erosion prediction and estimation, recognized topography/relief, rainfall and soil factors as being the main agents that determine the extent of soil erosion hazard. The soil factor represents the soil erodibility which is also a product of geology and soil characteristics. In showing how these factors influence the extent of soil erosion and gullying in southeastern Nigeria, there is going to be an attempt into discussing how these parameters contribute to gully erosion in other geographical zones.

Igbokwe *et al* (2008), in their study aimed at monitoring, characterization and controlling of flood water erosion in Southeastern Nigeria using remote sensing techniques, found out that gully developments are more pronounced in areas with high terrain undulation. In these areas as they said, the slopes of the ground are steep and vary. This inevitably results in increase in the speed and volume of the overland flow and subsequently, the rate of detachment and transportation of soil particles.

Ristic *et al* (2012) in their study of land degradation at the Stara Planina Ski resort using both experimental and survey methods, stated that the management of Ski resort development of south eastern Serbia caused severe degradation of top soil and native vegetation. According to their findings, the morphological characteristics of the area, lithological properties of the imposed materials and climate conditions resulted in various geomorphic impacts including, rills, deep gullies, and debris from rock weathering. They also discovered that the construction of ski runs and ski lifts, which includes, logging, large excavation activities and construction on steep slopes cause large environmental impacts and appearance of different forms of land degradation.

2.2.1.2 Geology and Nature of Soil

Ofomata (1965, 1967) in his study of the factors of soil erosion in Enugu and Awgu areas of Nigeria respectively using survey methods, established that the nature of surface materials influences the rate of infiltration and thereby, of slumping and/or sliding, it also affects the nature and rate of surface runoff and thereby the nature and rate of incision. Okagbue (2005) in his detailed study on the factors which govern the development of gully erosion and landslides in southeastern Nigeria, suggested that gully erosion is controlled by physiography, geology, hydrogeology, and engineering properties of the soil materials. This is in agreement with the findings of Igbokwe *et al* (2008) who reported that soils in south eastern Nigeria are mostly loose and very porous. The soil particles are not consolidated and therefore detach easily when imparted by flood water. Sandy soils are more easily eroded than clayey soil. A clayey or shaley maybe eroded slowly, gradually and continuously until a sandy zone is intersected then the rate of erosion changes.

Egboka, Nfor and Banlanjo (2006), conducted an analysis of the Water Budget of Agulu Lake in Anambra State, Nigeria through field survey. In their description of the study, they stated that Anambra Basin is as a result of the Subsidence of the Anambra plate due to folding and uplift of the Abakaliki-Benue fold belt in the Santonian stage produces the Anambra Basin. The basin is dominantly filled with clastic sediments constituting several distinct lithostratigraphic units deposited from Upper Campanian to Recent. The lithostratigraphic units have a thickness of up to 2,500m. These include; Nkporo Shale, mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Shale, Nanka/Ameki, Sands/Formation, Nsugbe Formation and Ogwashi-Asaba Formations. The sediments were derived from the uplands beyond the Benue Hinge Line, the Abakaliki Uplands and the Benue fold belt. The youngest sediments are loose and exceptionally prone to erosion, according to them the geologic formation mostly prone to gullying is the Nanka sand which is a member of the Ameki formation.

Osadebe and Enuvie, (2008), did a factor analysis of soil spatial variability in gully erosion area of Southeastern Nigeria, with Agulu- Nanka- Oko Areas as case study. In their findings, they suggested that soil properties like organic carbon, chemical properties, textural characteristics and moisture content of the soil are the most useful factors to be considered in a detailed survey on the control of gully.

2.2.1.3 Climate and Vegetation

According to the works of numerous scholars on the causes of the gully advancement in Agulu-Nanka erosion zone, like Egboka and Okpoko (1984), Egboka and Nwankwor (1985) all of whom applied both survey and experimental methods, it was reported that the incidence and existence of the menace can be due to the fragile geological formations, the high intensity tropical rainstorms that last up to eight months in the year, the long history of settlement deforestation, geotechnical and hydro geochemical characteristics of the area as well as with regards to poor land use practices. Egboka and Nwankwor (1985) had earlier discovered from their interaction with the natives of Agulu/Nanka gully erosion sites that the fragile soils were much earlier in time protected by dense forest cover which the people have removed thus exposing the fragile soils to the heavy downpours and concentrated runoffs. The runoffs created the gullies which have blossomed into the badland topography of today and the continuous back wearing (advancement) of the gully heads via sliding processes. This is supported by the work of Igbokwe*et al* (2009).

Ofomata (2002) in his investigation of soil erosion in southeastern Nigeria using both experimental and filed survey methods, developed a model for the humid tropics showing the major factors of soil erosion in southeastern Nigeria. The model was developed using anthropogenic factors, relief, rainfall, vegetation and surface materials as the most critical prevailing parameters in the development of erosion in the southeast of Nigeria as at the time of the development of the model.

Akpokodje *et al* (2010) in their analysis of the Management implications of Gully Erosion and other Geo-hazards in Southeastern Nigeria using survey method opined that the role of rainfall in initiation and rapid growth of gullies is demonstrated by the fact that the major landslides and slumping which are responsible for rapid growth of gullies generally occur after heavy rain. The high intensity of tropical rainfall in south eastern Nigeria produces high volume of overland flow and runoff that possess high erosive energy. This combines with erodibility property of the said soil to produce the numerous severe complex gullies. Areas under effective cover of vegetation are more prone to sliding and slumping (provided that the gradients is steep enough) as they are characterized more by infiltration than surface runoff.

Obiadi *et al* (2011) in their study of Gully Erosion in Anambra State, Southeastern Nigeria using both experimental and survey methods, opined that the seasonal changes in temperature, runoff water, humidity and atmospheric pressure contribute to the disintegration and washing away of the soil and rock units in the area.

Ehiorobo and Izinyon (2011) did some measurement and documentation for Flood and Erosion Monitoring and control in the Niger Delta States of Nigeria Using Geoinformation and Geotechnical Engineering Survey Methods", noted that gully erosion occurs when water concentrates to form big furrows with a steep head-cut wall. They may also occur when run-off volume from a sloppy terrain increases sufficiently or increase in flow velocity as to cut deep holes along its path.

2.2.1.4 Anthropogenic Factors

According to Ofomata (1964) and Salbury (1964) in their studies of Soil Erosion in the Enugu Area of Nigeria and the Ecological and Agricultural problems of soil erosion in relation to construction activities respectively, supported that erosion is a fundamental and complex natural process that is modified (generally increased) by human activities such as land clearance, agriculture, forestry, surface mining, urbanization, industrialization and general infrastructural development. This is in line with the postulation by Darlymple (1976) that erosion due to interference by man is known as accelerated erosion, pin pointing that man and livestock can easily disturb nature's ecological equilibrium and so trigger off services of erosion by water and wind. They activities of man that trigger off erosion may include the following:

a. Agricultural Practices/Deforestation

Mabbutt (1984) conducted a global assessment of the status and trends of désertification. In his report he opined that excessive feeding of the animals on the available range land beyond its capacity (over-grazing), accounts for almost 90% of decertified land. When insufficient amount of grass are left for the soil, soil organisms die and soil looses fertility. Miller (1990) in his write up titled “Living in the Environment” supported that overgrazing is the major cause of desertification adding that it also causes soil erosion. According to him, some herdsmen intentionally set fire to grass so as to stimulate growth of dormant grass buds as a means of ensuring availability of fresh green pasture and this also triggers erosion especially in areas of low soil resistance.

Orji and Bhatt (1990) in their study of trees in Girei District and their relevance to technical development using survey method, observed that as much as 70% of the forest land in some states in the arid areas is burned over each year through annual bush fire, thus encouraging soil degradation and erosion.

Igwe (1994) in his evaluation of the applicability of the Universal Soil Loss Equation (USLE) erosion model on soils of southeastern Nigeria noted that the anthropogenic factors of erosion/soil loss are mainly technical factors comprising mainly of land use and tillage methods, the choice and distribution of cultures and the nature of agro-technology. Earlier, Giordano *et al*. (1991) who did a work on the methodological approach to soil erosion and important land resources evaluation of the European community, noted that in Northern hemisphere including many countries of Europe, among the factors that encourage soil erosion are vegetation clearance, intensive harvesting and over-grazing leaving the soil bare. Other factors are soil compaction caused by heavy machinery which reduces the infiltration capacity of the soil and thus promoting excessive water runoff and soil erosion.

Orji (1995) in his bid to analyze deforestation, bush burning and Bio-diversity frame work for effective control towards environmental management policy for sustainable development in Anambra State Nigeria observed that when man cultivates the land without conscious efforts to protect the land, there is usually serious degradation of the land which encourages erosion. Large portions of the vegetative cover are cleared annually for farming purposes, thereby exposing the top soil to erosion. When the soil is exposed, it is no longer capable of resisting the erosive actions of the rain water which provokes heavy carrying away of the soil by surface runoff, resulting in gully erosion. He also observed that there is an intensive exploitation of scanty vegetation to meet the ever increasing demand for fire wood and poles for buildings, which has led to deforestation and exacerbation of erosion in that area.

Valentin, Poesen and Li (2005) studied the impacts, factors and control of gully erosion adopting both experimental and survey methods, in their findings, gullies not only occur in marly badlands and mountainous or hilly regions but also more globally in soils subjected to soil crusting such as loess (European belt, Chinese Loess Plateau, North America) and sandy soils (Sahelian zone, north-east Thailand) or in soils prone to piping and tunnelling such as dispersive soils. Most of the time, the gullying processes are triggered by inappropriate cultivation and irrigation systems, overgrazing, log haulage tracks, road building and urbanization. As exemplified by recent examples from all over the world, land use change is expected to have a greater impact on gully erosion than climate change. Yet, reconstructions of historical causes of gully erosion, using high-resolution stratigraphy, archaeological dating of pottery and ^{14}C dating of wood and charcoal, show that the main gully erosion periods identified in Europe correspond to a combination not only of deforestation and overuse of the land but also to periods with high frequency of extreme rainfall events.

Izinyon *et al*, (2013) discussed the use of structural and non-structural approaches for the control and management of the Queen Ede gully in Benin City found that Gully erosion is due to unsustainable farming practices, path and road construction, poorly constructed drainage system, it takes place when excessive surface run-off flowing with high velocity and force, detach and carry soil particles down the slope. According to them, gullies may also occur when run-off volume from a sloppy terrain increases sufficiently or increase in flow velocity as to cut deep holes along its path.

b. Excavations and Sand Mining

Igbokwe *et al* (2008), in their study aimed at monitoring, characterization and controlling of flood water erosion using remote sensing techniques, described sand mining as one of the booming business in south eastern Nigeria which is encouraging erosion, as the excavations are carried out by individuals along the existing road sides in many areas. The action of rain which results into floods causes the washing off of the land surface and as it moves, it carries lots of sand from these open excavation sites and deposit them along the roads blocking the roadways in some areas. In some places, people have illegally acquired the permission to excavate sands commercially and these mining sites eventually develop into huge gullies as rainwater continues to impact on them.

Onwuka and Okoye (2013), studied the socio-economic impacts of tin mining in Rayfield of Jos, Plateau State, Nigeria using survey method. They discovered that social components resulting from tin mining vary. They opined that mining and quarrying cause erosion problems in a lot of ways in urban centres through the following ways:

i. The removal of the sub-surface materials that give rise to subsidence and landslide.

ii. The exposure of harmful chemicals that help to degrade and weaken the sub surface and surface rock.

iii. Excavations that further develop to gullies and landslides.

c. Settlement Patterns, Urban and Infrastructural Development

Igbokwe *et al* (2008), also found that settlement patterns, the nature of housing and infrastructural development contribute to the development of gullies in south eastern Nigeria. In the discussion of their findings, they stated that in the southeastern part of Nigeria, most of the settlements are not planned; houses are built indiscriminately without consideration to natural flood paths, and drainage system. Infrastructures such as roads are built without proper environmental studies (environmental impact assessment). Population increase helps to exacerbate gully erosion because there will be high population pressure in housing, water supply, road construction and power supply. The desperate and unplanned move to satisfy the housing and infrastructural needs only creates favourable condition for gully erosion. Izinyon *et al*, (2013) in their study noted that gully erosion is an environmental disaster currently plaguing lands that would have otherwise been used for infrastructural developments. Recently, Nigeria has grown with numerous development projects involving land clearing, forest cutting, land reclamation, housing schemes and highway constructions, unsatisfactory waterways and improper design of culverts and other structures to mention a few. The continuous increase of impervious areas results in the decreasing amount of land available for rainwater to soak in, giving more surface runoff resulting in erosion.

2.2.2 Effects of Gully Erosion

Ofomata (1964**,**1973), in his study of soil erosion in Enugu and Ozuitem respectively, stated that the consequences soil erosionin terms of what is relevant to soil conservation, are two-fold: general decrease in soil fertility (as a result of the action of sheet and/or wind erosion), and diminution of cultivable land (as a result of the occurrence and expansion of gullies). The later consequence has wider implications which include displacement of population following loss of residential houses and farm crops, changes in the topography and hydrology of affected areas, and disruption of roads, such as can be seen at Ngwo Agu, Agulu and Oko.

Valentin *et al* (2005), in their study of the impacts, factors and control of gully erosion in which they adopted both experimental and survey methods, opined that for farmers, the development of gullies leads to a loss of crop yields and available land as well as an increase of workload (i.e. labour necessary to cultivate the land). Gullies can also change the mosaic patterns between fallow and cultivated fields, enhancing hillslope erosion in a feedback loop. In addition, gullies tend to enhance drainage and accelerate aridification processes in the semi-arid zones. Fingerprinting the origin of sediments within ca*tc*hments to determine the relative contributions of potential sediment sources has become essential to identify sources of potential pollution and to develop management strategies to combat soil erosion. In this respect, tracers such as carbon, nitrogen, the nuclear bomb-derived radionuclide 137 Cs, magnetics and the strontium isotopic ratio are increasingly used to fingerprint sediment. Recent studies conducted in Australia, China, Ethiopia and USA showed that the major part of the sediment in reservoirs might have come from gully erosion.

According to Igwe (2005), the consequence of the soil erosion is loss of land for agriculture and for habitation. During some slides caused by gully formation, lives have been lost while some communities have been separated because of deep and very wide gullies that may reach in some cases 12 m deep and more than 1.5 km long like the Nanka/Agulu gully complexes or in Oko in Aguata, Anambra State. Crop yields have been reduced, thus creating problem in the “green revolution” campaign.

Izinyon *et al*, (2013) also found that the development of gullies has caused extensive damage to the environment and has driven many people away from their farmlands and homes.

2.2.3 Executed Control Measures in Some Developing Countries

There are many ways by which erosion is controlled and the methods adopted in any locality depend on the prevailing type of erosion, (Shealiker 1987).

Rapp (1976) in his study of Soil Conservation and Management in developing countries in which he applied field survey method, reported that researches are necessary for a meaningful control of any gully erosion to be achieved. Such research will include soil type, topography of area involved, vegetation and activities (natural or human) that brought about the erosion. Morgan (1986) studied soil erosion and conservation. In his write up, he advocated that well designed soil erosion control method depends on how well the nature of the erosion problem has been identified, and on the suitability of the selected soil conservation measures. Morgan also noted that forest provide excellent protection for the soil against erosion. He maintained that forest maintain high rates of evapor-transpiration, interception and infiltration and therefore generate only small quality of runoff. Nearing (1991) in his research work aimed at proposing a probability model of soil detachment by shallow turbulent flow through laboratory experiments and field survey measurements, recommended research before engaging in any erosion control measure as some attempts at solving erosion problems have, in fact, precipitated even worse erosion disasters, as was in the case at Umuowa-Orlu South eastern Nigeria reported by Niger-Techno (1978).

Okorie (1997) who studied the use of Dacryodes edulis in Erosion control in Agricultural Lands in Nigeria using field survey method, advocated for effective reforestation/afforestation of gully erosion prone areas by using trees such as *pines caribaea*, *gemelina* or *arboea*, food/fruit trees like *freculina Africana, Irviniga spp, penaclethra macro phyla* and shrubs like *Alchornea cordifolia* and *Dactyladenia bartieri*. He also showed that afforestation improves the floral development of gullies; enhance soil fertility and stability, increase organic matter content, increase macro and micro-organisms, including earthworms, biomass production of the trees and increase food production. Okorie (1995) in his ecological disaster research on gully erosion and aforestation in Southeastern Nigeria using field survey method, recommended the planting of seeds, rhizomes, roots and stem cutting of rapid growing grasses and herbs, along with structural alteration and earth dam construction, on both the exposed surfaces and the untouched surrounding land, including the gully floor. This is in line with the findings and recommendations of Igbozuruike (1977) in his review on Socio-economic Impact of Soil erosion and Lal, (1994) who analyzed for Soil resilience in stressed agro-ecosystems in Acapulco, Mexico using field survey measurements both reported that tree cover protects the soil from erosion by intercepting raindrops and absorbing their kinetic energy. Babalola, Jimba, Maduakolam, and Dada, (2003) investigated the efficacy of the use of vetiver grasses for soil and water conservation in Nigeria through literature review and site survey and after collation of their findings recommended that the use of vetiver grasses on gully/valley beds and sloppy walls as a way of soil conservation and a remedial measure gully erosion.

According to Valentin *et al* (2005), in their survey of the global trend gully erosion impacts, factors and control found that many techniques have proved to be effective for gully prevention and control, including vegetation cover, zero or reduced tillage, stone bunds, stone pitching, terracing and check dams. However, these techniques are rarely adopted by farmers in the long run and at a larger spatial scale because their introduction is rarely associated with a rapid benefit for the farmers in terms of an increase in land or labour productivity and is often contingent upon incentives.

Ojha and Shrestha, (2007) conducted a study on Bio-Engineering Measures for Stabilizing Cut- Slopes of Dipayal-Mellekh road, Far Western Nepal using field survey method. They found that grasses species such as Eulaliopsiss binata (Babiyo), Neyraudia reynaudiana (Dhonde), Cymbopogon microtheca (Khar), Saccharum pontaneum (Kans) and Thysanolaena maxima (Amliso), Arunduella nepalesis (Phurke) and Themeda species are suitable especially for slope stability.

Simpson (2010) in his paper titled “Prevention and Control of Gullying Processes in Diverse Climatic Settings: Lessons for the age of global climate change” commented on cultural method (which he referred to as vegetative techniques) of erosion control. He said it has been found to be a cheap and effective method, for instance planting of plantain and banana on the floodplains have also been proven to be effective in controlling erosion.

According to Obiadi *et al* (2010) in their study of Gully erosion in Anambra State Nigeria using both field survey and experimental methods, found that the drainage channel instructed to be constructed along Nanka and Oko sector was the only visible sign of government's intervention. They further opined that intensive afforestation program can be very effective in the control of gully erosion especially when well applied. This helps to protect the soil from the direct impact of raindrops and runoff as well as maintain the moisture content of the soil at responsible level during the dry season.

Akpokodje *et al* (2010) worked on Gully erosion Geo-hazards in Southeastern Nigeria using both field survey and experimental methods. They noted that the control measures that have been applied for management of gully erosion in south eastern Nigeria can be grouped into two categories, namely (a) control/curative and (b) preventive measures. According to them, the basic philosophies behind the curative/control measures are to:

i. Prevent runoff water from reaching the gully as much as possible.

ii. Enhance the stability of the slopes.

These methods reduce both quantity and velocity of flood water in the gullies and this in turn, leads to significant reduction in the erosive power of the gully flood water. The most commonly used structures are:

i. Interceptor – Open drains or canals.
ii. Catch pit or soak-away pit
iii. Underground drainage pipe.

Preventive measures are usually easier and cheaper to execute. The preventive concept is aimed at encouraging all practices that prevent erosion while discouraging all those practices or conditions that either initiate or accelerate gully erosion. It emphasizes correct land-use practices. However, for them to be effective, they require the mobilization and active participation of all people that are directly or indirectly connected with land use.

The three tiers of government (federal, state and local) have made several efforts to control/prevent erosion through:

i. Construction of erosion control engineering structures

ii. Legislature

iii. Public enlightenment and campaign.

However, there are major setbacks in government efforts which include:

(i) Poor design of structures arising from failure to adequately incorporate the properties of the soil, and the characteristics of the runoff/groundwater flow (volume and velocity).

(ii) Inadequate or non-maintenance of erosion control structures.

(iii) Failure to enforce anti-erosion laws and

(iv) Non-involvement of the rural dwellers (at community or individual level) in erosion prevention/control measures.

The effective management control and prevention of gully erosion in the south eastern Nigerian States is faced with two major problems, namely, funding and political will by the government. The funding required to control/prevent gully erosion in the affected states is so enormous and beyond the financial capabilities of local and state governments. Significant and sustainable financial assistance from federal government and International Community is required. There is lack of political will and policy for sustained and continuous implementation of well articulated, holistic, short and long term control/prevention of gully erosion.

The need to arrest the wasteful trend in soil loss has been widely recognised and various soil conservation measures have been taken at various levels to deal with the problem. Ofomata in his series of studies in (1973, 1981b and 1981a) in which he applied both experimental and survey methods, categorized these measures have been mostly curative and preventive. On the curative side, the two lines of action depend on whether the type of erosion involved is gullying, sheet or wind erosion. On gullies, the attempt has always been to prevent as much runoff as possible from reaching the gullies, as well as to stabilise the slopes. A combination of afforestation, ridging, contour ploughing, bunding, the construction of side-drains leading to soak-away pits (sumps) and the construction of concrete structures and drainage channels has usually been applied. On sheet erosion, the emphasis is co-reducing the extent of bare soils in any area and by planting such areas to grasses, such as bahama grass and shrubs, such as *Acioa barteri,* as well as other local varieties. Wave bedding is also important to either of the above measures. In the case of wind erosion, emphasis is again on limiting the extent of bare soils and providing wind breaks (trees, shrubs, etc) to check the process. On the preventive side, where the incidence of erosion is either not known or not yet serious, a number of measures are taken in addition to the above simple curative devices to check the inception of soil erosion. These other measures include limitation of the extent of forest degradation by evolving a system of cultivation which will always ensure that the ground surface is under effective cover of vegetation; controlling the extent and timing of bush burning; adaptation of contour ploughing; introduction of inter and multiple cropping and effective use of cover crops; zoning and controlling the use of pastures.

Obidinma and Olorunfemi (2011) conducted a survey on the ways of resolving the gully erosion problem in Southeastern Nigeria, through public awareness and community – based approaches. In their findings, they noted that control measures to stem gully erosion that are incipient are most effective when erosion is still at an early stage. This was supported by the findings of Osadebe and Enuvie, (2008), who suggested organic carbon, chemical properties, textural characteristics and moisture content of the soil as the most useful factors to be considered in a detailed survey and control of gully. They recommended that these factors and others should be carefully examined in the erosion-prone regions of the country in a bid to better design preventive measures.

Izinyon *et al*, (2013) discussed the use of structural and non-structural approaches for the control and management of the Queen Ede gully in Benin City by evaluating and analyzing available geotechnical, hydrological, morphological, meteorological, bio-resources and other pertinent data relating to the site and subject matter. They recommended that the gully can be controlled and managed through a combination of structural and non-structural methods consisting of drop structures at the gully head, check dams at the bed and reshaping of the gully walls which are structural; and non-structural means through the planting of vetiver grass on the bed and reshaped walls of the gully as well as mounting of community awareness programmes to the gully menace through proper dumping of wastes and termination of drains. It is therefore recommended that drains in the catchment area be properly terminated and energy dissipaters i.e rock chutes and flared structures to reduce the runoff velocity to a non-erosive level and the use of vegetation or their combination thereof should be adopted.

2.2.4 Efforts of Nigerian Erosion and Watershed Management Project (NEWMAP)

NEWMAP is a new agency which combines the effort of the Government and the support of World Bank in combating erosion problems. Being a new agency, much has not been recorded about their achievements, only information gotten from new papers and documentaries in their website. There is yet to be an empirical study into the evaluation of the control measures adopted by NEWMAP and possibly the level of success achieved. It is worthy to note that the intervention of NEWMAP at present has toed the part of engineering construction of channels and road networks, sensitization of the affected masses and bioremediation control measures. Some of the NEWMAP erosion control projects and achievements are shown in Appendix 1.

According to Adebayo Thomas of NEWMAP, One of the most crucial aspects of the Nigeria Erosion and Watershed Management Project (NEWMAP) is the watershed component. This was conceived not only to mitigate the adverse effect on soil but with an integrated approach to provide a better living condition to the people that are affected by gully erosion and to as well enhance their livelihood. Some of the principles include; supports for community's soil and water conservation; livelihood enhancement activities such as re-grassing and afforestation; income generation, agricultural skill acquisition of the affected community; continuous engagement and participation of the affected communities; sensitization and awareness creation towards environmental sustainability (http://newmap.gov.ng/newmap-tackling-erosion-and-improving-lives-using-the-watershed-concept/).

The general objectives of watershed management projects which include; to protect, conserve and improve the land of watershed for more efficient and sustained production; to protect and enhance the water resource originating in the watershed; to check soil erosion and to reduce the effect of sediment yield on the watershed; to rehabilitate the deteriorating lands; to moderate the floods peaks at downstream areas; to increase infiltration of rainwater; to enhance the ground water recharge, wherever applicable. to reduce the occurrence of floods and the resultant damage by adopting strategies for flood management; and, to provide standard quality of water by encouraging vegetation and waste disposal facilities; were all summarized by the Nigeria Erosion and Watershed Management Project into one: “to reduce vulnerability to soil erosion in targeted sub-watershed”.

Suffice to state; therefore that the activities of the NEWMAP project in Nigeria is no less in implementation as described above. According to Salisu Dahiru, NEWMAP National Coordinator, the integrated watershed management approach; most especially the Livelihood and Community participatory aspect, made the project attractive to a great number of stakeholders. “This was why initially, eleven states indicated the desire to start off the project, however seven states; Abia, Anambra, Cross Rivers, Ebonyi, Edo, Enugu, and Imo now referred to as the first mover states were objectively considered and selected. In December 2014, after series of evaluation of applications from additional states, the FPMU and in collaboration with the Federal Ministry of Finance (FMoF) and World Bank (NEWMAP Project Task Team), seven additional states of Delta, Oyo, Sokoto, Gombe, Plateau, Kogi and Kano were cleared to join the Project, thus making the total number of NEWMAP Project states fourteen (14). These new additional states have recorded considerable progress in their efforts to commence Project implementation (*http://newmap.gov.ng/newmap-tackling-erosion-and-improving-lives-using-the-watershed-concept/*).

Speaking further, Dahiru revealed that presently the projects 21 gully erosion sites across the first mover states have achieved varying degrees of appreciable percentage completion after compulsory payment of compensation to about 500 project affected persons (PAP). He also noted that the project has provided job opportunities to more than 300 Nigerians (*http://newmap.gov.ng/newmap-tackling-erosion-and-improving-lives-using-the-watershed-concept/*).

Recently the Nigeria Erosion and Watershed Management Project conducted a section of the media to some of its Project sites in Enugu(9th Mile and Ajali water works); Anambra, (Amachalla); Edo (Queen Ede & Oshiobhugie in Auchi); Ebonyi(Nguzu Eda in Afikpo); and Cross river(Ikot Anwatim, Atakpa and Nyanghasang). The first leg of the tour was with the Honourable minister of state, Federal Ministry of Environment, Alhaji Ibrahim Jibril. The oversight activity commenced from the coal city of Enugu and ended in Awka, Anambra state (*http://newmap.gov.ng/newmap-tackling-erosion-and-improving-lives-using-the-watershed-concept/*).

2.2.5 Grouting as a Method of Soil Stabilization

History

Over the past two decades, chemical grouting technology gained acceptance as a bona fide construction tool. Current practice makes use of sophisticated multipump grout plants and grout pipes, with accurate controls and monitors that permit full exploitation of the unique properties of available grouting materials. Further, the engineering profession also has accepted the fact that a technology exists and that there are reasonable and reliable methods of applying engineering principles to the design of a grouting operation. As we enter the 1980s, chemical grouting is taking its place alongside other accepted water control and strengthening techniques such as well pointing and underpinning.

Chemical grouting is a relatively recent technology, its modern era beginning in the early 1950s. Only in the past decade have the materials and techniques gained universal acceptance in the construction industry.Even so, there are many practicing construction engineers who retain doubtsabout the selection and use of chemical grouts. As recently as 1984, a federalgovernment publication (U.S. Department of the Interior, Bureau of Reclamation, 1984) contained the following statements: (1) ‘‘There is considerable literature on the subject of chemical grouting, but it is diverse, unorganized and often outdated.’’ (2) ‘‘In selecting a chemical grout, it is difficult, when reviewing the literature to find anything which states which grout is probably best for a given application or how to go about making such a decision.’’ In contrast to these somewhat negative statements, the same publication four pages later lists a number of government publications that contain excellent details of grouting materials and procedures.

The first chemical grout is credited to a European, Jeziorsky, who was granted a patent in 1886 based on injecting concentrated sodium silicate into one hole and a coagulant into another (nearby) hole. In 1909, Lemaire and Dumont patented a single-shot process consisting of a mixture of dilute silicate and acid solutions. Shortly thereafter, A. Francois used a mixture of sodium silicate and aluminum sulfate solutions brought together at the injection hole. Francois found that the use of silicate grouts facilitated the subsequent pumping of cement grout. He concluded that the silicate was acting as a lubricant. The use of sodium silicate as a ‘‘lubricant’’ persisted on a small scale until several decades ago. Actually, it is more probable that either (1) the pressure fractured the formation making for larger voids to be filled by cement or (2) the silicate grout gelled in the smaller voids, preventing these voids from filtering the water from the cement grout. A Dutch engineer, H. J. Joosten, is credited with the earliest demonstration of the reliability of the chemical grouting process in 1925. Joosten used concentrated sodium silicate injected into one hole and a strong calcium chloride solution injected under high pressure into an adjacent hole. This process, known by the name of the man who originally demonstrated its value, is still in use today, although on a very limited scale, both with and without modification. In fact, from the first use in the late 1800s until the early 1950s, sodium silicate was synonymous with chemical grouting, and all chemical grouts used during that interval were sodium silicate based.

Other silicate formulations developed soon after Joosten’s original work. Between 1930 and 1940, field work using sodium bicarbonate, sodium aluminate, hydrochloric acid, and copper sulphate as reagents was successfully performed. A new era in chemical grouting started in the United States at aboutmid-century. Since its introduction, research aimed at reducing the Joosten process to a reliable single-shot injection system had been ongoing. The breakthrough came as a result of advances in polymer chemistry and culminated in the early 1950s with the marketing of AM-9 (trademark, American Cyanamid Company), a mixture of organic monomers that were polymerized in situ after any selected time interval. The rapid development of new markets for chemical grouts was given great impetus by Cyanamid’s marketing decision, which included the establishment of a research center (initially called Soils Engineering Research Center and later Engineering Chemicals Research Center, located in Princeton, New Jersey. From 1956 to 1967, this center published over 1000 pages of technical reports related to chemical grouts and grouting) to develop grouting techniques and technology.

At about the same time, chrome-lignin grouts (lignosulfonate solutions catalyzed with chromate salts) were proposed and developed for field use. In Europe, phenol and resorcinal formaldehydes, developed in the latter 1940s, came into use. During the next several years, ureaformaldehyde-based grouts giving high strength such as Halliburton's Herculox and Cyanamid's Cyanaloc were developed and marketed (about 1956). In 1957, Soletanche in France developed a single-shot silicate grout using ethyl acetate as the reagent. Other esters came into use in the following years. Around 1960, Diamond Alkali Company entered the market with a single-shot silicate-based grout trade named SIROC, which offered high strength or low viscosity, each coupled with gel time control. At about this time Terra Firma, a dried precatalyzed lignosulfonate, also entered the market.Several years later Rayonier Incorporated marketed Terranier, a single-shot grout comprised of low-molecular-weight polyphenolic polymers (about 1963). Then, Borden Inc. marketed Geoseal, a resin prepolymer (patent filed in 1968).

Developments in chemical grouting were also taking place in Asia. In Japan, an acrylamide grout was marketed in the early 1960s as Nitto SS, and the TACSS system, a polyurethane which uses groundwater as the reactant, was marketed several years later. In Europe, during the 1960s, refinements were made to the silicate systems, and in the late 1960s and early 1970s, acrylamide-based grouts appeared. Rocagil AL (Rhone-Poulenc Inc.,France) is a mixture of an acrylic monomer and an aqueous dispersion resin, while Rocagil BT is primarily methylol acrylamide.

In the United States, the market was shared primarily by AM-9 and SIROC until 1978, with SIROC getting the lion's share. Proprietary grouting materials had and still have a small part of the market. According to Yonckura and Kaga (1992), in Japan, acrylamide grouts were banned in 1974 (five reported cases of water poisoning were linked to use of acrylamide on a sewer project), and several months later the ban was extended to include all chemical grouting materials except silicate-based grouts not containing toxic additives. These events were to have strong effects on grouting practice in the United States. Since the early 1970s concern over environmental polution had been growing rapidly. In 1976 a federal agency (probably influenced by events in Japan) sponsored a study of acrylamide-based grouts used in the United States. Acrylamide is a neurotoxic material, and the first draft of the report (which was never published) recommended that acrylamide grouts be banned. In later revisions, the report recommended that regular medical supervision of personnel using acrylamide be made a condition for its use.

Concurrently with the acrylamide study, reports issued by other federal agencies suggested that DMAPN (the acrylamide accelerator) may be carcinogenic. Implementation of the recommendations made in these reports became unnecessary, because early in 1978, the domestic manufacturer of acrylamide grout withdrew AM-9 from the market, and made its components unavailable to anyone who might wish to use them for grouts. The loss of AM-9 as a construction tool was lamentable, but not catastrophic. The furor among grouters would have died down quickly except for one factor. Over the years since its introduction, a very specialized and sophisticated sewer sealing industry had grown around the use of AM-9. Those involved in this industry began an immediate search for an AM-9 replacement.

This search quickly brought a Japanese equivalent of AM-9 to the United States. This product, originally known as Nitto SS became available early in 1979 as AV-100. European products were available for a short time on a trial basis only. They were not marketed commercially.

The search for new and less hazardous materials took longer to consummate. By the middle of 1979, Terragel became commercially available. This product was a concentrated solution of methylolacrylamide. It was withdrawn from the market within a short time due to storage stability problems. In 1980 CR-250, a urethane product, was marketed specifically for sewer sealing applications. Improved and modified versions have since appeared. At the same time, Injectite 80, an acrylamide prepolymer (relatively nontoxic), also became available for sewer sealing applications. This product has not been marketed aggressively. Later in the same year, AC-400, a relatively nontoxic mixture of acrylates was marketed as a general replacement for acrylamides. Its properties are similar to those of acrylamide grouts, and AC-400 is regaining the market previously held by the acrylamides. Another acrylate grout appeared on the market in 1985.

At present, most chemical grouting in the United States is done with silicates. This is not because other materials are not available. By way of contrast, phenoplasts, aminoplasts, chrome lignins, and acrylamides are all used in Europe. These products are well known to American grouting firms. However, in the United States, Terra Firma and Terranier (chrome lignin and phenoplast) fell by the wayside some years ago, primarily due to the toxic properties of the dichromate catalyst. Herculox and Cyanaloc (aminoplasts) had limited application to begin with because they require an acid environment. In addition, the formaldehyde component can cause chronic respiratory problems. Geoseal also contains formaldehyde. Imported acrylamide dominated the sewer-sealing industry until the acrylate grouts appeared. Both are now in use, with the acrylamides still getting the lion's share. Although concern over environmental pollution and personnel health hazards has been an important factor in the limited use of specific chemical grouts (except for sodium silicate, all the chemical grouts are to some degree toxic, hazardous, or both), there has never been a ban against use of acrylamide-based grouts in the United States. In fact, the use of acrylamide has grown significantly over the past decade, like in small area along a river bank about a mile downstream of a power dam near Albany, New York; in Cleveland, Ohio; and at Minneapolis, Minnesota where was used to increase the formation strength.

According to Reuben (2003), the modern era of chemical grouting began a half century ago, with the introduction of many new materials, and the significant modifications to the silicates. The earliest two products, silicates with gel time control and the acrylics still dominate the domestic market, although many other products are in regular use throughout the world. Grout properties that play a role in the selection and use of the various products are permanence, penetrability, strength, safety, ease of handling, availability, and cost. Values differ widely among the available products. An ideal chemical grout would combine the best properties of the commercial products. In reality, there is a trade-off in properties for each grout (for example, to get high strength silicates you sacrifice low viscosity). Except for the area of strength, acrylamides come close to being ideal grouts.

Edil, (2003) in his write up on Recent advances in geotechnical characterization and construction over peat and organic soils, defined soil stabilization as a technique to improve the engineering characteristics in order to improve the parameters such as shear strength, compressibility, density, hydraulic conductivity. According to him, the techniques of soil stabilization can be classified into a number of categories such as vibration, surcharge load, structural reinforcement improvement by structural fill, admixtures, and grouting and other methods. There are many techniques that can be used for different purposes by enhancing some aspects of soil behavior and improve the strength and properties of soil. The important features of ground treatment includes: improving the bearing capacity of the ground, reducing the potential for total and differential settlement, reducing the time during which the settlement take place, reducing potential for liquefaction in saturated fine sand or hydraulic fills, reducing the hydraulic conductivity of the ground, removing or excluding water from the ground. The conventional method of soil improvement is to replace the soft soil by suitable imported fill materials. However, this practice is naturally very expensive due to the cost of excavation, dumping and the filling material.

Sina and Maassoumeh (2012) in their Review of soft soils stabilization by grouting and injection methods with different chemical binders, affirmed that soil stabilization has become one of the useful solutions to treat the soft soils to achieve the required engineering properties and specification so that structures can be placed safely without undergoing large settlements and can also be applied in erosion control, landslide management and to check issues like subsidence and differential settlement. Soil stabilization by admixture was developed in Japan during 1970s and 1980s. The treated soil has greater strength, reduced compressibility and lower hydraulic conductivity than the original soil. The use of admixture such as lime, cement, oils and bitumen is one of oldest and most widespread method for improving soil. When mixed with soil, it forms a material called soil-cement. The original technique known internationally as the deep mixing method (DMM) was developed simultaneously in Sweden and Japan in the mid-1970s. It is an *in-situ* soil treatment technology whereby the soil is blended with cementitious and/or other materials. Jet grouting is suitable to be used as the injection method for the DMM. It utilizes a fluid jet (air, water and/or grout) to erode and mix the *in-situ* soft or loose soils with grout. The grouting method is one of the ground improvement methods suitable for the soft soil.

Sina and Maassoumeh (2012), went further to state that chemical stabilization is the effective method to improve the soil properties by mixing additives to soils. Usually the additives are cement, lime, fly ash and bituminous material. The chemicals usually used are sodium silicate, acrylamide, N-methylolacrylamide, polyurethane epoxy resins, aminoplasts, phenoplasts, lignosulfonates, among others. Calcium Chloride has also been used for soil stabilization over time. Calcium chloride has two characteristics that enable it to be useful for dust control applications. First, it is hygroscopic. In other words, it attracts moisture from the atmosphere and surrounding environment and resists evaporation as it works to remain in its natural liquid state. Second, calcium chloride is deliquescent, which means the solid form can dissolve into a liquid by absorbing moisture from the atmosphere and surroundings. When calcium chloride is spread on low-volumeunpaved roads in the spring, its moisture-attraction ability works to keep the surface damp and to keep dust down, usually throughout the summer. Calcium chloride has other properties that contribute to the improvement and performance of unpaved roads. For example, compared with plain water, calcium chloride has a stronger moisture film, higher surface tension, lower vapor pressure, and lower freezing point. The combination of these properties enables the chemical to keep unpaved surfaces damp and to keep fines, or tiny dust particles, in place (Calcium Chloride Institute (1953). Additionally, calcium chloride actually helps bind the aggregate particles togetherand, as a result, the surface becomes compacted by traffic.

Over time, calcium chloride slowly penetrates the surface by several inches, which creates a stabilizing effect to the road. The longer calcium chloride is used, the more stability that is achieved. Finally, the chemical's lower freezing point helps

unpaved roads resist frost heave in late fall and early winter. The choice of a particular chemical for soil stabilization or grouting will depend upon many factors like, purpose, soil strength desired, toxicity, rheology among others.

METHODS OF SOIL STABILIZATION

1. SOIL STABILIZATION BY ADMIXTURE

Soil stabilization by admixture was developed in Japan during 1970 and 1980. It uses rotating mixer shafts, paddles, or jets that penetrate into the ground while injecting and mixing Portland cement or some other stabilizing agent. These techniques include deep cement mixing, soil mix walls, deep mixed method and other. The treated soil has greater strength, reduced compressibility and lower hydraulic conductivity than the original soil

(Raison, 2004). The use of admixture such as lime, cement, oils and bitumen is one of oldest and most widespread method for improving soil. When mixed with soil, it forms a material called soil-cement. The objective of admixture is to provide artificial cementation, thus increasing the strength and reducing both compressibility and hydraulic conductivity. Admixture treated soil also have been used as erosion protection on the face of the earth dams, levees and channels. The disadvantage of this method is that specialized equipment is usually required to achieve a sufficient thorough mixing. If the mixing is inadequate, the resulting product will consist of alternating over treated hard spot separated by untreated soft spot, a situation that may be worse than no treatment at all (Ingles and Metcalf, 1973).

2. DEEP MIXING METHOD (DMM)

Deep mixing method can be applied in most soft soils. The mechanized process of mixing is by using a rotating mixing tool, drilling the tool into the soil. After this, the drilling rotation is reversed, extracting it and at the same time as the dry binder is injected and mixed into the soil. Through the rotating movement, the soil is mixed with the binder and an immediate reaction starts. The improved soil acquires the share of a column (Kazemian, 2009). The column so formed can have diameters ranging from 0.5 to 1 m and the lengths up to 25 m. The columns can also be interlocked to provide cellular structure of *in-situ* wall or the entire mass cab be stabilized. Dry mixing is a highly effective ground treatment system used to improve the load performance of soft soils. By varying the proportion of lime, cement and admixtures, a range of strength gains can be achieved. The greatest improvements can be achieved in inorganic soils with low moisture content (Hashim and Islam, 2008). The original technique known internationally as the deep mixing method (DMM) was developed simul-taneously in Sweden and Japan in the mid-1970s. According to Kazemian and Barghchi (2105), DMM is a ground treatment, improvement, and support method of global application and increasing popularity and value (Mitchell and Jardine, 2002). Compared with other similar ground improvement methods, the deep mixing method (DMM) is the method specially designed to treat the soft soils. DMM are divided into three systems namely, shallow soil mixing (SSM), deep soil mixing (DSM) and jet grouting systems (JGS) (Keller, 2009).

Deep mixing method is an *in-situ* soil treatment technology whereby the soil is blended with cementitious and/or other materials. The deep mixing method is often classified into two methods: dry and wet method, based on the type of binder, the mechanism of bleeding in rotary or jet assisted, and the vertical extent over which blending is accomplished (Bruce, 2000). The former utilizes the dry powdered binder whereas the latter utilizes the water-binder slurry. Naturally, there are some differences in the execution machines between dry and wet methods. However, there is no substantial difference in the characteristics of treated soils between them. The apparent difference in the design procedure and application comes from the purpose of improvement, which in turn gives rise to the difference in the installation patterns and in the order of strength required (Bromes et al., 1999).

Deep mixing method emphasizes on column type techniques using lime/cement. It is a soil improvement method, which is performed to improve the strength, deformation properties and hydraulic conductivity of the soil. It is based on mixing binders, such as cement, lime, fly ash and other additives, with the soil by the use of rotating mixing tools in order to form columns of a hardening material since pozzolanic reactions between the binder and the soil grains are developed. The main advantage of these methods is the long-term increase in strength, especially for some of the binders used (Anagnostopoulos and Chatziangelou, 2008). Pozzolanic reaction can continue for months or even years after mixing, resulting in the increase in strength of cement stabilized soil with the increase in curing time (Bergado, 1996; Hashim and Islam, 2008a).

3. GROUTING AND INJECTION METHOD

Typically, grouts that are continually moving will turn into a gel less quickly, and the penetration from continuous injection will be greater than that from the same volume of grout used in batch injection. When gelling occurs before pumping is halted, the last injected grout typically moves to the outside of the grouted mass, and both large and small openings are filled. Jet grouting is suitable to be used as the injection method for the deep mixing method (DMM). It utilizes a fluid jet (air, water and/or grout) to erode and mix the in-situsoft or loose soils with grout. It utilizes high velocity, 28 to 42 MPa back pressure and jet to hydraulically shear the soil and adding suitable binder to form a column (Keller, 2009).

The result significantly increased shear strength and stiffness of the soil (Mitchell and Jardine, 2002). The first patent regarding jet grouting was applied for in England in the 1950s; however, the actual development of jet grouting was in Japan during 1960s and 1970s. Jet grouting is the newest method compared with other methods. In the mid 1970s, jet grouting was exported to Europe and has become popular worldwide. This technology was initially aimed at improving the effectiveness of water tightness, in chemical grouting, by eroding the untreated or partially treated soil, which was then ejected to the surface for disposal being replaced with cement-based slurry for imperviousness (Moseley, 2000).

Jet grouting is the construction of hard, impervious column in the ground by the enlargement of a drill hole using rotating fluid jets to liquefy and mix grout with, or to excavate and replace, soil (Raison, 2004). Jetting and grouting are carried out during controlled withdrawal and rotation of the drill string and the jetting head from the hole. There are several variations depending on the nature and pressure of the jetting and grouting the in-situsoil may be mixed with the grout, partly mixed and partly removed or wholly replaced. In general, there are four basic jet grouting systems which are widely used and classified as Single phase (grout injection only), Dual phase (grout + air injection), Triple phase (water + air injection and followed by grout injection), Super Jet Grouting (air injection + drilling fluid by grout injection) (Keller,2009).

The grouting method is one of the ground improvement methods suitable for the soft soil. Modern grouting began in the mining industries, concerned with the seepage and strength control in mines, tunnel and shaft, then was taken up by civil engineering. Various functions of grouting available depend on the intention and the condition of the site. It includes permeation grouting, compaction grouting, hydro fracture grouting, jet grouting, rock grouting, compensation grouting, cement grouting and fracture grouting. Because of the various functions of grouting, the differences between grout characteristic and differences between the soil type to be grouted need to be addressed. Therefore, the generalisation about the grouting equipment and method are difficult to achieve (Shroff and Shah, 1999). A grout is also simply defined as a material used for grouting (Karol and Dekker, 1983).

Selecting the right method for deep soil stabilizing however, depends on several conditions like the type and alternative layers of soil, load size, the situation and type of project, among others (Mitchell and Jardine, 2002). Grouting generally is used to fill voids in the ground (fissures and porous structures) with the aim to increase resistance against deformation, to supply cohesion, shear-strength, compressive strength and finally to reduce hydraulic conductivity or interconnected porosity in an aquifer (Moseley and Kirsch, 2004).

The mechanism of grout can be explained in the process of pressure filtration of grout in which the grout is injected under pressure into the soil and the mix will loose water into the surrounding ground. This loss of water will cause a thickening and reduction in volume of the mix. As a result of generation of internal friction, increased viscosity and yield of the grout will finally block the flow or movement of grout into the soil. Through the theoretical and experimental considerations, as soon as internal friction in a particulate mix occurs, grouting will be stopped. This pressure filtration phenomenon state that when the cement grains are not transported freely by the fluid but come into contact, friction between the particles will develop and will cause the grouting to be terminated (Mitchell and Jardine, 2002).

Generally, the grouting method is classified as suspension type grout and solution type grout. The suspension type grout includes soil, cement, and lime asphalt and emulsion, while the solution type includes a wide variety of chemicals such as silicate based grout, resins and epoxy (Rawlings et al., 2000).

4. CHEMICAL AND CEMENTATION GROUTS

Chemical stabilization is the effective method to improve the soil properties by mixing additives to soils. Usually the additives are cement, lime, fly ash and bituminous material. These additives enhance the properties of soil. Generally, two major reactions for the chemical stabilization are cation exchange reaction and cementation (Mitchell, 1993). The common chemical agent for cementation process is Portland cement, lime, fly ash, sodium silicate polyacrylamides and bituminous emulsion.

Many of chemical grouts are based on the combination of sodium silicate and a reagent to form gel. The Joosten process used in coarse granular soils uses calcium chloride as a reagent. Other reagents are organic ester, sodium aluminates and bicarbonates. The reagent and the proportion can be chosen to control the gel time, the initial viscosity and the order of strength of the grouted soil. Chemical grouts are injected into voids as a solution, in contrast, to cementitious grouts, which are suspension of particle in a fluid medium. The difference between chemical grout and cementitious grout is the chemical grout can be used to fill the finer voids of soil particles up to 10 to 15 ηm in diameter. In other word, it has better penetration ability than the cementitious grout (US Army Corps of Engineers, 1995).

Chemical grout can be classified in single step and two step processes. In one step process, all the ingredients are premixed prior to injection, the system are designed that the reaction takes place *in-situ*. In the two step process, the initial chemical is injected into soil mass then follow by the second chemical material to react with the first *in-situ* and to stabilize the mass. There are several types of chemical grouts, each type of grout have different characteristics and different applications. The most common are sodium silicate, acrylate, lignin, urethane, and resin grouts (Shroff and Shah, 1999).

TYPES OF CHEMICALS USED FOR GROUTING

1. Sodium silicate system

Sodium silicate grouts are most popular grouts because of their safety and environmental compatibility. It has been developed into various grout system such as silicate chloride amide system, among others. Most of the systems are based on the reacting a silicate solution to form a colloid which polymerizes further to form a gel that binds the soil particles. The silicate solution concentration that may be used in grouting is in range of 10 to 70% by volume, depending on the material being grouted and the desired result to achieve. For a system of using amide as reactant, the amide concentration may vary from less than 1 to greater than 20% by volume. In practice, the amide concentration ranges from 2 to 10% (US Army Corps of Engineers, 1995).

The initial minimum viscosity of a grout that can produce a gel has a $SiO_2:Na_2O$ ratio of 3.6 with a pH value of 8.5 to 9.2 for a given dilution within an ideal framework of gel time. The rate of reaction and strength of gel are directly proportional to the concentration of silicate and catalysts in the grout at constant temperature respectively (Shroff and Shah, 1999). Sodium silicate is noncorrosive to metals. Reactants such as amide and their water solutions will attack copper and brass, but they are noncorrosive to aluminates and stainless steel. The chloride solutions are not corrosive to iron and steel in the sense that acids are; however, if steel in a chloride solution is exposed to air, rusting will occur at the junction of the liquid and air. Bicarbonate is noncorrosive (US Army Corps of Engineers, 1995).

2. Silicate chloride amide system

The silicate chloride amide system is one of the widely use silicate grout system containing sodium silicate as a gel forming material. The silicate aluminates-amide system has been used for strength improvement and water cut-off. Its behaviour is similar to the silicate-chloride-amide system but is better for shutting off seepage or flow of water. The cost is slightly higher, and this system can be used in acidic soils. Amide will act as a reactant and the calcium chloride, sodium aluminates will be used as the accelerator. These reagents bring an almost instant setting time and produce very low penetrability type gel that are unsuitable for permeation treatments (Rawlings et al., 2000).

The function of the accelerator is to control gel time and impart strength to the gel. The effect of the accelerator is important at temperatures below 37°C and increases in importance as the temperature decreases. Excessive amounts of accelerators may result in undesirable flocculation or formation of local hardening. This causes variations in both the gel and setting times that would tend to plug injection equipment or restrict penetration, resulting in poorly grouted area. Therefore, a retarder should be added in the mixture for delaying the setting time and formation of gelation (US Army Corps of Engineers, 1995).

Reuben (2003), also noted that over the last 30 years, a few hundred different compounds of chemical grout are available. However, the origin of chemical grout still remains a few types such as silicates, acrylamide, epoxy, and some fatty acid derivates. Generally, chemical grouts are intended to penetrate and fill narrow joints or soils with very small pore size.

Basically, the comparison will be made according to the penetrability of grout in soil and the range of curing time for each type of grout (Magill and Berry, 2006).

3. Acrylamide

Acrylamide based grouts come closest to satisfying the attributes of an ideal grout. They show easy penetration and maintain their initial viscosity until at the very end of the gelling stage when they rapidly set. They have good gel time control and adequate strength for most applications (Karol, 1983). The grout exhibits good penetrability, with a constant low viscosity during induction period and better gel control with adequate strength. However, it is highly toxic and unsuitable for potable water application (Shroff and Shah, 1999). Acrylamide has a low chemical resistance toward acidity condition; therefore, it is not suitable for application in peat because peat is acidic in nature. The new acrylate gels are suitable for works that require low viscosity and a well controlled gel time, however, the cost is higher than sodium silicates (Nonveiller, 1989).

4. N-Methylolacrylamide

N-Methylolacrylamide (NMA) is inert and essentially non-toxic if properly catalyzed. So it is better than acrylamide grout. However, NMA has an extremely low viscosity with about 1 to 2 cP. The viscosity is similar to that of water; therefore the pumping flow rate will be same as the water. It has low stability under constant head pressure of the groundwater and is especially bad where acidic conditions and organic contaminants are present. The gel time is affected by the temperature and catalyst concen-tration. Acrylate grout is rarely used in geotechnical field since the gel will swell considerably in the presence of water. As a result, strength of the grout will further reduce since existence of water will dilute the concentration of grout (Magill and Berry, 2006).

5. Polyurethane

Polyurethane chemical grout is composed of two com-ponents of water activated material called hydro-phobic and hydrophilic resin. However, many of other type resin are produced base on these two resins. The viscosity of grout is very high with its range from 300 to 2500 cPs. The limitation is that the pH of water will affect the reactivity of grout. A higher pH value with more than pH 7 will increase the activity of grout. Thus, it is favorable for the alkaline soil and unsuitable for the acidity soil like peat. Besides, the gel time of the polyurethane is controlled by the molecular weight, intermolecular forces, and stiffness of chain units, crystallization and cross linking (Reuben, 2003). The polyurethane is toxic in nature, so, it is mostly applicable in forming to block water inflow (water reactive resins).

6. Epoxy resins

Epoxy resins are liquid pre-polymers with hardening agent, they usually exhibit very high tensile, compressive and bond strength. Generally epoxy resins will have either good chemical resistance or good heat resistance (Magill and Berry, 2006). The low viscosity has a better penetrability but greater shrinkage and less strength due to the weak bonding lead to more subsidence, whereas the high viscosity may better if adequate pressure is maintained long enough to permit the grout filling into small void (Erickson, 1968). However, epoxy is one of the resins types which are toxic in nature and requires special care during handling (Rawlings et al., 2000).

7. Aminoplasts

Aminoplasts consist of urea and formaldehyde. The rapid grout reaction in hot and acidic environments makes this product difficult to handle. An intermediate stage between liquid and solid urea-formaldehyde is used instead of the pure liquid phase. Aminoplasts with formaldehyde and acid catalyst contents are toxic and corrosive. Amino-plasts contain formaldehyde and an acid catalyst, which are both toxic and corrosive. In the gelled state, the aminoplast may contain leachable, unreacted formal-dehyde. It is suitable for ground with pH less than 7 (Karol, 1983).

8. Phenoplasts

Phenoplasts are "polycondensates resulting from the reaction of a phenol on an aldehyde." There are several factors that control the phenoplast gel time including pH. For any given solution concentration, a pH slightly above 9 achieves the shortest gel time. Nonetheless, a catalyst, usually sodium hydroxide, is required to control pH. Another variable factor affecting gel time is the diluted grout concentration. Initial viscosity for field work ranges from 1.5 to 3 cP. The strength of phenoplasts is compar-able to the high-concentration of silicates. Phenoplasts are less sensitive to the rate of testing strain than other grouts, and their creep endurance limits comprise a greater percentage of their unconfined compression values. However, phenoplasts are toxic. The phenol, formaldehyde, and alkaline base are all health hazards and environmental pollutants.

9. Lignosulfonates

Lignosulfonates are waste by-products of wood processing in paper manufacturing. Though the grout is non-toxic by itself, both in its original liquid state and dried form, the sodium dichromate additive is highly toxic (Nonveiller, 1989). If the lignosulfonate is acidic (pH < 6), no additive is required. Acids and acid salts are used only to control pH > 6 (Karol and Dekker, 1983). The grout has a viscosity range between 3 to 8 cP with strength comparable to acrylamide grouts (Nonveiller, 1989). However, it is highly toxicity and not suitable used in domestically.

Table 2.1: Ranking Based on Toxicity, Viscosity and Strength.

Grouts	**Toxicity**	**Viscosity**	**Strength**
Silicate			
Joosten process	Low	High	High
Siroc	Medium	Medium	Medium- High
Silicate –Bicarbonate	Low	Medium	Low
Lignosulphates			
Terra Firma	High	Medium	Low
Blox- All	High	Medium	Low
Phenoplasts			
Terramier	Medium	Medium	Low
Geoseal	Medium	Medium	Low
Aminoplasts			
Herculox	Medium	Medium	High
Cyanaloc	Medium	Medium	High
Acrylamides			
AV-100	High	Low	Low
Rocagel BT	High	Low	Low
Nitti- SS	High	Low	Low
Polyacrylamides			
Injectite 80	Low	High	Low
Acrylate			
AC- 400	Low	Low	Low
Polyurethane			
CR-250	High	High	High

Source: Shroff and Shah, (1999).

Decision on choosing the grout

Reuben (2003) in his conclusion stated that if the goals of research to develop a new chemical grout were to be listed, they would state that the basic materials should be as follows:A powder readily soluble in water (this eliminates the expense of transporting a solvent, and water is the least expensive solvent); Inexpensive and derived from chemicals in abundant supply; Stable at all anticipated storage conditions; Nontoxic, Noncorrosive and Nonexplosive; the grout solution should be a low-viscosity solution, preferably that of water, Stable under all normal temperatures, Nontoxic, noncorrosive, nonexplosive, catalyzed with common, inexpansive chemicals, insensitive to salts normally found in groundwater, of stable pH on the positive side (so that it may be used in conjunction with cement), readily controlled for varying gel times and able to withstand appreciable dilution with groundwater; the end-product should be: a permanent gel, unaffected by chemicals normally found in groundwater, nontoxic, noncorrosive, non-explosive and of high strength.

In the real situation no such material exists. However, every criterion listed can be found in one or more commercially available materials. It is important, therefore, to determine which grout properties are critical to a specific project in order to have a sound basis for selecting a grout.

In order to choose a grout type, several properties of grout should be concerned such as rheology, setting time, toxicity, strength of grout and grouted soil, stability or permanence of the grout and grouted soil and the penetrability and water tightness of the grouted soil (Rawlings et al., 2000). Moreover, the spreading of grout plays an important role in the development of grouting technology. In the actual filed, the grouting method requires a extensive consideration on the grout hole equipment, distance between boreholes, length of injection passes, number of grouting phases, grouting pressure and pumping rate (Shroff and Shah, 1999).

2.3 Synthesis of Literature

Below is a highlight of the findings generated from the literature reviewed.

Gully Erosion Causes: There are several causative factors activating intense erosion and gully formation. From the reviewed literature they are majorly classified into two as given below:

a. Natural / Physical Factors

b. Anthropogenic / Human Factors

The natural/physical factors identified from the review include: Nature of Topography, Geology and Nature of Soil, Climate (High rainfall) and Vegetation Cover. It is noteworthy that some of the works reviewed studied in Anambra state and affirmed that Nanka Sand is the geologic unit within the state that is mostly prone to gullying (Egboka *et al*, 2006 and Igbokwe *et al*, 2008). This is in line with the information received from the National Geohazards Centre Awka on the effects of geology on gully erosion in Anambra State.

From the review identified human activities that have contributed immensely to soil erosion and gully erosion problems include: Agricultural Practices (Deforestation, Bush burning, Continuous cropping, Excavation of soil, Overgrazing), Mining Operations (Sand Mining), Settlement Patterns, Urban and Infrastructural Development (Lack of good drainage system, Road Construction processes).

Effects: the negative effects of erosion as contained in the literature review includes; loss of lives and properties (houses, farmlands, livestocks), loss of forest, displacement of populations, damage of roads, loss of soil fertility, creation of badlands, among others.

Control: in Nigeria, the already adopted control measures includes: Afforestation; Contour planting of crop; Construction of drainage channels, gabions and check dams; Mulching; Planting of cover crops and carpet grasses eg. the vetiver grasses (Babalola *et al*, 2003); Control of bush burning; Use of crop rotation; Multiple cropping; Zoning/controlling of use of pasture; Public awareness (Ezezika and Adetona, 2011) and many other Government policies and programmes on erosion control.

Grouting and Grouting Chemicals:that chemical stabilization is the effective method to improve the soil properties by mixing additives to soils. Usually the additives are cement, lime, fly ash and bituminous material. The chemicals usually used are sodium silicate, acrylamide, N-methylolacrylamide, polyurethane epoxy resins, aminoplasts, phenoplasts, lignosulfonates, among others. The choice of a particular chemical for soil stabilization will depend upon many factors like, purpose, soil strength desired, toxicity and others (Sina and Maassoumeh, 2012).

Standards for Good Chemical Grouts

The following table 2.2 summarized the standards for good chemical grouts, as solid grouts, as solution and after application to the soil or rock under treatment.

Table 2.2: Standards for Chemical Grouts Extracted from Literature

As a Solid Grout	As a Solution Grout	After Grouting, the End Product
i. A powder readily soluble in water (this eliminates the expense of transporting a solvent, and water is the least expensive solvent) ii. Inexpensive and derived from chemicals in abundant supply (readily available and affordable) iii. Stable at all anticipated storage conditions iv. Non-toxic v. Non-corrosive vi. Non-explosive	i. A low-viscosity solution, preferably that of water ii. Stable under all normal temperatures iii. Nontoxic, noncorrosive, nonexplosive iv. Catalyzed with common, in-expansive chemicals v. Insensitive to salts normally found in groundwater vi. Of stable pH on the positive side (so that it may be used in conjunction with cement) vii. Readily controlled for varying gel times viii. Able to withstand appreciable dilution with groundwater	i. Permanent gel ii. Unaffected by chemicals normally found in groundwater iii. Non-toxic, iv. Non-corrosive, v. Non-explosive vi. High strength.

(Sources: Extracted from Nonveiller, 1989; Rawlings et al., 2000; Mitchell and Jardine, 2002; Reuben, 2003; and Magill and Berry, 2006)

2.4 Gaps in Literature

From the literature review, the following gaps were identified:

1. None of the works tried to experiment or evaluate any form of soil stabilization or groughting but many of them found geology and soil characteristics as a major cause of soil erosion and gullying.

2. There is need to advance into determining the chemical composition of the rocks underlying the gullies as most of the works reviewed affirmed that geology of the area is a major factor of gully erosion, but none of the works tried to determine the elemental constituents of the underlying rocks of a gully prone area in order to establish its deficiencies.

3. Established from review of literature and field survey is the fact that most of the channelization and other control structures like the gabions and sand bag check dams failed with time, but none of the researchers tried to find out the major causes of their failure.

CHAPTER THREE

THE STUDY AREA

This chapter discussed the study area under the following headings:

- Geographical Location
- Climate
- Geology
- Study Sites
- Relief and Drainage
- Vegetation and Soils
- Ecological Hazards

3.1 Geographical Location

The study area is Anambra State, located between latitudes 05^o 40'N and 07^0 10N' and longitudes 06^o 35'E and 07^0 20'E, in the South-Eastern part of Nigeria (Onwuka, 2009). Boundaries are formed by Delta state to the west, Imo state and Rivers state to the south, Enugu state to the east and Kogi state to the north. The origin of the name is derived from the Anambra River (Omambala) which is a tributary of the famous River Niger.

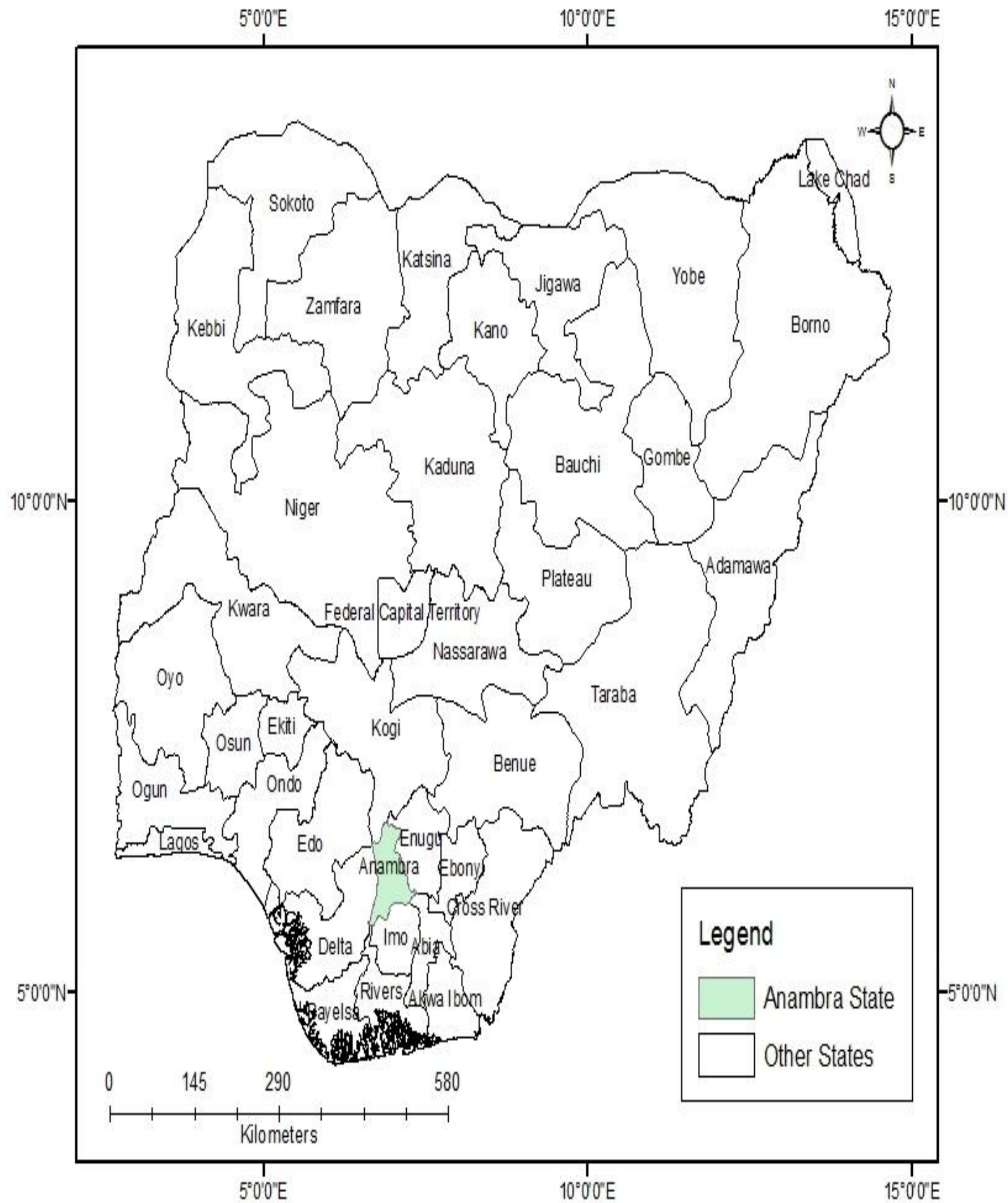

Fig. 3.1: Nigeria Showing Anambra State (Source: National Geohazards, Awka, (2017)

Anambra is the eight most populated state in the Federal Republic of Nigeria and the second most density populated state in Nigeria after Lagos state (N.P.C, 2006). The stretch of more than 45km between Oba and Amorka contains a cluster of numerous thickly populated villages and small towns giving the area an estimated average density of 1,500 – 2,000 persons per square kilometer (UN- Habitat.2009).

3.2 Climate

Two climatic seasons exist in the study area, namely rainy season (March- October) and dry season (November- March). The annual rainfall of the area is about 2000mm. According to Onwuka (2009), the study area lies within the rain-forest belt of Nigeria. In the south, the area is bounded by mangrove swamp forest, and in the north, by savannah grassland. The rainy season is characterized by heavy down pours accompanied by thunder storms, heavy flooding, soil leaching, extensive sheet out wash, ground infiltration and percolation, (Afigbo, 1981; Egboka and Okpoko, 1984). Daily rainfall records of between 5. 87mm (at the beginning of rainy season) to 289.95mm (at the peak of rainy season) are common. This increases the volume of water vapour in the atmosphere and eventually to leads high relative humidity, heavy thunder storms and high rainfall intensity except sometimes during the month of August when there is a noticeable drop in rainfall. This phenomenon is often referred as August break.

The dry season on the other hand begins when the dry continental northeastern wind blows from the Mediterranean Sea across the sahara Desert down to southern Nigeria. It is characterized by extensive aridity and a lot of particulate and dust generation. The dry season is characterized by chilly and dry hamattan wind. There is equally a marked lowering of water table and intense leaf fall (Afigbo,1981). Anambra state experiences high temperatures in the range of 27˚ - 28˚ C, which increase to a peak of about 35˚ C between February and April, the hottest period. The coolest periods occur from mid July through December to early January, coinciding with middle of the rainy season and the harmattan respectively.

3.3 Geology

Anambra State is underlain by sedimentary formations of varying types and ages. Consequently, most of the formations, being mainly sandstone, are good aquifers of high economic viability (Onwuka, 2009). Anambra State lies in the Anambra Basin, the first region where intensive oil exploration was carried out in Nigeria. The Anambra basin has about 6,000 m of sedimentary rocks. Onuoha and Onwuka, (2014).The sedimentary rocks comprise ancient Cretaceous deltas, somewhat similar to the Niger Delta, with the Nkporo Shale, the Mamu Formation, the Ajali sandstone and the Nsukka Formation as the main deposits. On the surface the dominant sedimentary rocks are the Imo Shale a sequence of grey shales, occasional clay iron stones and Sandstone beds; and the Ameki formation.

The stratigraphic profile below summarizes the depositional process, environment and age of the various geologic formations in Anambra basin which underlies the study area.

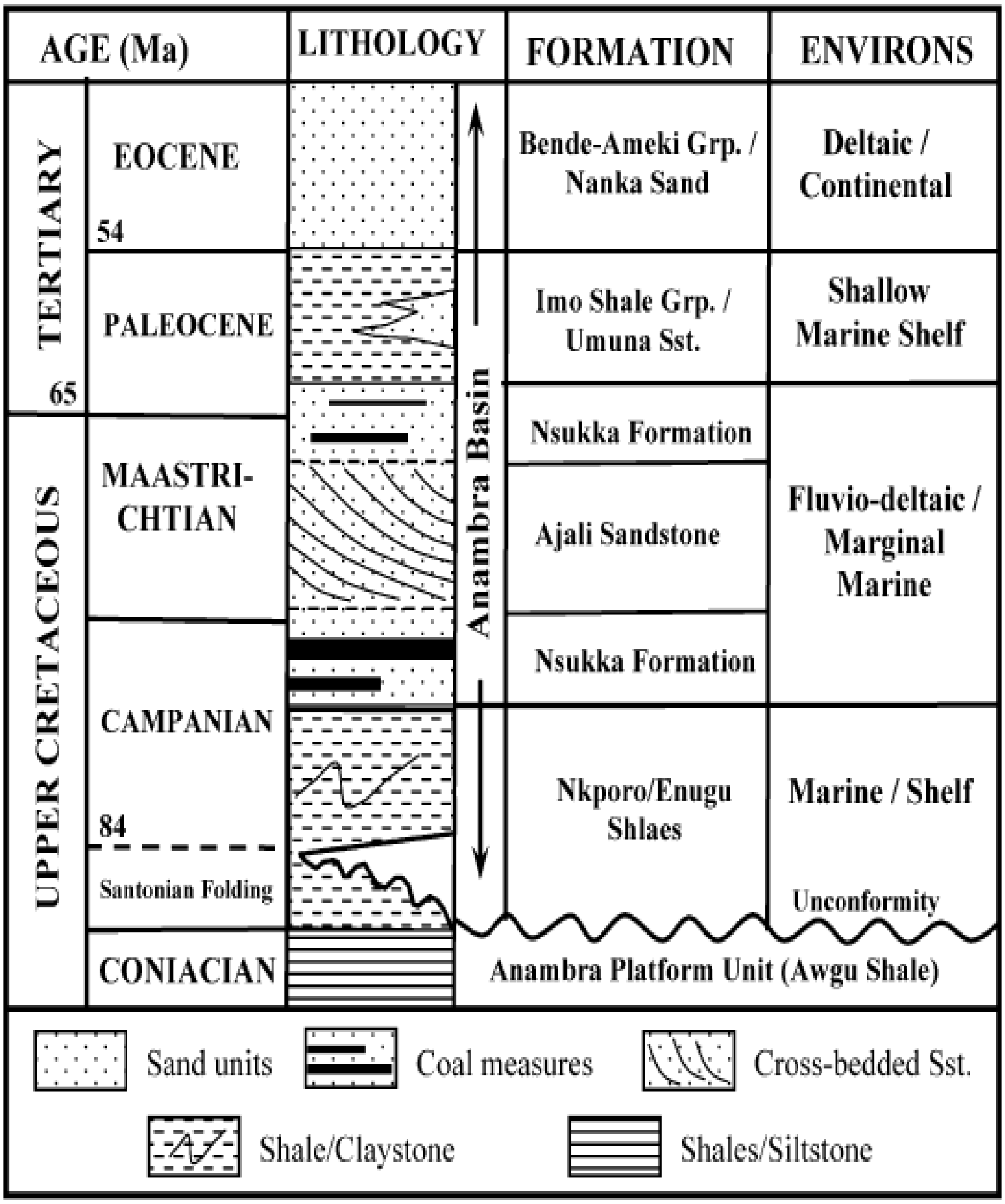

Fig.3.2:Stratigraphic profiles and depositional environment of the sedimentary units within the Anambra Basin Nigeria.

Source: Adapted from Onuoha and Onwuka, (2014).

Ameki Formation (Nanka Sand, Umunya Shale and other intercalating units), comprises the Nanka Sand and its lateral equivalence, it is part of the sediments deposited in the Anambra Basin of Southeastern Nigeria (Reyment, 1965; Murat, 1972; and Nwajide, 2005). The formation consists of fine to coarse sandstones with abundant intercalations of calcareous shale and thin shally limestone below, and of loose cross bedded white or yellow sandstone with bands of fine grained sandstone and sandy clay on top. Nanka Sand is of Eocene age and was deposited in an inter-tidal relatively high energy marine environment (Nwajide and Hoque, 1979 and Nwajide, 1980).

The Imo Shale underlies the eastern part of the state, particularly in Ayamelum, Awka North, and Oruma North LGAs. Next in the geological sequence, is the Ameki Formation, which includes Nanka Sands, laid down in the Eocene. Its rock types are sandstone, calcareous shale, and shelly-limestone in thin bands. Outcrops of the sandstone occur at various places on the higher cuesta, such as at Abagana and Nsugbe, where they are quarried for construction purposes. Nanka sands out crop mainly at Nanka and Oko in Orumba North LGA.

Lignite was deposited in the Oligocene to Miocene; and it alternates with gritty clays in places. Outcrops of lignite occur in Onitsha and Nnewi. The latest of the tour geological formations is the Benin Formation or the coastal plain sands deposited from Miocene to pleistocene. The Benin Formation consists of yellow and white sands. The formation underlies much of lhiala LGA. Thick deposits of alluvium were laid down in the western parts of the state, south and north of Onitsha in the Niger and Anambra river floodplains.

The following is a geological map of Anambra state sourced from the National Geohazards Centre Awka, detailing the different geologic formations and units present in the state and most importantly the formation of interest (Nanka Sand)

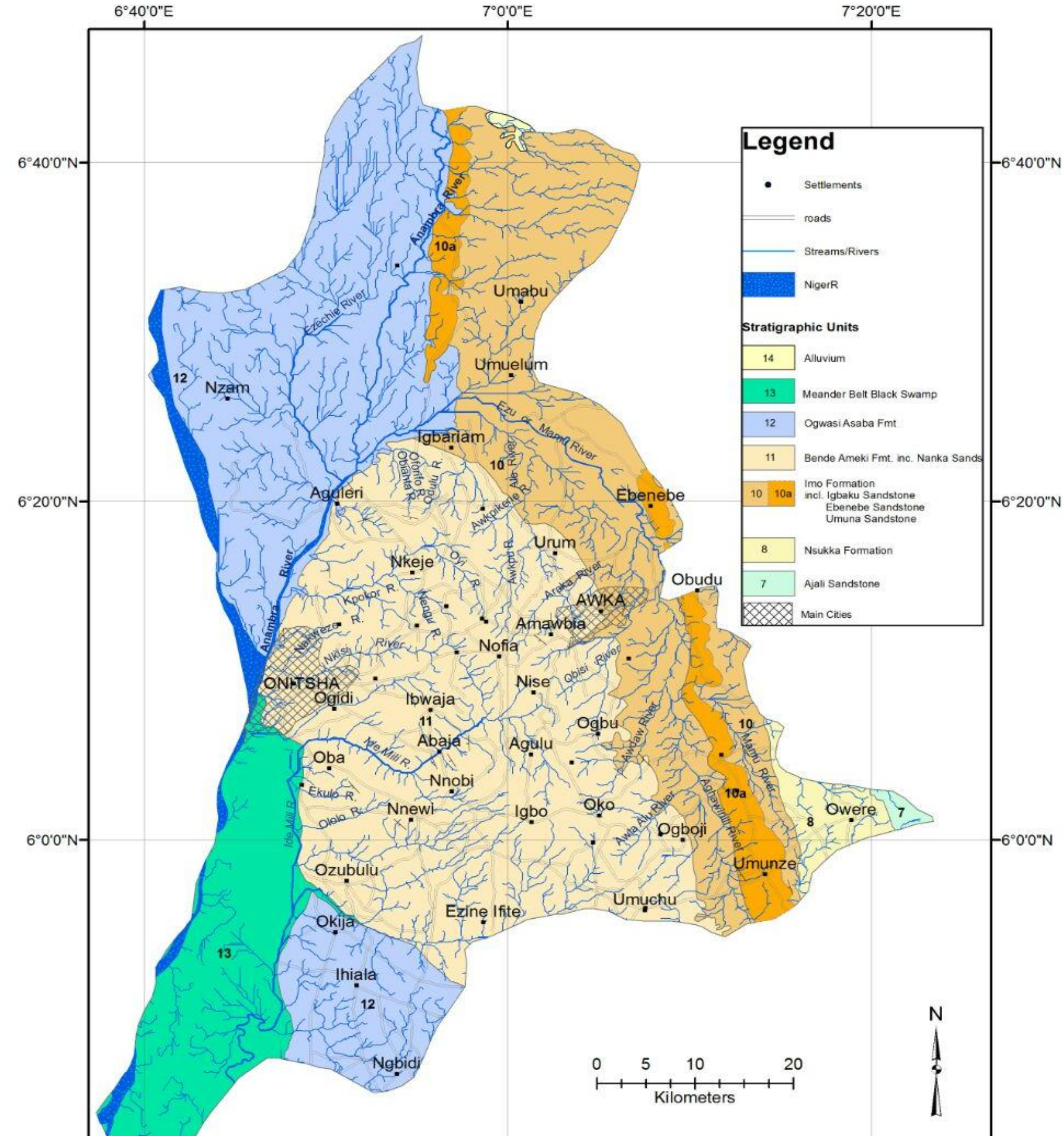

Fig..3.3: Geologic Map of Anambra State Showing Nanka Sand and other formations underlying the State

Source: National Geohazards Centre Awka, (2017).

3.3.1 Study Location

The study site here, discussed the section of Anambra State covered by Nanka Sand geologic unit under study. The following figure 3.4 is a map of the section of Anambra State underlain by Nanka Sand Geologic Unit of the Ameki Formation. This sand member of the Ameki formation is the predominant unit of the formation. Loose and very friable sand unit with lots of gullies situated on it as can be seen in the map in figure 3.4.

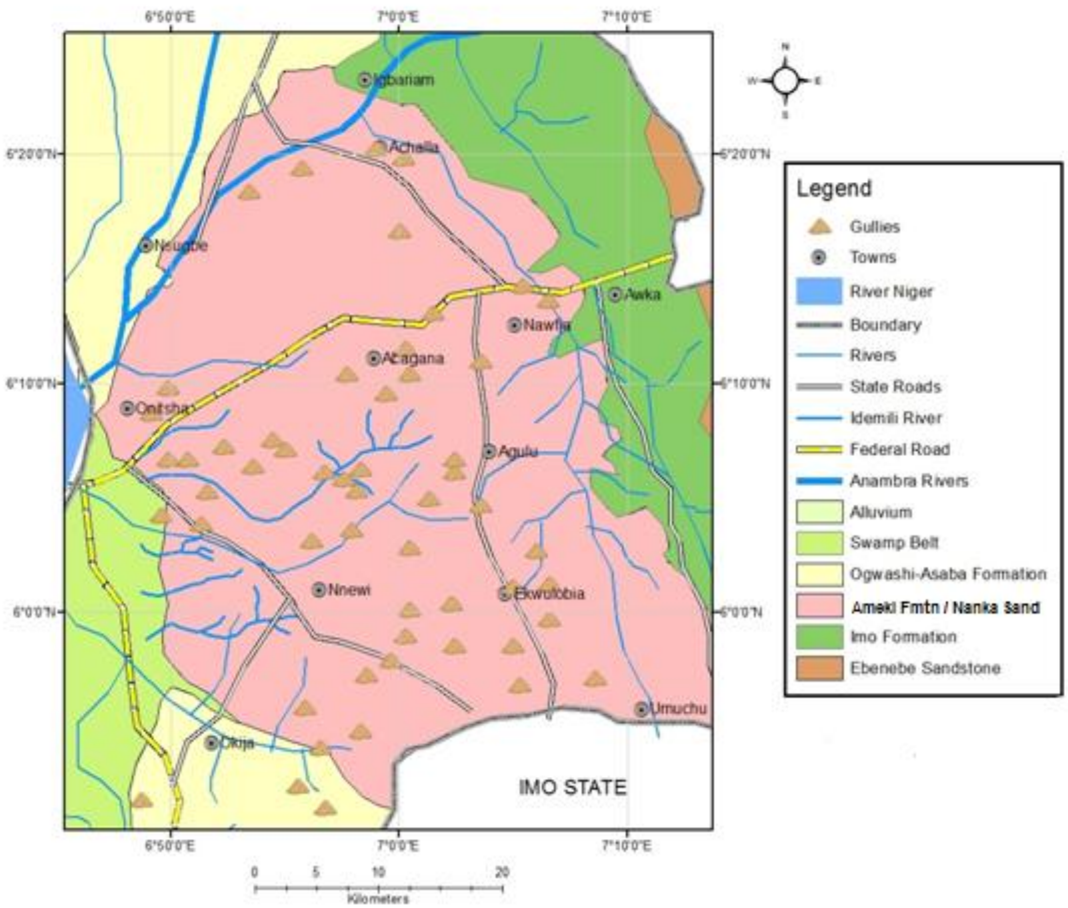

Fig. 3.4: Map Showing the Section of Anambra State underlain by Nanka Sand
Source: Modified from National Geo-hazard, 2017)

3.4 Relief and Drainage:

Anambra State falls into two main landform regions: a highland region of moderate elevation that covers much of the state south of the Anambra River, and low plains to the west, north, and east of the highlands. The highland region is a low asymmetrical ridge or cuesta in the northern portion of the Awka-Orlu Uplands, which trend roughly southeast to north west, in line with the geological formations that underlie it (UN-HABITAT, 2009)..

It is highest in the southeast, about 410m above mean sealevel, and gradually decreases in height to only 33m in the northwest on the banks of the Anambra River and the Niger. At Onitsha and Otuocha, the cuesta provides well drained low land, very close to the river, thereby enabling settlements to extend to the banks of the river. The cuesta has confined the wide and braided channel of the Niger to a comparatively narrow valley bed at the southern part of Onitsha, making an appropriate location for the construction of bridge across the river. The highlands consist of two cuestas, a lower and a higher one, each with an east-facing escarpment.

The two cuestas merge south of Nanka. The lower cuesta, formed by the more resistant sandstone rocks of the Imo Shale, rises to only 150m above mean sealevel at Umuawulu and decreases in height northwestward to only 100m or less at Achalla. Its escarpment faces the Mamu River plain and has a local relief of between 80 and 300m. West of it, is the higher cuesta, formed by the sand stones of the Ameki Formation. Its height is above 400m in the south-east at lgboukwu and lsuofia decreasing northwestward to less than 300m at Agbana and to only 100m at Aguleri.

There are only of moderate height, they provide elevated, welldrained and attractive settlement sites, hence, they are closely settled even up to their crests. Agulu, Agbana, Awkuzu, Nteje and Aguleri are some of the settlements on the crest the higher cuesta, and lfiteAwka, Mgbakwu, Amanuke and Achalla are some of those on the crest of the lower cuesta. The dip slope of the cuesta extends westwards for over 30km and is heavily settled. Plains lie west and north of the highland. The River Niger plain south of Onitsha, about 9km wide and the Niger-Anambra River plain north of Onitsha, which stretches for over 36km east of the Niger, are really low plains, well below 30m above mean sealevel, and are liable to flood. They are underlain by recent alluvium; and, east of the Anambra River, by the Imo Shale formation.

The plains are almost featureless, except for sporadic broad undulations, rising above the flood plains and forming sites for the farming and fishing settlement near the area. Such settlements include Nzam, Nmiata, and Anam in Anambra West LGA and Atani, Odekpe, and Oshita in Ogbaru LGA. East of the Anambra River, a narrow and elongated sand, stone ridge, projecting about 30m above the level at the plain, formed settlement sites for Anaku, lgbakwu, lfute, and Umueje inAyamelum LGA.

(*http://links.onlinenigeria.com/anambraadv.asp?blurb=195).*

The Mamu River plain east of the cuesta landscape, is a little higher than the other two plains. It lies between 30 and 70m above sealevel in the areaand is underlain by the Imo Shale, rising higher southwards. East of the Mamu River are found the more, resistant sandstone ridge, at some 50 m above the level of the plains. The extension of this ridge southward forms the settlement for the people of Ufuma, Ajalli, lsu Ulo, Ezira, and Umunze.

The natural flow patterns of the rivers in the area and their tributaries are dendritic drainage pattern (Igbokwe et al, 2008). The main drainage system in the state is the Anambra River which rises on the Gala Plateau near Ankpa in Kogi State and, for its over 85km course in Anambra State, flows through the northern low plain where it, as well as its right bank tributaries, meander heavily, developing oxbow lakes and abandoned meander channels. Its largest left bank tributary is the Mamu River, which drains the eastern low plain on the Imo Shale Formation.

The higher cuesta forms the watershed separating the numerous east-flowing tributaries of the Mamu River from the west-flowing rivers, the Idemili, the Nkisi, and the Oyi, which drain the dip slope of the cuesta. All but one of the main rivers in Anambra state empty into the River Niger, which forms the western boundary of the state and constitutes the local baselevel for the rivers.

The exception is the Ulasi River, which rises near Dikenafai in Imo State, flows northward to Ozubulu in Anambra State and then turns round in a wide loop and heads for the Atlantic ocean. The dip slope of the higher cuesta between Nsugbe, Onitsha, Ogbunike and Umunya is dissected by the numerous tributary streams of the MamuAnambra into a rolling landscape (http://links.onlinenigeria.com/anambraadv.asp?blurb=195).

3.5 Vegetation and Soils:

Although annual rainfall is high in Anambra State, ranging from 1,400mm in the north to 2,500mm in the south, it is concentrated in one season , with about four months of dryness, November to February. Consequently, the natural vegetation in the greater part of Anambra State is tropical dry or deciduous forest, which, in its original form, comprised tall trees with thick under growth and numerous climbers. Pressure on land in form of agriculture and commerce has largely reduced the vegetation here to mixed savanna. Only along stream courses and in few preserved areas can one find some rain forest trees such as Iroko, soft wood, domesticated species like oranges, mangoes etc UN-HABITAT(2002). Palm trees and Coconut trees are quite common in residential areas due to their economic value. However, the predominant vegetation here is mixed savanna. The wetter river valleys support dense rainforest. Rain forest of evergreen vegetation abounds along streams.

The typical trees (silk cotton, Iroko and oil bean) are deciduous, shedding their leaves in the dry season. Only in the southern parts of the state, where the annual rain fall is higher and the dry season shorter, is the natural vegetation marginally the tropical rainforest type. Because of the high population density in the state, most of the forests have been cleared for settlement and cultivation.What exists now is secondary re-growth , or a forestsavannah mosaic, where the oil palm is predominant, together with selectively preserved economic trees. Relics of the original vegetation may, however, be found in some "juju" shrines or some inaccessible areas.

Three soil types can be recognised in Anambra State. They are: (i) alluvial soils, (ii) hydromorphic soils, and (iii) ferallitic soils. The alluvial soils are palebrown loamy soils. They are found in the tow plain south of Onitsha in Ogbaru and in the Niger Anambra low plain north of Onitsha. They differ from the hydromorphic soils in being relatively immature, having no welldeveloped horizons.

They, however, sustain continuous cropping longer than the other two types. Hydromorphic soils are developed on the Mamu plain east of the cuesta, extending northward into the eastern part of Anambra River floodplain, where the underlying impervious clayey shales cause water-logging of the soils during the rainy season. The soils are fine loamy, with lower layersfaintly mottled; while the subsoil layers are strongly mottled and spotted, containing stiff grey clay. The soils are good for yam, cassava and maize, and for rice in the more heavily waterlogged areas. The cuestas and other elevated areas under lain by sandstones and shales of the Ameki Formation and the Nanka Sands are regions of ferrallictic soils. The soils are deep, red to reddish brown loamy sands, often referred to as "redearth" or acid sands because of low fertility. They are easily eroded into gullies.

3.6 Ecological Hazards:

The main ecological hazards in the state are accelerated gully erosion and flooding. Extensive forest clearing, often by bush burning, and continuous cropping with little or no replenishment of soil nutrients, resulted in the disruption of the ecological equilibrium of the natural forest ecosystem. Such a situation in a region of loosely consolidated friable soils is prone to erosion, giving rise to extensive gully formation. Urbanization processes involving road construction, building developments are on the increase in the area. This is due to the economic activities that go on in many parts of the area. Igbokwe, Akinyede, Dang, ... and Onwuka (2008) discovered that due to the level of urbanization processes in the area, coupled with indiscriminate sand-mining, the area is prone to immense gully development. The geology of the area affects gully development, the main geologic unit that is most prone to gullying within the study area is the Nanka Sand, which is part of the sediment deposited in the Anambra Basin of southeastern Nigeria (Reyment 1969, Murat 1972; Wright of 1985 and Nwajide, 2005).

In the Agulu, Nanka and Oko areas, which are underlain by the Nanka Sands, the gullies have attained spectacular and alarming proportions, making the area inaccessible for economic acrtivities." Many of the gullies are at the head streams of the rivers that flow down the cuestas. The head streams carve their valleys deep into the deeply weathered red earth, developing dendritic patterns of gullies.

Such gullies are also found in Nnobi, Alor and Ideani, along the course of the Idemili River. Besides, the greater part of the state is prone to severe sheet erosion. In the low plains of the Niger and Mamu Rivers, heavy rains often result in excessive flooding, such that the undulations occupied by settlements are marooned for some months. The people resort to the use of canoes for movement and transportation. Oba Ofemili and Ugbene on the plains of the Mamu River are sometimes, in the rainy season, cut off from others as their roads remain flooded knee-deep for many weeks. The floods also cause serious damage to crops (http://links.onlinenigeria.com/anambraadv.asp?blurb=195).

CHAPTER FOUR

RESEARCH METHODOLOGY

This chapter discussed in details the methodology adopted for this study under the following headings:

- Research Design
- Data Needs
- Sources of Data
- The Study Population
- Sampling Size and Techniques
- Method of Data Collection
- Method of Data Analysis and Presentation

4.1 Research Design

The study adopted experimental research design and survey method. The experimental design involves procedural laboratory analyses of soil samples collected from the selected gully erosion sites within Nanka sand geologic unit of Anambra State. The survey method involved field observation of the gully erosion site sampled within the study area and the subsequent site investigation to ascertain the gully characteristics like elevation, coordinate, geometry and dimension; and to collect sample for laboratory analyses and finally the questionnaire survey and interview to ascertain the information on the causes and effects of gully erosion in the study area and the control measure to be adopted in the study area for better management of gully erosion.

4.2 Data Needs

There was need for series of data in this study to pursue the set objectives and subsequently actualize the aim. A contemporary data on the geology of Anambra state was necessary as it helped the researcher in delineating the areas sampled, this was sourced from National Goehazards Center Awka. Data on the description of the gully sites studied was essential and was gotten by the researcher through field measurements. Data on the chemical composition of the samples collected at the gully sites and the chemical composition of water passed through the grouted rock samples was ascertained through the laboratory analyses. While data on the WHO standards for portable water was necessary to determine the safety of groundwater if a specified grouting chemical is applied.

4.3 Sources of Data

This study relied on two types of data, the primary data and the secondary data. The primary data includes data that was generated by the researcher through field observations and laboratory analyses of the samples collected. The secondary data are information sourced from published textbooks, Journals, conference papers, articles, records of some governmental and nongovernmental agencies and unpublished project works.

4.4 The Study Population

Considering the nature of the study, the main interest of the researcher was to sample the rocks underlying the gullies within Anambra state. The target population studied therefore will be the gully erosion sites within Anambra state underlain by Nanka Sand geology.

4.5 Sampling Size and Techniques

Considering the nature of the study and haven restricted the target population of study to gully sites within Anambra State underlain by Nanka Sand, due to the literature fact that Nanka Sand is the Geologic Unit mostly gullied within the state, the judgmental sampling technique was adopted. Here five gully sites were purposively selectedunder the following conditions:

a. the gully site is presently active,
b. no two samples were selected within the same Local Government Area and
c. at least one sample was selected within each of the senatorial zones of the state falling into the target population zone.

Considering the nature of the study and the target of reaching out to the inhabitants of the study area to ascertain the opinion of the inhabitants of the area on the causes and effects of the gully erosion in their area and the possible control measures, the researcher purposively choose to sample 200 persons for wider coverage, 40 from each gully area studied. The sampling technique adopted was stratified random sampling. Here each sample area/town was devided into four using the four cardinal points and at least ten persons were sampled from each side/strata with each person coming from a different household. Where there are instituutions of higher learning, the researcher ensured that some members of the community were also sampled. Also at least three of the indigenes of the sampled gully sites were interviewed especially those who were unable to fill the questionnaire. For the purpose of this study the researcher deemed it good to use the few professionals who are leaders of the erosion control agencies as he believed they have done series of research on the subject matter and should have authentic infornation on the data needed. Altogether 20 persons were interviewed that is 15 inhabitants of the gully prone areas studied and 5 professionals chosen from National Geohazard Centre Awka, Rhino Construction Company and Odumegwu Ojukwu University, Uli.

4.6 Method of Data Collection

The methods of data collection adopted for this study include the following:

4.6.1 Questionnaire Survey

Here a well structured questionnaire was developed and used to source information on the causes, effects and possible control measure to better control the gully erosion problem in the study area. The questionnaire was of three sections; section A contains questions on personal data of the respondent like: age, sex, academic qualification and how long the respondent has been in the study area. Section B contains questions on the causes and effects of gully erosion in the study area while section C contains questions on the possible measures to be adopted fo better control of gully erosion in the study area.

4.6.2 In-depth Interview with Professionals and Inhabitants of the Study Area

This involved visit to the National Geohazards Center Awka and other establishments to source for data like for updated maps and inquire from their staffs on their latest erosion control strategies to enhance the database for the research work. One or more companies or contractors working in the gully erosion sites in the area were visited as well, like Rhino who were just rounding off their contract at the largest gully site in the study area at Nanka, which is also seen as the biggest in the whole of West Africa. Some inhabitants of the study area who were unable to fill the questionnaire were also interviewed.

The following interview questions were used as a guide:

1. What is the origin of the gully in your area?
2. How long has the gully been?
3. What do you think are the main causes of the gully?
4. What are the main effects of the gully?
5. What control measures have your agency recommended or adopted for gully erosion control in Anambra State?
6. Have you observed any erosion control project failure(s)? If yes what are the major causes?
7. Have you tried chemical grouting?
8. What do you advice on the application of chemical grouting in gully erosion control and its environmental implication(s)?

While questions 1-4 were used for the inhabitants (indigenes) of the gully sites sampled, questions 4-8 were used for the professionals.

4.6.3 Field Work and Measurements

This involves an on-site-survey of the gully erosion sites sampled within the study area to ascertain the gully characteristics like elevation, coordinate geometry and dimensions; and to collect samples for laboratory analyses. The main instruments used here include the GPS, sampling bags, geologic hammer, chisel, shovel, tape, camera and field record book.

Five samples were collected in all from the five sample stations, they were collected using a chisel, harmmer and shovel. Thus, the samples were disturbed. The sdamples were stored in sampling bags doubled to avoid contamination and labeled according to the stations to avoid misplacement. The samples at each station were collected between the depth of 1-2m, from the surface. The parameters measured insitu include the gully length and width, gully depth and coordinates. While the laboratory work concentrated on the chemical characteristics of the samples collected so as to determine the status of the soils before grouting. Also analyzed were the physical characteristics which include porosity, permeability and erodibility before and after grounting with the selected chemical in other to ascertain the impact of the grouting chemicals on these physical parameters.

4.6.4 Laboratory Analyses

This was done in five stages as follows:

The first stage involved a laboratory analyses using the Atomic Absorption Spectrography method (AAS method) to thoroughly digest and determine the chemical elemental composition of the samples collected.

The second stage involved a procedural laboratory approach in testing the water quality after passing it through the grouted samples in order to compare it with the WHO standard for portable water.

The third stage involved the determination of the porosity and permeability of the samples collected before and after grouting.

The fourth stage involved the determination of the erodibilities of the samples collected before and after grouting.

Finally, the last stage involved the analysis of the water samples collected after the application of the various grouting chemicals.

The procedures to be adopted in the laboratory analyses and the chemical parameters to be tested for are as follows:

Procedure For SoilExchangeable Acidity

Weigh 5g of dry soil into a clean 50ml beaker. Add 25ml KCL solution and stir thoroughly 1.0m.

Place filter paper in a funnel over a 100ml collecting bottle. Pour the soil suspension through the filter. When the liquid has drained, leach the soil with 3 further 25ml portions of KCL, allowing each to drain before adding the next (total of 100ml leaching solution). Return the leachate for analysis of Ca, Mg and acidity once drainage has stopped.

Determination of Exchangeable Ca and Mg

- Using a measuring cylinder, transfer 25ml of the leachate to a clean beaker and add 1ml of strontium nitrate solution.
- Determine the concentration (as mol l^{-1}) of Ca and Mg in the leachate by Atomic Absorption Spectrophotometer. (AAS)
- Calculate the exchangeable Ca, Mg in the soil sample (as mol Kg^{-1}) by multiplying the conc of each by 20.

Determination of Exchangeable Acidity

- Using a measuring cylinder, transfer 25ml of the leachate to a 50ml flask. Add 5 drops phenolphthalein indicator.
- Place the flask on a magnetic stirrer and titrate against 0.01m NaOH. Add NaOH slowly from a burette until the first appearance of a faint pink color. Record the burette reading.
- Calculate exchangeable acidity as $mmolKg^{-1}$ by multiplying by 8.

Determination of Cation Exchange Capacity and Base Saturation

Use the formula below to calculate CEC (mmol kg^{-1} and BS (%).

CEC =Ca + Mg + Na

$$\text{Base saturation} = \frac{100\ (ca + mg)}{CEC.}$$

Determination of pH in CaCl

- Weigh out approximately 10g of the air dried and sieved soil sample
- Place the soil into a glass container and add approximately 10ml of 0.01 CaClsolution.
- Mix thoroughly and let stand for 1 hour
- Sipheon and read the pH

Gravimetric Determination of TotalSulphur

Fusion: 1.0m of finely powdered soil was mixed with 5.0g of $Naco_3$ and $NaN0_3$, in a crucible. The mixture was preheated at 400^0c for 30mins in an electric muffle furnace, and then fused at 950^0c after the fusion, the crucible was allowed to cool and was placed on its side in a $150cm^3$ beaker. Enough deionized water barely to cover the content of the crucible was added and the beaker was heated at a temperature just below boiling on a hot plate, until the melt was thoroughly disintegrated. The crucible was then removed and washed with deionized water. At this point $20cm^3$ of 6mHCL was added to neutralize the $NaCo_3$ and tomake the solution slightly acidic. This was filtered into a $100cm^3$ volumetric flask and the volume made up to the mark with deionized water.

Precipitation of $BaSo_4$: The solution was brought to boiling and $10cm^3$ of 10%$Bacl_2$wasslowlyaddedto precipitate the sulphate. The solution was allowed to cool and was filtered. The residue was washed with deionized water.

Ignition of $BaS0_4$

The ashless filter paper was ignited at low temperature (40^0c) and the precipitate weighed. The percentage sulphur in the precipitate was calculated from the expression below

$$\% \text{ sulphur} = \frac{\text{gmBaSo}_4 \times 13.17}{\text{wt. of sample in gm.}}$$

Determination of % Silt, Clay, Sand.

- 50g of the soil sample into a 250ml beaker
- Fill the beaker with distilled water to 200ml mark.
- Wash the sand four times with distilled water. Prepare 25% sodium hexametaphosphate.
- Add 20ml of the solution and 200ml of distilled water
- Allow to stand for 16hrs (ieover night)

- Transfer into 0.2mm sieve is the sand, the sieve and pan. The soil in the sieve is the sand while the soil in the pan is the silt
- The sample in the silve and pan are dried overed a constant weight.

$$\% \text{ Sand} = \frac{\text{weight of residue} \times 100}{\text{Weight of sample used}}$$

$$\% \text{ silt} = \frac{\text{weight of residue} \times 100}{\text{Weight of sample used}}$$

% Clay = 100 - % Silt + % Sand.

Methods for the Heavy Metal Analyses

Heavy metal analysis was conducted using Varian AA240 Atomic Absorption Spectrophometer according to the method of APHA 1995 (American Public Health Association)

Working principle: Atomic absorption spectrometer's working principle is based on the sample being aspirated into the flame and atomized when the AAS's light beam is directed through the flame into the monochromator, and onto the detector that measures the amount of light absorbed by the atomized element in the flame. Since metals have their own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiational interferences. The amount of energy ofthe characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample.

Dry Preparation of Minerals

1. 2g of the soil sample

2. Heat in a furnance for 4hrs at 550^0c

3. 20ml of 20% H_2SO_4 was added and boil for 30mins, it was filtered and make up to 50ml mark with distilled water.

Preparation of Reference Solution:

A series of standard metal solutions in the optimum concentration range was prepared, the reference solutions were prepared daily by diluting the single stock element solutions with water containing 1.5ml concentrated nitric acid/litre. A caliberation blank was prepared using all the reagents except for the metal stock solutions.

Caliberation curve for each metal was prepared by plotting the absorbance of standards versus their concentrations

Alkalinity (Bicarbonate)

1. Rinse the 50ml burret with several rinses with 0.02 N HCL.
2. Fill the burret with the HCL solution, make sure there are no air bubbles in the tip, and make sure the meniscus is readable at close to 0.00ml on the burret scale.
3. Measure the 100.0ml of the water sample to be analysed into a 250ml Erlenmeyer flask.
4. Titrate to a bromcresol green (pH = 4.5) end point.
5. If the water is high in alkalinity, smaller volumes of the sample may be titrated as seems appropriate.
6. Do at least duplicate (preferably triplicate) titrations on each sample being investigated.

Calculations alkalinity is expressed in terms of milligrams of calcium carbonate per liter.

Alkalinity = (ml HCL titrant) x (normality of HCL) X (50,000) / (ml of water sample).

Chloride Determination

Method: Chloride analysed according to APHA standard method (APHA; 1998)

Procedure

A 100ml of the clear sample was pipetted into an Erlenmeyer flask and the pH adjusted to 7-10 with either H_2S0_4 or NaOH solution. Then 100ml of K_2Cr0_4 indicator solution was added with standard solution of $AgN0_3$ in a permanent reddish brown colouration. The

$AgNo_3$tittrant was standardized and a reagent blank established. A blank of 0.2-0.3ml is usual for the method

Calculation

Chloride conc = Titre value (x) x 10 =10xmg/l

Phosphate Determination

Methods: Phosphate was measured using Standard Method 4500-P B.5 and 4500-PE (APHA; 1998)

Procedure: Exactly 100ml of the homogenized and filtered sample was pipetted into a conical flask. The same volume of distilled water (serving as control) was also pipette into another conical flask. 1ml of 18M H_2S0_4 and 0.89g of ammonium persulphate were added to both conical flasks and gently boiled for 1 ½ hrs, keeping the volume of 25-50cm^3 with distilled water.

It was then cooled, one drop of phenolpthelein indicator was added and after neutralized to a faint pink colour with the 2M Na0H solution. The pink colour was discharged by drop wise addition of 2M HCl, and the solution made up to 100ml with distilled water. For the colorimetric analysis, 20ml of the sample was pipette into test tubes, 10ml of the combined reagent added, shaken and left to stand for 10mins before reading the absorbance at 690nm on a spectrophotometer, using 20ml of distilled water plus 1ml of the reagent as reference.

Methods for Calibration

Standard phosphate solution: 219.5 mg of dried AR potassium hydrogen phosphate was dissolved in distilled water and made up to 1000ml, where 1ml = 50.0 μg. Of phosphate. 10ml of the stock solution was made up to 1000ml to give 1ml = 0.05 mg. Standards of strength ranging from 0 (blank) to 0.05mg/L at intervals of 0.01mg is prepared by diluting the stock with distilled water.

Conc of sample = $\frac{\text{Abs of sample}}{\text{Abs of std}}$ x conc of std

Loss of organic matter Determination (AOAC, 1984)

(I) Place a 5g scoop of soil into a tared 20-ml beaker

(II) Dry for 2 hours or longer at 105^0c

(III) Record weight to ± 0.001g

(IV) Bring oven to 360^0c. samples must then remain at 360^0cfor 2 hours.

(V) Cool to < 150^0c

(VI) Weigh to ± 0.001g, in a draft – free environment

Calculation

$$\text{Loss of organic matter} = \frac{(\text{wt. at } 105^0\text{c}) - (\text{wt.at}360}{\text{wt.at } 105^0\text{c}}\ 100$$

Nitrogen Determination

(AOAC, 1984)

Principle: the method is the digestion of sample with hot concentrated sulphuric acid in the presence of a metallic catalyst. Organic nitrogen in the sample is reduced to ammonia. This is retained in the solution as ammonium sulphate. The solution is made alkaline, and then distilled to release the ammonia. The ammonia is trapped in dilute acid and then titrated.

Procedures

. Exactly 1g of sample was weighed into a 30ml kjehdal flask (gently to prevent the sample from touching the walls of the side of each and then the flasks were stopped and shaken. Then 1g of the kjedahl catalyst mixture was added. The mixture was heated cautiously in a digestion rack under fire until a clear solution appeared.

. The clear solution was then allowed to stand for 30 minutes and allowed to cool. After cooling about 100ml of distilled water was added to avoid caking and then transferred to the kjedahl digestion apparatus.

. A 500ml receiver flask containing 5ml of boric acid indicator was paced under a condenser of the distillation apparatus so that the tap was about 20cm inside the solution. The 10ml of 40% sodium hydroxide was added to the digested sample in the apparatus and distillation commenced immediately until distillation reaches the 35ml mark of the receiver flask, after which it was titrated to pink colour using 0.01N hydrochloric acid.

Calculations

% Nitrogen = Titre value x 0.01 x atomic mass of nitrogen x 4

Where 0.01 = normality of the acid.

Loss of organic matter Determination (AOAC, 1984)

(I) Place a 5g scoop of soil into a tared 20-ml beaker

(II) Dry for 2 hours or longer at 105^0c

(III) Record weight to ± 0.001g

(IV) Bring oven to 360^0c. samples must then remain at 360^0cfor 2 hours.

(V) Cool to < 150^0c

(VI) Weigh to ± 0.001g, in a draft – free environment

Calculation

$$\text{Loss of organic matter} = \frac{(\text{wt. at } 105^0\text{c}) - (\text{wt.at360}}{\text{wt.at } 105^0\text{c}}\ 100$$

Determination of Total Organic Carbon: Determinethe moisture content of the air – dry soil which has been grounded to pass a 0.42 sieve. Weigh accurately enough soil to contain between 10g and 20mg of carbon into a dry tared 20ml conical flask (between 0.5g and 1g for 1g for top soil and 2g and 4g for subsoil).

- Accurately add 10ml .1N K_2Cr20_7 swirl the flask gently to disperse the soil in the solution. Add 20ml concentration of H_2So4 directing the stream into the suspension. Immediately swirl the flask until the soil and the reagent are mixed. Insert a 200^0cthermometer and heat while swiring the flask and the content on a hot plate or over a gas burner and guaze until the temperature reaches 139^0C.

- Set aside to cool slowly on an asbestos sheet in a fume cupboard. Two blanks (without soil) must be run in the same way to standardized $FeSo_4$ solution.

- When cool (20 – 30mins), dilute to 200ml with de-ionised water, and proceed with the $FeSo_4$ titration using either the ferroin indicator or potentiometrically with an expending scale PH/MV meter or auto titrator.

Ferroin Titration

Add 3 or 4 drops of ferroin indicator and titrate with 0.4N $Feso_4$. As the end points is approached, the solution takes on a greenish colour and den changes to a dark green. At this point, add the $Feso_4$ drop- by- drop drop until the colour changes from blue – green to reddish–grey. If the end point is overshort, add 0.5 or 1.0ml of 1N $K_2Cr_20_7$ and approach the end point, drop by drop. Correct for the extra volume added if over 8ml of the 10ml dichromate have been consumed the determination must be repeated with a smaller soil sample.

From the equation;

$$2CR_20_7^{-2}\ F3C + 16H^+ = 4Cr^{5+} + 8\ H_20 + 3\ C0_2$$

1ml of 1N dichromate solution is equivalent of to 3 mg of carbon. Where the equality and normality of the acid (Dichromate mixture) used are as stated in the method, the percentage carbon is determined from the following.

$$OC\ \% = \frac{0.003g \times N \times (0ml \times (1- T/S)}{ODW} \times 100$$

$$= \frac{3\,(1 - T/S)}{W}$$

Where ; N = Normality of $KaCr_20_7$ solution

T = volume of $FeS0_4$ used in sample titration (ml)

S = volume of $FeS0_4$ used in blank titration (ml)

33 ODW = Oven – dry sample weight (g) (American Public Health Association, 1995; and Adrian, 1973).

Erodibility Test

This is a laboratory test aimed at determining the rate at which various soils can be eroded or the abilities of various soils to resist erosion when subjected to the action of certain agents of erosion like water and wind. Two main methods of erodibility measurement applied by earlier researchers as observed in the literature review are the JET (Jet Erosion Test) and the HET (Hole Erosion Test) methods, while some researchers run their analysis by collating the geotechnical parameters of the soil considering the topography, vegetation cover, climate etcetera as factors of soil erosion. Here a rainfall simulator will be used to obtain the erodibility of the various samples collected.

Apparatus

Rainfall simulator was used to measure the erodibility of the various samples to be collected. The adoption of a rainfall simulator is based on the fact that the main agent of erosion acting in the area under study is water through rainfall.

Procedure

An artificial rainfall simulator was used, with a chamber that can take about 5kg of the disturbed sample subjected to equal degree of compaction will be exposed to the varied droplets of the artificial rainfall and the records of the soil loss taken. The various samples will be exposed to the droplets of varied ml per minutes to represent drizzle, raindrops and heavy rain; and the records taken. The slope of the chamber will also be varied and the soil loss also measured to establish the effect of topography change on the erodibilities of the soils. The various results will then be collated and analyzed.

Grouting With the Selected Chemicals

In line with the aim and in pursuit of the objectives of the study, the samples collected from the various stations were grouted using four chemical compounds out of the many available chemicals for grouting, which includes: Sodium silicate, Aluminum Iron Silicate, Calcium Chloride and Calcium Hydroxide. The choice of Sodium and Aluminum Silicates was because of their binding properties as confirmed from literature, Rawlings et al., 2000; Mitchell and Jardine, 2002; Reuben, 2003; and Magill and Berry, 2006. While the choice of Calcium Chloride and Calcium Hydroxide was because of their complimentary action as calcium is seen to be deficient in some of the soils tested (see Table 5.2). Also cost and availability of the chemicals were also considered in making the choice of these chemicals.

The concentration of each chemical was put at 0.1ml per dm^3, and 2000ml of each chemical was used for 2000grammes of every sample that is 1ml to 1g.

Plate 4.1: Manual Rainfall Simulator Used for Erodibility Test

The plate 4.1 above shows the rainfall simulator and the chamber used for erodibility test. The surface area of the chamber used was 900cm^2 with an approximate volume of about 2700cm^3, With a thickness of about 30cm. After the sprinkling of the chemicals on the dressed sample in the chamber, the sample was allowed for 48hrs to compact and settle with the injected chemicals. After which Erodibilites were checked again by allowing the artificial rainfall simulator to spray water on the sample in the chamber at varied flow rate and the weight of sample eroded is measured. Part of the grouted sample was collected and water of known quality was poured on it and allowed for 24 hours to pass through. This was collected and analyzed to examine the effect of a speicif chemical on water quality.

4.7 Method of Data Analysis and Presentation

The results of the various laboratory analyses were collated and analyzed using some statistical tools. Hypotheses 1, 2 and 5; were tested using Analysis of Variance (ANOVA). While hypothesis 3 and 4 were tested using paired sample t-test and one sample t-test respectively.Two-Way ANOVA was also adopted in analyzing for the best chemical among the four chemicals tested.

The statistical tools, ANOVA and T-test were chosen because of the nature of data collated. While one-way analysis of variance is used to compare more than two variables T-test compares only two variables.

For easy statistical analyses, the following computer softwares were used: SPSS and Microsoft Excel. The resulting data from all the analyses were presented in tables.

CHAPTER FIVE

DATA PRESENTATION AND ANALYSES

This chapter presents the data obtained from the various field mappings and laboratory analyses performed.

5.1 Presentation of Data from Field Survey

The data from the field survey of the five stations sampled in the study area is presented in Table 5.1

Table 5.1: Description of Sampled Gully Site

STN S	GPS coordinate/ Elevation		Site location/ Local Govt.	Approximate Dimension (L,W, & D)			Major process/trigger	Gully Status
	Elev	GPS co		L	W	D		
St 1	112m	$6^o14^1 24.21^{11}N$ $7^o6^1\ 13.829^{11}E$	Behind Ekwueme Sq./ Awka S. LGA	1.500m	100m	350m	Debris fall, slide and earth flow/ concentrated runoff	Very active
St 2	179m	$6^o5^1\ 2.278^{11}N$ $7^o5^1 43.677^{11}E$	Nanka Anaocha	2000m	1000m	>150m	Debris fall, slide and earth flow/ concentrated runoff	Very active
St 3	70m	$6^o4^1\ 54.47^{11}E$ $6^o50^1 27.38^{11}E$	Oba /Idemili N. LGA	600m	150m	57m	Debris fall, slide / soil excavation & surface runoff	Active
St 4	110m	$6^o2^{11} 31.515^{11}E$ $6^o55^1\ 7.732^{11}E$	Nnewichi/ Nnewi N. LGA	500m	40m	35m	Debris fall, slide, slums & earth flow/improper channelization & stumbling	Active
St 5	95m	$6^o4^1\ 59.537^{11}E$ $6^o57^1 0.119^{11}E$	Oraukwu/ Idemili S. LGA	40m	24m	10m	Slums & Debris flow/ runoff and bad road construction.	Active

Source: Author’s field survey, (2017)

From the table 5.1 above, it is clear that the study concentrated on active gully site as can be seen in the gully status of the five stations. Station 1 is very active and is presently about to engulf the old Governor’s lodge, haven swallowed up the fence already. The newly constructed asphalt pavement road beside the federal high court is just about to be cut by this. The construction of new drainage channels which blocks some old natural river channels or flow parts creates more problems than solution as the accumulation of runoffs from all the blocked area concentrate on the new area and causes more havoc. Within the Awka area, the completion of the drainage channel and control of gully beside the Geohazard centre Awka at the back of government house actually was a welcome development, but has led to the development of a new gully site right beside Milatel hotel within the same Agu-Awka Area. Therefore, many factors like sources of surface flow, volume is success flow, direction of surface flow, topography and geology must strictly be considered before any control measure (channelization is put in place).

Station 2 showcased a mighty gully erosion site seen as the biggest in the whole of West Africa which looks almost impossible for Anambra state government to control alone without other bigger sources of financial support. The coalition of the state government, world Bank and other international bodies brought about the present control measures being put in place by Rhino Maritime Construction Company. This German based company succeeded in structuring some civil engineering construction control measures which includes Gabions and Sand Bag check dams. But due to the geology and topography of the area which is very friable and steep respectively, in less than 8 months of the construction just under two rainy season experience, there are signs of failure of the measure (Appendix 2.)

Station three actually is another active zone which is triggered by the excavation activities of Sand Miners and at present there is serious rock falls and slides going on there with its attendant consequences as loss of farm lands and open spaces are being engulfed.

Station four, the Nnewichi site was triggered off by inefficient drainage channelization and enhanced by the steep topography and very weak geology. Lots of work has been done on this site to bring it under control, but due to incomplete stone pitching, of the gullied areas and the stoppage of the constructed concrete channel before the actual gully end, new gully areas regenerates thus it becomes active across rainy seasons.

Station five at Oraukwu have the villagers suffering from the consequences of haphazard road construction. The accumulated surface flow from the tarred areas flow down this zone in accordance with the slope of the topography causing serious debris flow, and because the gully area is untarred, the concrete channels/ gutters put in place to control the erosion are serious being undermined and uprooted creating a bigger gully. It should be noted that in all the stations sampled, there is physical evidence of the soil being weak and in some cases very friable. The locations of the sample stations as contained in Table 5.1 were represented in figure 5.1.

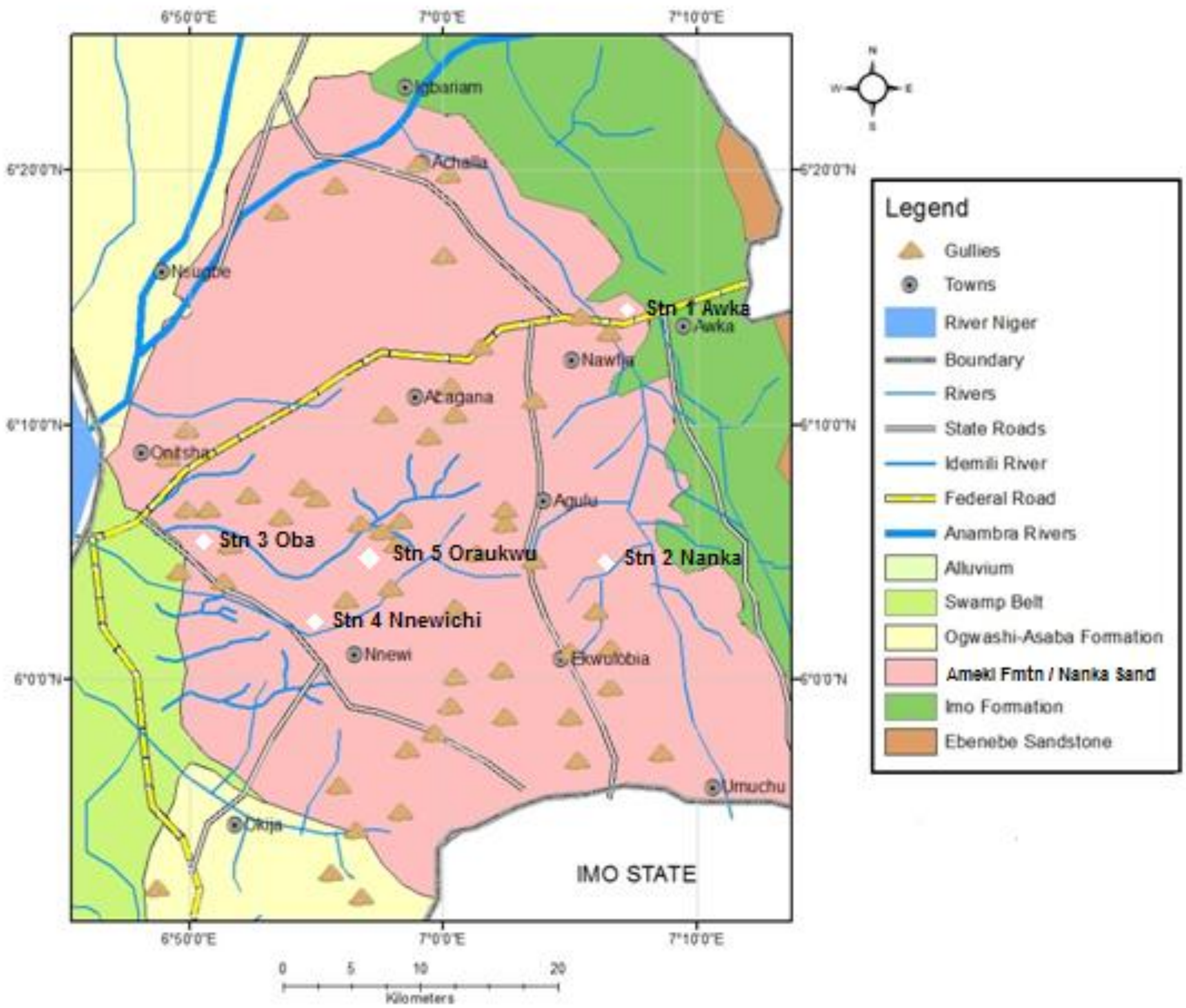

Fig. 5.1: Identified Gullies within Nanka Sand Geologic Unit of Ameki Formation in Anambra State and the Five Sample Stations.

Source: Modified from a base map sourced at Geohazard Centre Awka with data from authors field work, (2017).

Section 5.1, Table 5.1 and figure 5.1 answered objective 1 which is to identify and sample the active gully sites on the Nanka Sands geologic unit of Anambra State

5.2 Presentation of Data from Laboratory Analyses

The collated data from the analyses of soil samples collected from various gully site (sample station) were being summarized in the following tables:

Table 5.2: Summary of the Atomic Absorption Spectrometry of the Soil Samples for the five Stations.

Parameters Tested for	Station 1	Station 2	Station 3	Station 4	Station 5
Copper (ppm)	0.525	0.158	2.101	4.043	1.296
Cobalt (ppm)	0.119	0.018	0.094	1.822	0.092
Lead (ppm)	0.729	0.502	3.527	0.820	0.615
Mercury (ppm)	0.00	0.00	0.742	0.484	0.138
Chromium (ppm)	0.085	0.016	0.083	0.584	0.424
Nickel (ppm)	0.574	0.264	0.314	1.454	0.845
Aluminium	12.783	16.637	14.754	12.134	12.335
Manganese (ppm)	3.629	1.283	1.728	6.167	14.169
Iron (ppm)	44.948	43.101	20.145	21.484	21.410
Zinc (ppm)	3.509	1.480	4.067	8.407	9.706
Silver (ppm)	0.117	0.087	2.281	0.840	0.490
Cadmium (ppm)	0.101	0.176	0.655	0.453	0.154
Calcium (ppm)	0.066	0.044	12.867	9.256	8.258
Magnesium (ppm)	2.387	2.291	15.801	15.985	17.548
Sodium (ppm)	6.633	6.744	2.474	30.8642	32.3722

Tin (ppm)	0.012	0.011	0.009	0.009	0.012
Molybdenium (ppm)	0.633	0.382	0.365	0.360	0.512
Arsenic (ppm)	0.000	0.000	0.000	0.000	0.000
Selenium (ppm)	0.067	0.047	0.044	0.048	0.052
Barium (ppm)	0.003	0.000	0.002	0.002	0.003
Potassium (ppm)	7.033	8.125	12.67	11.231	8.223
Ca (mol/kg	0.00016	0.00011	0.0322	0.02314	0.020645
Na (mol/kg	0.01441	0.01466	0.0054	0.06709	0.07037
Mg (mol/kg	0.00994	0.00693	0.0658	0.0660	0.07311
Total Base	0.02451	0.0217	0.1034	0.15623	0.164125
Exchangeable Acidity mg/kg	11.2	7.2	6.4	3.2	7.2
Cation Exchange Capacity mg/kg	11.2101	7.20704	6.498	3.28914	7.293755
Sulphur %	9.219	6.585	10.96	11.853	19.755
Phenolic Content mg/kg	0.9150	0.7189	0.6754	1.0021	1.111
Total Nitrogen %	1.176	0.504	0.672	0.336	0.448
Total Organic Carbon %	0.0290	0.05517	0.0513	0.0181	0.0354
Organic Matter %	1.6	1.253	1.45	1.05	1.95
Moisture Content %	0.45	0.4	0.35	0.25	0.45
pH in water	6.80	5.66	4.48	5.43	6.07
pH in CaCl	5.10	5.38	4.64	5.21	5.84
Phosphorous mg/kg	13.1120	6.3112	13.4385	11.7519	10.6637

Ca. Hardness mg/kg	20	20	6.8	46	32
Total Hardness mg/kg	82	64	14	68	80
Chloride mg/kg	164	204	214	160`	143
Alkalinity mg/l	15	12.5	17.5	20	30
Conductivity us/cm	164	146	168	173	217
Resistivity cm/us	0.006097	0.00685	0.0059	0.0057	0.0046

Source: Authors Laboratory analysis

Table 5.2 shows a detailed result of the complete elemental analysis of the soil samples, collected from the five stations using atomic absorption spectrometry. From the table, there is reasonable amount of Alumina, Sodium, Iron, Potassium and magnesium, while elements like Copper, Lead, Manganese are in small quantities and other rare elements like Cobalt, Mercury, Chromium, Molybdenum, Tin, Arsenic and Selenium tends to zero. While the Ph in water ranges from 4.48 to 6.80, the Ph in CaCl ranges from 4.64 to 5.84 with higher conductivity and lower resistivity and the lower resistivity is evident in the bullying of the land mass of these areas.

The results summarized in Table 5.2 answered objective 2 which is to determine the chemical composition of soil samples from Nanka Sands geologic unit. The determination of the chemical characteristics of the soil is essential as the control measure being evaluated deals with the addition of chemicals to stabilize the soil or to increase its resistance.

Table 5.3: Summary of the Analyses Result for the Physical Characteristics of the Soil Samples for the five Stations.

Parameters Analysed for	Station 1	Station 2	Station 3	Station 4	Station 5
Particulate Matter mg/kg	1.15	2.8	0.95	2.15	3.55
% clay	24.83	6.6	20.6	7.1	13.5
% silt	34.77	34.7	47.8	25.3	29.7
% Sand	40.4	58.7	31.6	67.6	56.8
Bulk Density g/ml	1.087	1.214	1.083	1.318	1.324
Porosity Before Grouting	0.389	0.342	0.429	0.486	0.396
Permeability Before Grouting	68	82	72	69	94

Source: Author’s laboratory Analyses (2017).

Table 5.3 summarized the physical characteristics of the soils of the five stations sampled. The particulate matter ranges from 0.95mg/kg at station 2 to 3.55mg/kg at station 5 which was the highest recorded across the five stations. The clay is to sand ratio followed a trend of approximately 2:1 at station 1 and 3; 9:1 at station 2 and 4 and 5:1 at station 5. The soil of the area have good porosity and very high permeability which supports the collation an infiltration and consequently higher erosion.

Table 5.4: Summary of the Analyses Result for the Physical Characteristics (Porosity and Permeability) of the Soil Samples for the five Stations After Grouting.

Parameters Analyzed For	$AlFeSiO_4$					$NaSiO_2$					CaCl					CaOH				
	St 1	**St 2**	**St 3**	**St 4**	**St 5**	**St 1**	**St 2**	**St 3**	**St 4**	**St 5**	**St 1**	**St 2**	**St 3**	**St 4**	**St 5**	**St 1**	**St 2**	**St 3**	**St 4**	**St 5**
Porosity before Grouting	0.389	0.429	0.342	0.486	0.396	0.389	0.429	0.342	0.486	0.396	0.389	0.429	0.342	0.486	0.396	0.389	0.429	0.342	0.486	0.396
Porosity after Grouting	0.0177	0.0556	0.0419	0.051	0.0816	0.0902	0.0756	0.013	0.0497	0.00601	0.1053	0.181	0.1155	0.1366	0.1354	0.1454	0.1339	0.1229	0.1150	0.1060
Permeability before Grouting	68	72	82	69	94	68	72	82	69	94	68	72	82	69	94	68	72	82	69	94
Permeability after Grouting	40.23	19.19	20.22	18.19	29.42	35	28.40	22.18	29.30	36.19	29.84	11.85	6.38	8.40	31.34	30.61	7.60	5.11	11.34	26.74

Source: Author's laboratory Analyses (2017).

Table 5.4 shows the porosity and permeability of the soils of the five stations after grouting with the four selected chemicals. The general trend experienced in the grouting with the four chemicals ($AlFeSiO_4$, $NaSiO_2$, CaCl, & CaOH) is that of higher porosity and higher permeability before grouted and lower porosity and permeability after grouting.

This trend favours the reduction in erodibility judging from the concept of resistance which sounds as a bedrock to this study, the higher the resistance, the lower the erodibility and the lower the erodibility, the lower the tendency of being gullied. Caution must be applied in adopting this measure because as porosity and permeability tends to zero, there is very high tendency of flooding especially in flat terrain or level topography.

Tables 5.5.1 to 5.5.5, Summarized the Analyses Result for the Erodibilities of the Soil Samples for the five Stations Before and After Grouting as follows:

Table 5.5: Results of Erodibilities for Station 1

FLOW RATE (ml/min)	ANGLE OF SLOPE (^{o})	Wt. of Soil Used (g)	Wt. of Soil Eroded Before Grt. (g)	Wt. of Soil Collected After Grouting (g).			
				Al, Fe, Silicate	Na. Silicate	CaCl	CaOH
60	25	2,000	190.55	47.78	59.12	89.02	81.33
	45	2,000	220.34	60.10	80.55	104.30	136.13
120	25	2,000	340.70	69.46	85.12	111.42	139.05
	45	2,000	420.45	102.12	121.15	158.47	180.10
180	25	2,000	501.12	98.11	141.90	159.15	186.01
	45	2,000	898.16	140.05	160.77	266.91	243.99

Source: Author's laboratory Analyses (2017).

Table 5.5 above shows the erodibility test results for station 1. There are three different flow rates (60,120, and 180ml/min) under two slope variations of 25^0 and 45^0 respectively, with a constant weight of soil. The application of thre flow rates were based on the literature facts that the rainfall intensity in the area ranges from 100 – 120mm. The higher the amount of soil collected, the higher the erodibility, and the lower the amount of soil collected the lower the erodibility. The trend is such that there is reduced erodibility with the application of each grouting chemical. This agrees with inference from the result of the porosity and permeability of the soils before and after grouting.

Table 5.6: Result of Erodibilities for Station 2

FLOW RATE (ml/min)	ANGLE OF SLOPE (°)	Wt. of Soil Used (g)	Wt. of Soil Eroded Before Grt. (g)	Wt. of Soil Collected After Grouting (g).			
				Al, Fe, Silicate	Na. Silicate	CaCl	CaOH
60	25	2,000	207.90	33.26	55.80	60.68	81.67
	45	2,000	246.12	51.88	91.05	98.04	141.14
120	25	2,000	249.15	50.16	94.27	96.09	132.20
	45	2,000	460.18	91.16	136.66	141.33	184.91
180	25	2,000	620.17	102.81	134.95	139.00	188.39
	45	2,000	913.22	131.18	156.97	281.08	249.18

Source: Author's laboratory Analyses (2017).

Table 5.6 above shows the erodibility test results for station 2. There are three different flow rates (60,120, and 180ml/min) under two slope variations of 25^0 and 45^0 respectively, with a constant weight of soil. The application of thre flow rates were based on the literature facts that the rainfall intensity in the area ranges from 100 – 120mm. The higher the amount of soil collected, the higher the erodibility, and the lower the amount of soil collected the lower the erodibility. The trend is such that there is reduced erodibility with the application of each grouting chemical. This agrees with inference from the result of the porosity and permeability of the soils before and after grouting.

Table 5.7: Result of Erodibilities for Station 3

FLOW RATE (ml/min)	ANGLE OF SLOPE (^{o})	Wt. of Soil Used (g)	Wt. of Soil Eroded Before Grt. (g)	Wt. of Soil Collected After Grouting (g).			
				Al, Fe, Silicate	Na. Silicate	CaCl	CaOH
60	25	2,000	202.10	60.03	54.96	50.23	78.02
	45	2,000	331.17	80.06	83.38	90.06	96.02
120	25	2,000	422.90	77.71	80.92	104.07	94.15
	45	2,000	846.67	93.12	123.16	119.32	145.54
180	25	2,000	803.81	101.24	126.13	162.21	196.22
	45	2,000	934.33	138.45	148.02	218.83	271.98

Source: Author's laboratory Analyses(2017).

Table 5.7 above shows the erodibility test results for station 3. There are three different flow rates (60,120, and 180ml/min) under two slope variations of 25^0 and 45^0 respectively, with a constant weight of soil. The application of thre flow rates were based on the literature facts that the rainfall intensity in the area ranges from 100 – 120mm. The higher the amount of soil collected, the higher the erodibility, and the lower the amount of soil collected the lower the erodibility. The trend is such that there is reduced erodibility with the application of each grouting chemical. This agrees with inference from the result of the porosity and permeability of the soils before and after grouting.

Table 5.8: Result of Erodibilities for Station 4

FLOW RATE (ml/min)	ANGLE OF SLOPE (°)	Wt. of Soil Used (g)	Wt. of Soil Eroded Before Grt. (g)	Wt. of Soil Collected After Grouting (g).			
				Al, Fe, Silicate	Na. Silicate	CaCl	CaOH
60	25	2,000	311.06	44.42	62.00	71.22	69.17
	45	2,000	390.12	49.06	74.45	98.86	94.07
120	25	2,000	387.94	79.01	79.98	99.91	106.45
	45	2,000	709.05	100.06	91.00	142.18	161.77
180	25	2,000	901.11	94.01	124.33	180.43	173.80
	45	2,000	968.06	123.28	135.15	222.19	246.60

Source: Author's laboratory Analyses (2017).

Table 5.8 above shows the erodibility test results for station 4. There are three different flow rates (60,120, and 180ml/min) under two slope variations of 25^0 and 45^0 respectively, with a constant weight of soil. The application of thre flow rates were based on the literature facts that the rainfall intensity in the area ranges from 100 – 120mm. The higher the amount of soil collected, the higher the erodibility, and the lower the amount of soil collected the lower the erodibility. The trend is such that there is reduced erodibility with the application of each grouting chemical. This agrees with inference from the result of the porosity and permeability of the soils before and after grouting.

Table 5.9: Result Erodibilities for Station 5

FLOW RATE (ml/min)	ANGLE OF SLOPE (°)	Wt. of Soil Used (g)	Wt. of Soil Eroded Before Grt. (g)	Wt. of Soil Collected After Grouting (g).			
				Al, Fe, Silicate	Na. Silicate	CaCl	CaOH
60	25	2,000	186.47	26.81	51.11	68.66	65.16
	45	2,000	401.38	41.13	60.04	74.29	86.21
120	25	2,000	416.90	46.13	60.49	81.40	109.10
	45	2,000	738.11	72.69	81.60	138.51	156.00
180	25	2,000	716.44	82.26	89.09	119.09	184.81
	45	2,000	871.82	102.06	101.31	207.98	274.02

Source: Author's laboratory Analyses (2017).

Table 5.9 above shows the erodibility test results for station 5. There are three different flow rates (60,120, and 180ml/min) under two slope variations of 25^0 and 45^0 respectively, with a constant weight of soil. The application of thre flow rates were based on the literature facts that the rainfall intensity in the area ranges from 100 – 120mm. The higher the amount of soil collected, the higher the erodibility, and the lower the amount of soil collected the lower the erodibility. The trend is such that there is reduced erodibility with the application of each grouting chemical. This agrees with inference from the result of the porosity and permeability of the soils before and after grouting.

Across the five stations, $AlFeSiO_4$ showed the highest reduction in erodibility followed by a sudden $NaSiO_2$, CaCl and finally CaOH, although there are few outliers where CaOH proved to strengthen the soil resistance more than CaCl. The trend also followed that with every increase in the slope and increase in the rate of flow (intensity of the artificial raindrops), there is subsequent increase in erodibility. This obeyed the natural law of slope and resistance. There were also very few cases where increase in the intensity of raindrops did not bring about increased erodibility, but at all points across the five stations after grouting with the four chemicals, increase in both topography and rainfall intensity yielded commensurate increase in the amount of soil eroded. It was also clear that the erodibility before grouting is far much higher than the erodibility after grouting.

Tables 5.10 to 5.13 summarizes the Result of the water analyses for the five stations before and after grouting with the four chemicals used, that is $FeAlSiO_{4,}$ $NaSiO_{4,}$ CaCl and CaOH.

Table 5.10: Summary of the Result of the water analyses for the five stations before and after grouting with $AlFeSi0_4$.

Parameters Analysed	WHO Standard	Original H_2O Quality	$AlFeSiO_4$				
			STN 1	STN 2	STN 3	STN 4	STN 5
pH	6.5-7.8	6.77	5.87	5.29	5.46	5.74	5.98
Hardness mg/l	70max	64	307	322	198	224	188
Turbidity NTU	250max	0.01	122	121	122	107	152
Conductivity us/cm	500max	141.80	108	322	498	377	308
Nitrate mg/l	5.0max	0.3070	1.463	3.538	1.072	1.432	1.197
Phosphate mg/l	5.0max	0.274	1.023	3.972	1.637	1.265	0.973
Sodium (ppm)	5.0max	0.112	11.194	7.453	6.183	11.197	10.234
Calcium (ppm)	10.0max	0.00	5.376	5.299	4.742	3.749	3.188
Lead (ppm)	0.05max	0.07	0.482	0.193	0.227	0.168	0.478
Copper (ppm)	0.3max	0.013	0.035	0.018	0.044	0.098	0.026
Manganese	0.3max	0.697	0.463	0.453	0.462	0.361	0.373
Mercury (ppm)	0.03max	0.338	0.372	0.112	0.147	0.289	0.193
Chloride mg/l	120max	5.00	144	108	127	166	187
Silver (ppm)	0.05max	0.053	0.022	0.19	0.013	0.34	0.065
Cobalt (ppm)	0.05max	0.048	0.00	0.00	0.00	0.00	0.00
Magnesium (ppm)	10max	3.386	5.297	5.363	7.278	8.574	9.474
Selenium (ppm)	0.1max	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic (ppm)	0.00max	0.00	0.00	0.00	0.00	0.00	0.00

Cadmium (ppm)	0.3max	0.004	0.012	0.014	0.026	0.072	0.011
Chromium (ppm)	0.3max	0.00	0.026	0.037	0.059	0.084	0.065
Cobalt (ppm)	0.03max	0.205	0.00	0.00	0.00	0.00	0.00
Potassium (ppm)	5.00max	1.186	8.648	6.478	4.299	5.383	3.843
Aluminium (ppm)	0.00	0.00	39.474	47.354	31.464	42.654	48.474
Zinc (ppm)	0.3max	0.028	0.156	0.267	0.119	0.289	0.122
Molybdenum (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tin (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron (ppm)	0.3max	0.02	32.648	44.673	32.762	38.279	41.353
Silicon ((ppm))	98.342	85.278	91.473	80.189	72.383	98.342	85.278

Source: Author's laboratory Analyses (2017).

The summary of the result of water analysis after grouting with $AlFeSiO_4$ showed basically clear-cut variation in the aluminum contents silicon contents and iron contents. While the Ph and turbidity was still in range with the WHO standard. The hardness increased to almost a double of the WHO standard and the original quality of the water. The conductivity, though maintained the range of the WHO standard has its least at station 1 where it was lower than the original water quality, but doubled the original water quality at stations 2-5. Thus, from the table one may conclude that the addition of $AlFeSiO_4$ increases the hardness and conductivity of the water percolating through it.

Table 5.11: Summary of the Result of the water analyses for the five stations before and after grouting with $NaSi0_4$.

Parameters Analysed	WHO Standard	Original H_2O Quality	$NaSi0_4$ STN 1	STN 2	STN 3	STN 4	STN 5
pH	6.5-7.8	6.77	6.10	6.08	5.92	5.88	6.29
Hardness mg/l	70max	64	124	108	146	157	287
Turbidity NTU	250max	0.01	88	92	108	127	146
Conductivity us/cm	500max	141.80	489	506	638	592	397
Nitrate mg/l	5.0max	0.3070	0.435	0.267	1.569	1.367	2.67
Phosphate mg/l	5.0max	0.274	1.936	1.473	1.063	1.367	1.288
Sodium (ppm)	5.0max	0.112	18.464	22.474	28.164	20.288	27.454
Calcium (ppm)	10.0max	0.00	4.365	5.363	4.373	4.193	4.289
Lead (ppm)	0.05max	0.07	0.467	0.297	0.153	0.289	0.356
Copper (ppm)	0.3max	0.013	0.056	0.467	0.028	0.036	0.019
Manganese	0.3max	0.697	0.464	0.378	0.564	0.298	0.946
Mercury (ppm)	0.03max	0.338	0.036	0.045	0.037	0.178	0.172
Chloride mg/l	120max	5.00	120	122	146	139	160
Silver (ppm)	0.05max	0.053	0.00	0.00	0.00	0.00	0.045
Cobalt (ppm)	0.05max	0.048	0.00	0.00	0.00	0.00	0.00
Magnesium (ppm)	10max	3.386	9.474	7.564	6.748	8.373	6.464
Arsenic (ppm)	0.00max	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium (ppm)	0.3max	0.004	0.012	0.025	0.018	0.022	0.020
Chromium (ppm)	0.3max	0.00	0.108	0.116	0.035	0.102	0.117
Cobalt (ppm)	0.03max	0.205	0.00	0.00	0.00	0.00	0.00
Potassium (ppm)	5.00max	1.186	6.474	7.363	4.638	5.038	4.284
Aluminium (ppm)	0.00	0.00	1.163	1.662	1.073	1.443	2.063
Zinc (ppm)	0.3max	0.028	0.286	0.167	0.107	0.119	0.267
Molybdenum (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tin (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron (ppm)	0.3max	0.02	3.986	4.972	3.937	4.738	6.537
Silicon ((ppm))	98.342	85.278	89.732	78.363	58.373	67.291	67.362

(Source: Authors laboratory analyses, 2017).

The summary of the result of the water analysis after grouting with $NaSi0_4$ at the five stations showed little or no variation with the other elements but a clear-cut variation (increase) in sodium. Majority of the elemental composition after grouting maintained the range of the WHO standard. The Ph was within the range of the WHO standard and the original water quality. The hardness doubled at the five stations on the average for both the WHO standard and the original water quality. The turbidity although below (in range with) the WHO standard, but increased significantly above the original water quality same with the conductivity which almost tripled at all the stations with the original water quality. One may conclude that the addition of $NaSi0_4$ as a grouting chemical increases the hardness, turbidity and conductivity of the water percolating through it.

Table 5.12: Summary of the Result of the water analyses for the five stations before and after grouting with CaCl.

Parameters Analysed	WHO Standard	Original Water Quality	CaCl				
			STN 1	STN 2	STN 3	STN 4	STN 5
pH	6.5-7.8	6.77	1.948	2.292	2.863	1.011	1.028
Hardness mg/l	70max	64	1.291	2.422	2.593	2.499	2.863
Turbidity NTU	250max	0.01	1.948	2.292	2.863	1.011	1.028
Conductivity us/cm	500max	141.80	1.291	2.422	2.593	2.499	2.863
Nitrate mg/l	5.0max	0.3070	1.948	2.292	2.863	1.011	1.028
Phosphate mg/l	5.0max	0.274	1.291	2.422	2.593	2.499	2.863
Sodium (ppm)	5.0max	0.112	24.161	24.393	18.750	19.033	17.742
Calcium (ppm)	10.0max	0.00	169.15	262.90	114.81	204.50	287.09
Lead (ppm)	0.05max	0.07	0.820	1.010	0.440	0.445	0.762
Copper (ppm)	0.3max	0.013	0.033	0.003	0.035	0.065	0.019
Manganese (ppm)	0.3max	0.697	1.410	1.781	0.363	0.332	0.591
Mercury (ppm)	0.03max	0.338	0.131	0.110	0.100	0.166	0.126
Chloride mg/l	120max	5.00	136	255	1888	215	320
Silver (ppm)	0.05max	0.053	0.00	0.00	0.00	0.00	0.00
Cobalt (ppm)	0.05max	0.048	0.00	0.032	0.00	0.029	0.00
Magnesium (ppm)	10max	3.386	18.036	18.005	11.831	17.086	1530
Selenium (ppm)	0,1max	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic (ppm)	0.00max	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium (ppm)	0.3max	0.004	0.012	0.00	0.008	0.00	0.009
Chromium (ppm)	0.3max	0.00	0.088	0.080	0.039	0.039	0.064
Cobalt (ppm)	0.03max	0.205	0.00	0.00	0.00	0.00	0.00
Potassium (ppm)	5.00max	1.186	12.247	38.167	31.156	27.384	21.283
Aluminium (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zinc (ppm)	0.3max	0.028	0.476	0.585	0.630	0.736	0.696
Molybdenum (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tin (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron (ppm)	0.3max	0.02	2.640	1.280	0.547	3.207	3.207

(Source: Authors laboratory analyses, 2017).

The summary of the result of the water analysis after grouting with CaCl shows a tremendous increase in the volume of housing and chloride contained in the soil, and also a surprised increase in sodium and iron contents. The Ph was far much below the WHO standard and the original water quality, that is highly acidic. The hardness and the conductivity across the five stations reduced drastically when compared with the WHO standard and the original water quality. Turbidity showed increase when compared with the original water quality but was far more below the WHO standard across the five stations. One may conclude that the addition of CaCl as a grouting chemical reduces the hardness and conductivity of the water infiltrating through it but acidifies the water more.

Table 5.13: Summary of the Result of the water analyses for the five stations before and after grouting with CaOH.

Parameters Analysed	WHO Standard	Original Water Quality	CaOH				
			STN 1	STN 2	STN 3	STN 4	STN 5
pH	6.5-7.8	6.77	6.20	6.10	5.50	6.09	6.13
Hardness mg/l	70max	64	94	480	330	90	67
Turbidity NTU	250max	0.01	041	081	60	69	070
Conductivity us/cm	500max	141.80	492	453	395	493	303
Phosphate mg/l	5.0max	0.274	2.362	2.086	2.194	2.249	1.386
Sodium (ppm)	5.0max	0.112	11.69	13.819	15.00	21.27	24.624
Calcium (ppm)	10.0max	0.00	`135.7	109.4	97.01	217.7	228.36
Lead (ppm)	0.05max	0.07	0.153	0.157	0.869	1.052	0.613
Copper (ppm)	0.3max	0.013	0.040	0.024	0.011	0.003	0.003
Manganese	0.3max	0.697	0.216	0.287	0.585	0.161	0.741
Mercury (ppm)	0.03max	0.338	0.924	0.145	0.108	0.085	0.084
Chloride mg/l	120max	5.00	118	88	100	78	90
Silver (ppm)	0.05max	0.053	0.137	0.00	0.022	0.00	0.00
Cobalt (ppm)	0.05max	0.048	0.00	0.008	0.00	0.00	0.116
Magnesium (ppm)	10max	3.386	12.78	16.646	17.62	17.59	19.240
Selenium (ppm)	0,1max	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic (ppm)	0.00max	0.00	0.00	0.00	0.00	0.00	0.00
Cadmium (ppm)	0.3max	0.004	0.017	0.018	0.00	0.00	0.051
Chromium (ppm)	0.3max	0.00	0.030	0.049	0.038	0.074	0.074
Cobalt (ppm)	0.03max	0.205	0.00	0.00	0.00	0.00	0.00
Potassium (ppm)	5.00max	1.186	32.24	28.167	20.25	37.18	25.083
Aluminium (ppm)	0.00	0.00	0.059	0.00	0.00	0.00	0.00
Zinc (ppm)	0.3max	0.028	0.430	0.370	0.596	0.337	0.338
Molybdenum (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tin (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vanadium	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Iron (ppm)	0.3max	0.02	2.320	2.939	0.605	1.916	1.427

Source: Author’s laboratory Analyses (2017).

The summary of the result of water analysis after using CaOH as the grouting chemical showed a tremendous increase in calcium, with slight increase in magnesium and potassium. Other elements were in range with the WHO standard. There is slight increase in hardness at station 1, 4, and 5 but very high increase of approximately four times the WHO standard and original water quality at stations 2 and 3. The turbidity and conductivity varied with the original water quality, but remained below the maximum of the WHO standard. One may conclude that in addition to expect increase in calcium content, the application of CaOH as a grouting chemical increases hardness, turbidity and conductivity of the water infiltrating through it.

5.3 Results of Questionnaire Survey and Analyses

This section details the result of the questionnaire survey and analyses

Two hundred copies of the questionnaire were administered to the respondents in the study area and one hundred and eighty was recovered which is 90% of the number administered. The Cronbach's Alpha test was conducted using SPSS software and the result was 0.994. This goes to show that the instrument is very strong to satisfy the data need sought by the researcher as the rule says that Cronbach's Alpha test values of greater than 0.6 depicts a strong instrument, otherwise it is weak.

Below are the details of the responses of the respondents in the study area to the issues raised in the questionnaire.

Table 5.14: Age Distribution of the Respondents

Age		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	18 – 25years	25	13.9	13.9	13.9
	26-40years	41	22.8	22.8	36.7
	41-64years	89	49.4	49.4	86.1
	65years and above	25	13.9	13.9	100.0
	Total	180	100.0	100.0	

Source: Author's Questionnaire Survey.

Table 5.14 shows that 13.9% of the respondents were between the ages of 18 and 25 years; 22.8% were between the ages of 26 and 40 years; 49.4% between the ages of 41 and 64; while 13.9% were 65 years and above. The distribution therefore confirms that the respondents are by age mature enough to provide reasonable answers to the issues raised in the questionnaire.

Table 5.15: Responses on How Long the Respondents Have Been in the Study Area

How long?		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	From birth	32	17.8	22.7	22.7
	More than five years	58	32.2	41.1	63.8
	More than one year but less than five years	41	22.8	29.1	92.9
	Less than one year	10	5.6	7.1	100.0
	Total	141	78.3	100.0	
Missing	System	39	21.7		
Total		180	100.0		

Source: Author's Questionnaire Survey.

Table 5.15 shows the responses of the respondents on the question "how long have you been in the study area?". We can see that not all the respondents answered this question. Only 141 respondents out of 180 recovered questionnaire answered this question which is about 78.3% of the total recovered copies. 22.7% of the persons that responded to this question have stayed in the study area from birth, 41.1% have been there for more than five years, 29.1% for more than one year but less than five years while 7.1% have stayed there for less than one year. In a nutshell, over 63% of the respondents have stayed in the study area for more than five years. It thus becomes crystal clear that majority of the respondents have stayed in the study area long enough to have good knowledge of the issues raised in the questionnaire.

Table 5.15 is a summary of the responses of the respondents on how long they have been in the study area.

Table 5.16: Academic Qualification of the Respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	First school leaving certificate	12	6.7	6.7	6.7
	SSCE/WASC	32	17.8	17.8	24.5
	NCE/OND	26	14.4	14.4	38.9
	HND/BSc	52	28.9	28.9	67.8
	Masters	50	27.8	27.8	95.6
	PhD	8	4.4	4.4	100.0
	Total	180	100.0	100.0	

Source: Author's Questionnaire Survey.

Table 5.16 details the academic qualification of the respondents. 6.7% obtained just the first school leaving certificate (FSLC); 17.8% SSCE/WASC; 14.4% NCE/OND; 28.9% HND/BSc.; 27.8% Masters and 4.4% PhD. The academic status of the respondents shows that majority of the respondents can do justice to the issues raised or at least air their view without being biased. Although only a few are into erosion control and general environmental management, but their academic attainment supports the reliability of their responses.

The following tables summarizes the responses of the respondents on the causes of gully erosion, effects of gully erosion in the study area and what should be done in the study area to better control gullying in the study area.

Table 5.17: Responses of the Respondents on What are the Causes of the Gully Erosion in the area?

S/No	Causes	SA		A		NO		D		SD		Mean	Percent
		F	%	F	%	F	%	F	%	F	%		
1	High intensity of rainfall / climatic factors	98	54.4	47	26.1	0	0	32	17.8	3	1.7	4.1389	82.778
2	Friable Geology and loose soil type/Characteristics	94	52.2	56	31.1	3	1.7	27	15.0	0	0	4.2056	84.112
3	Topography / Geomorphology of the area	102	56.7	41	22.8	2	1.1	30	16.7	5	2.8	4.1389	82.778
4	Agricultural Activities/Farming/ Deforestation	49	27.2	115	63.9	4	2.2	10	5.6	2	1.1	4.1056	82.112
5	Soil excavation and sand mining	37	20.6	47	26.1	0	0	87	48.3	9	5.0	3.0889	61.778
6	Building constructions	33	18.3	31	17.2	3	1.7	69	38.3	44	24.4	2.6667	53.334
7	Corruption of the agencies saddled with the responsibilities of gully control	14	7.8	31	17.2	16	8.9	85	47.2	34	18.9	2.4778	49.556
8	Poor water Channelization / Drainage system	116	64.4	44	24.4	0	0	13	17.2	7	3.9	4.3833	87.666
9	Wrong government policies on erosion control	18	10.0	28	15.6	6	3.3	81	45.0	47	26.1	2.3833	47.666
10	Inefficiency in the project management by the manager or leader	22	12.2	22	12.2	1	0.6	86	47.8	49	27.2	2.3444	46.888
11	Wrong control measures	16	8.9	14	7.8	0	0	74	41.1	76	42.2	2.0000	40.000
12	Developmental activities	29	16.1	66	36.7	5	2.8	40	22.2	40	22.2	3.0222	60.444
13	Zero or low involvement of the affected communities to control the gullies	5	2.8	17	9.4	13	7.2	100	56.6	45	25.0	2.0944	41.888

	at young stage												
14	Political factors, change of governments, lack of interest in control projects	17	9.4	13	7.2	0	0	111	61.7	39	21.7	2.2111	44.222
15	Late intervention to gully cases	41	22.8	33	18.3	1	0.6	80	44.4	25	13.9	2.9167	58.334
16	Delays in accessing funds for control	31	17.2	0	0	1	0.6	121	67.2	27	15.0	2.2000	44.000
17	Ignorance of the masses on their role in gully control	12	6.7	11	6.1	14	7.8	100	55.6	43	23.9	2.1611	43.222
18	Poor information of bad communication link between the affected communities and agencies saddled with the responsibility of gully erosion control	4	2.2	24	13.3	33	18.3	91	50.6	28	15.6	2.3611	47.222
19	Poor planning of control measures	2	1.1	16	8.9	31	17.2	81	45.0	50	27.8	2.1056	42.112
20	Control project abandonment /Haphazard Construction	22	12.2	102	56.7	26	14.4	19	10.6	11	6.1	2.4167	48.334
Cluster mean and percent												**2.871**	**57.422**

Source: Analyses of Questionnaire Survey Responses

Table 5.17 summarizes the responses of the respondents on the major causes of the gully erosion in the study area. The percentage statistics from the weighted mean shows that the major causes of gully erosion in the study area are: high intensity of rainfall (climatic factors); friable geology and loose soil type/characteristics; topography / geomorphology of the area; agricultural activities/farming/deforestation; soil excavation and sand mining; poor water channelization / drainage system; developmental activities and late intervention to gully cases. This is in agreement with the findings of Egboka *et al* (2006), Igbokwe *et al*

(2008), Ehiorobo and Izinyon (2011), Obiadi *et al* (2011), among others supporting the fact that gully erosion are caused by both natural and anthropogenic factors. This is represented in figure 5.2.

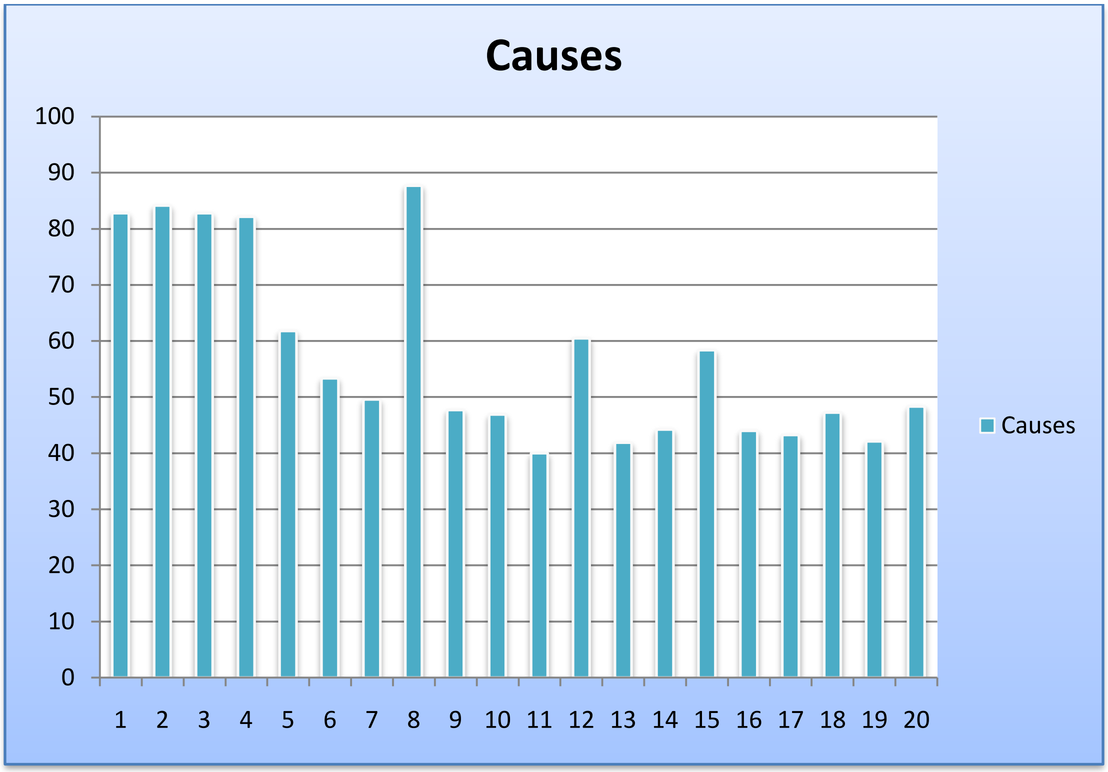

Figure 5.2: Bar Chart for Responses on the Causes of Gullying in the Study Area (Source: Analyses of Questionnaire Survey Responses).

Figure 5.2 is a bar chart representing the responses of the respondents on the major causes of gully erosion in the study area. A critical look at the chart shows that all the twenty causative factors enlisted were accepted by the respondents as factors of gully erosion in the study area. But some of the factors were accepted by more than 50% of the respondents and were adopted as the major causative factors. They include numbers 1, 2, 3, 4, 5, 6, 8, 12 and 15.

Table 5.18:Responses of the Respondents on What are the Effects of Gully Erosion in the area?

S/N	Solutions	SA		A		NO		D		SD		Mean	Percent
		F	%	F	%	F	%	F	%	F	%		
1	Siltation of nearby rivers/streams	36	20.0	76	42.2	0	0	41	22.8	27	15.0	3.2944	65.888
2	Loss of lives	49	27.2	77	42.8	0	0	32	17.8	22	12.2	3.5500	71.000
3	Low food production	11	6.1	17	9.4	1	0.6	68	37.8	83	46.1	1.9167	38.334
4	Inaccessibility of affected area	91	50.6	71	39.4	0	0	3	1.7	15	8.3	4.2222	84.444
5	Loss of communal heritage and monuments	65	36.1	49	27.2	1	0.6	45	25.0	20	11.1	3.5222	70.444
6	Boundary dissections	55	30.6	69	38.3	0	0	44	24.4	12	6.7	3.6167	72.334
7	Loss of properties and farmlands	48	26.7	69	38.3	24	13.3	29	16.1	10	5.6	3.6444	72.888
8	Emotional and psychological trauma	78	43.3	73	40.6	2	1.1	26	14.4	1	0.6	4.1167	82.334
9	Economical losses	59	32.8	55	30.6	0	0	32	17.8	34	18.9	3.4056	68.112
10	Relocation problems	44	24.4	76	42.2	2	1.1	47	26.1	11	6.1	3.5278	70.556
11	Creation of bad lands	51	28.3	31	17.2	21	11.7	42	23.3	35	19.4	3.1167	62.334
12	Increased health challenges like high blood pressure etc.	66	36.7	44	24.4	0	0	46	25.6	24	13.3	3.4556	69.112
Cluster mean and percent												**3.449**	**68.981**

Source: Analyses of Questionnaire Survey Responses

Table 5.18 summarizes the responses of the respondents on the major effects of the gully erosion in the study area. The percentage statistics from the weighted mean shows that the major effects of gully erosion in the study area are: siltation of nearby rivers/streams; loss of lives; inaccessibility; loss of communal heritage and monuments; boundary dissections; loss of properties and farmlands; emotional and psychological trauma; economic losses; relocation problems; creation of bad lands; increased health challenges like high blood pressure among others. This agrees with the findings of Valentin *et al* (2005), Igwe (2005), Izinyon *et al* (2013), among others. This is represented in figure 5.3.

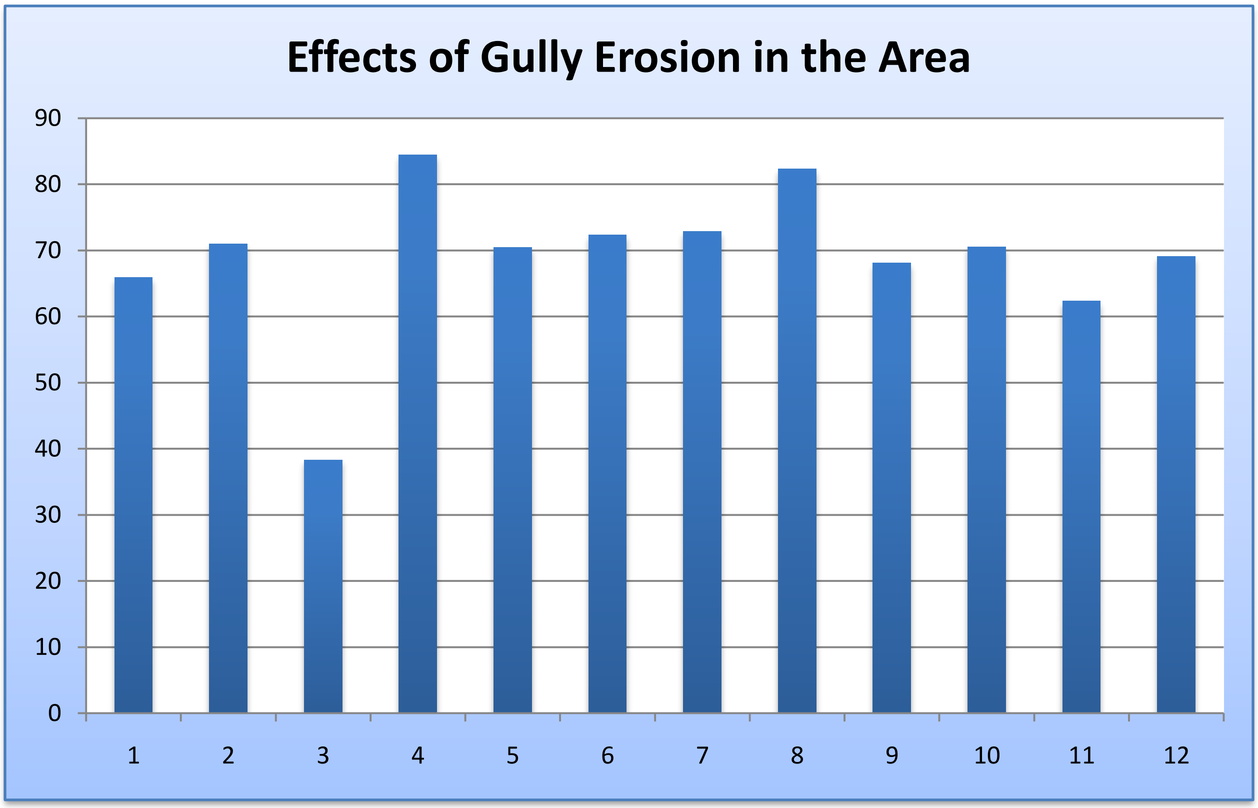

Figure 5.3: Bar Chart for Responses on the Effects of Gully Erosion in the Study Area. (Source: Analyses of Questionnaire Survey Responses).

Figure 5.3 is a bar chart representing the responses of the respondents on the major effects of gully erosion in the study area. A critical look at the chart shows that all the twelve potential effects enlisted were accepted by more than 50% of the respondents as effects of gully erosion in the study area except for number 3 which is low food production. This is in agreement with the information gathered through the in-depth interview.

Table 5.19:Responses of the Respondents on What should be done to better control Gully Erosion in the Area?

S/N	Challenges	SA		A		NO		D		SD		Mean	Percent
		F	%	F	%	F	%	F	%	F	%		
1	Early intervention to control emerging gullies	33	18.3	55	30.6	0	0	54	30.0	33	21.1	2.9500	59.000
2	Project continuity by new governments	29	16.1	41	22.6	14	17.8	59	32.8	37	20.6	2.8111	56.222
3	Construction of sound and wide drainage channels	29	16.1	61	33.9	1	0.6	61	33.9	28	15.6	3.0111	60.222
4	Reduction in the rate of soil excavation	6	3.3	13	7.2	2	1.1	82	45.6	77	42.8	1.8278	36.556
5	Prompt information to the agencies involved with gully control of newly developed gullies	8	4.4	19	10.6	0	0	81	45.0	72	40.0	1.9444	38.888
6	Soil stabilization through chemical means like grouting	70	38.9	39	21.7	1	0.6	26	14.4	44	24.4	3.3611	67.222
7	Prompt release of fund by the government and agencies involved in controlling gullies	73	40.6	41	22.8	4	2.2	24	13.3	38	21.1	3.4833	69.666
8	Adoption of sound project management policies for gully erosion control project to be successful Superiority Issues	16	8.9	37	20.6	1	0.6	6	3.3	120	66.7	2.0167	40.334
9	Combination of both civil engineering control strategies and chemical stabilization methods	13	7.2	87	48.3	7	3.9	56	31.1	17	9.4	3.1278	62.556
10	Control of Agricultural activities	19	10.6	81	45.0	0	0	61	33.9	19	10.6	3.1111	62.222
11	Improved community involvement / public participation	11	6.1	25	13.9	14	7.8	77	42.8	53	29.4	2.2444	44.888
12	Encouraging sound developmental	18	10.0	49	27.2	5	2.8	84	46.7	24	13.3	2.7389	54.778

	control practices that will not expose the environment to gullying												
13	Enlistment of climatologists, geologist and soil scientists in the team controlling the gullies to widen the knowledge about the area	26	14.4	29	16.1	0	0	91	50.6	34	18.9	2.5667	51.334
14	Extensive planning and proper implementation of gully erosion control measures	23	12.8	34	18.9	12	6.7	82	45.6	29	16.1	2.6667	53.334
15	Education of the inhabitants of the affected areas	19	10.6	33	18.3	4	2.2	74	41.1	50	27.8	2.4278	48.556
Cluster mean and percent												**2.685**	**53.718**

Source: Analyses of Questionnaire Survey Responses

Table 5.19 summarizes the responses of the respondents on what needs to be done to better control gully erosion in the study area. The percentage statistics from the weighted mean shows that the majority of the respondents suggested the following: early intervention to control emerging gullies; project continuity by new governments; construction of sound and wide drainage channels; soil stabilization through chemical means like grouting; prompt release of fund by the government and agencies involved in controlling gullies; combination of both civil engineering control strategies and chemical stabilization methods; control of agricultural activities; encouraging sound developmental control practices that will not expose the environment to gullying; enlistment of climatologists, geologist and soil scientists in the team controlling the gullies to widen the knowledge about the area; and extensive planning and proper implementation of gully erosion control measures. This is represented in figure 5.4.

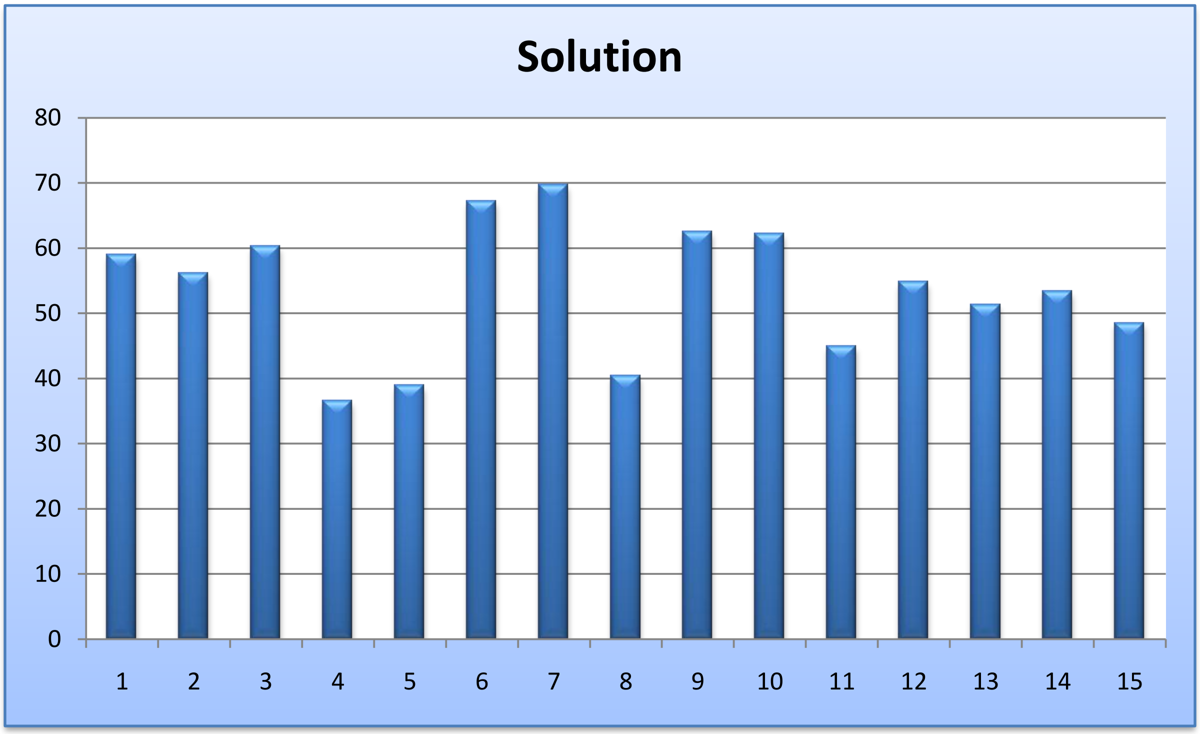

Figure 5.4: Bar Chart for Responses on What Should be done.

Figure 5.4 is a bar chart representing the responses of the respondents on what should be done to better control gully erosion in the study area. A critical look at the chart shows that all the fifteen control measures enlisted were accepted by a good number of the respondents as possible measures of controlling gully erosion in the study area. But some of the measures were accepted by more than 50% of the respondents and were adopted as the main control measures applicable to better control gully erosion in the area. They include numbers 1, 2, 3, 6, 7, 9, 10, 12 and 14. This is in agreement with the information gathered through the in-depth interview.

5.4 In-Depth Interviews Report

This section documents the summary the responses from the professionals and inhabitants of the gully sites localities being interviewed.

5.4.1 Report of Interviews with Some Erosion Control Professionals at National Goehazard Centre Awka.

In the process of sourcing materials from National Goehazards Centre Awka, two of their environmental geologists who specialized in environmental hazards control Pastor Oluwole Rotimi and Mr. Lechi where interviewed. Their responses supported the findings from literature and field survey that the major geologic unit hosting majority of the very active gullies in Anambra State in the Nanka Sand member of the Ameki formation. They noted that the major causes of gully erosion which they found out from their own research includes incomplete and hapharzard drainage systems, poor response to new gully development, Geology, Topography, accumulated surface run-off and other factors. They also were of the opinion that soil grouting or stabilization using chemicals is a very potential area to be explored in the research for a lasting control measure for the gully erosion menace in Anambra State. Pastor Rotimi stressed that the centre have done a lot of detailed research work and analyses in the area of gully erosion control especially considering the geotechnical parameters, but has not really considered the option of chemical stabilization or grouting. “Thus any successful research in that direction will be of interest to the centre”.

On the issue of the environmental implications of grouting, Rotimi and Lechi were of the opinion that every chemical substance introduced to the environment have their various effects, but care should be taken to know the type of chemical to be used considering the nature of the environment of treatment and the volume of the chemical to be introduced considering the environmental carrying capacity.

At the Nanka Gully erosion site where Rhino was working as at the time of this research, the staff of Rhino whose name was withheld but refered to as foreman said that the major causes of the gully erosion are weak and friable geology with dangerous slope. According to him with plain grounds and resistant geology human activities may not impact much to a point of creating dangerous gullies like the Nanka site where they are working on. He stressed that they adopted gabbions and sandbag checkdams as control measure for the site not because they were all they can offer as their best but because they were the best method for such an unstable area that can be accommodated by the available resources. He said other treatments may be very expensive for the sponsoring organization to bear. That is, above the budget of the present project.

When asked of the suitability of grouting and its implication, he said that grouting has worked out as a measure of stabilizing the soil which they have used successfuly in some projects in the Germany and other countries outside Nigeria to stabilize slopes for tunnel construction and other concrete works. He said that grouting will be good for the Nanka erosion site but will require a lot of in-depth study to ascertain the type of chemical needed which will have the least impact on the environment and the amount of such chemicals to be used.

According to him, every chemical has a way of affecting the soil/rock in which it is been introduced, but we must consider many factors like the concentration, the environmental condition of the site (chemical and physical characteristics) and the climate of the area. He recommended grouting for the Nanka erosion site and sites of similar geology around saying that the present research will really make a good starting point.

5.4.2 Report of Interviews with the inhabitants of the Gully Erosion Sites Sampled

The responses of the interview respondents at the various sample stations were summarized as follows:

At station 1 (Awka), one Mr. Charles Nweke Nwiyi of Amudo village Awka, was interviewed. He said that the gully originated over 20 years ago as small rills projecting from the Imo-Awka stream, which later degenerated to what it is today. He lamented that lots of properties worth fortunes has been lost through the menace and that he happened to be a victim as one of his landed properties which as at the time the first control project started was still intact, has now been totally engulfed by the gully. According to him the major cause was the late response of the government as if there has been an early intervention it would not have gotten to this level of massive debris fall and if left like this for the next few years, the worst will be seen. The responses of the other two people interviewed were in concordance with this.

At station 2 (Nanka) three of the villagers who were met at the site were interviewed. They said that the gully has been there for over 30 years, but it is getting worse by the day. They thanked the state government and other donor agencies for their recent intervention as the whole villages around should have been consumed but for their intervention. The eldest among them who identified himself as Papa Ejike stated that he has lived in that part of Nanka for over 50years and that the impact of the gully on the community cannot be over-emphasized as they have experienced loss of lives, properties, farmlands, and family inheritances due to the gully development. He said that there are cases of which some persons left their homes and ran away while others are emotionally traumatized as the next slide fall and submergence may hit their farms, houses and other landed properties unpredictably. The respondents here agreed that the soils of Nanka are really weak and prone to gullying unlike other soli types and the water flow direction moves inline with this weak zone, thus the major cause of the gully erosion menace. They suggested that the recent road construction and floodwater channel construction has really helped, therefore the state government and other agencies should do more.

At station 3 (Oba) one Mr. Okoye who claimed to have live in Oba for so many years while doing his business at Mgbuka-Obosi, stated that the gully was a rill branch of the Idemili river which started about 20 years back, but the recent massive development was due to sand excvavation and this has really made the whole area dangerous with lots of economic losses like loss of farmlands, devegetations, deforestation, and siltation of the Idemili river which seasonally kills lots of aquatic life due to tick muds introduced into the waters through the gully erosion and sand excavations. He suggested that the gullied areas be filled up, compacted again to increase its strength and the excavation activities chacked. Two others were interviewed who shared the same view with Mr. Okoye

At station 4 (Nnewichi) an old woman whose one storey building is few meters to being engulfed by a very large and scary gully was interviewed. She said as at the time she got married over 50 years ago, there were no gullies. The gully started after her father inlaw set up a wood sawmill in the area were little rills of a stream water channel passed through. She said the gully continued developing as all the promises made by the state government were not fulfilled. She voiced out that if not for the intervention of Dame Virgy Etiaba some

6years back, that the whole village could have been sunk down as before then ther road was cut off. On the part of the effects, she lamented that it was the worst thing that ever happened to her and her family as whenever she looks at the gully she will be looking at the sawmill which once was the major source of revenue for the family, she will remember the grave of her father inlaw which has been consumed. In her words, “in fact the daily thought and fear of my hushands house and grave being also swallowed up by this disaster gave me the hypertension I am suffering now”. She said that they have planted trees and grasses on their own as adviced by the agencies that had visited them earlier, but all ended up in the belly of the gully. She now suggested that the government and other non-governmental agencies should come to their aid. They two other people interviewed blamed the deplorable situation of the gully on the representatives of their constituency in Abuja and the member state house of assembly representing them sying that they have no other means of speaking to the government except through these persons.

At station 5 (Oraukwu), an old man and three women were met and interviewed at the site while collecting sample. The old man who vehemently refused that the sample will not be collected but agreed after so much explanation was of the opinion that many people com around from time to time to collect samples from the gully site, promising to do something but all end up doing nothing. The respondents stated that the major cause of the gully development is poor and inadequate response to the control processes. According to them the community have written to the state for help but their intervention was poor, even the gutters constructed earlier were done hapharzadly and failed overtime creating a wider scope of the gully. They said that the gully started little by little as rain water flood channel and since then has developed into a large one which now posses threat to their economic trees, farm crops, houses and many more.

In summary it is crystal clear that the negative effects of these gullies in the study area are too numerous to be over-emphasized. Also there lots of control measure already in place but the gullies still persists with their attendant negative effects. The agencies saddled with the responsibility of erosion control in the area are yet to try grouting and the professionals are in support that grouting should be experimented in the area. This is in line with the responses of the questionnaire where majority opined that chemical stabilization combined with the present ciiviil engineering structures should be adopted to ensure longevity and better control gullying. It is note worthy that most of the inhabitants failed to accept that some of their activities aggravate these gullies, thus should be educated.

5.5 Test of Hypotheses

Hypothesis1

H_0: There is no significant difference in the chemical composition of the soils of the gully erosion sites sampled within Nanka Sands geologic unit in Anambra State.

Statistical Tool: One way ANOVA

Reason for using One Way ANOVA:more than two group were compared; that is five stations.

Decision Rule: Accept the null hypothesis if the p – value is greater than or equal to 0.05, otherwise reject it.

Degree of freedom: 207

Test proper:

Table 5.20: Redult of ANOVA Test Result for Hypothese I

ANOVA

Data

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	266.587	4	66.647	.044	.996
Within Groups	309520.089	203	1524.730		
Total	309786.676	207			

Source: Author's SPSS Analysis

Decision and Reason for Decision: Looking at the table, we conclude that there is no significant difference between the five stations (they are significantly related) since the p – value is greater than 0.05, that is 0.996.

The result of this test of hypothesis 1 answered objective 3 which isto compare the chemical composition of all the analyzed samples in the study sites.

Hypothesis 2

H_0: There is no significant difference in the physical characteristics of the soils of the gully erosion sites sampled within Nanka Sands geologic unit in Anambra State.

Statistical Tool: One way ANOVA

Reason for using One Way ANOVA: More than two groups were compared; that is five stations.

Decision Rule: Accept the null hypothesis if the p – value is greater than or equal to 0.05, otherwise reject it.

Degree of freedom: 34

Test proper:

Table 5.21One-Way ANOVA Test Result for Hypothese II

ANOVA

Data

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	82.461	4	20.615	.022	.999
Within Groups	28227.093	30	940.903		
Total	28309.554	34			

Source: **Author's SPSS Analysis**

Decision and Reason for Decision: Looking at the table, we conclude that there is no significant difference in the physical characteristics of the five stations. That is, they are significantly related since the p – value is greater than 0.05, that is 0.999.

The result of the test of hypothesis 2 answered objective 4 which isto compare the physical characteristics (porosity and permeability) of all the analyzed samples in the study sites.

Hypothesis 3

H_0: There is no significant difference between the pre-grouting porosity and permeability and the post grouting porosity and permeability of the rock of the area.

Considering the nature of the data and the postulated hypothesis, the paired sample T-Test was adopted as the results for each station was paired under porosity or permeability before grouting and porosity and permeability after grouting these pairs were compared using each chemical.

T-Test

Table 5.22Resualt of T-Test for Hypothsis 3 (Porosity)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Porosity before Grouting with AlFeSiO4	.408400	5	.0533507	.0238592
	Porosity after Grouting with AlFeSiO4	.049560	5	.0231239	.0103413
Pair 2	Porosity before Grouting with NaFeSiO4	.4084	5	.05335	.02386
	Porosity after Grouting with NaFeSiO4	.0469	5	.03717	.01662
Pair 3	Porosity before Grouting with CaCl	.4084	5	.05335	.02386
	Porosity after Grouting with CaCl	.1348	5	.02907	.01300
Pair 4	Porosity before Grouting with CaOH	.4084	5	.05335	.02386
	Porosity after Grouting with CaOH	.1246	5	.01549	.00693

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Porosity before Grouting with AlFeSiO4 & Porosity after Grouting with AlFeSiO4	5	.196	.752
Pair 2	Porosity before Grouting with NaFeSiO4 & Porosity after Grouting with NaFeSiO4	5	.344	.571
Pair 3	Porosity before Grouting with CaCl & Porosity after Grouting with CaCl	5	.474	.420
Pair 4	Porosity before Grouting with CaOH & Porosity after Grouting with CaOH	5	-.186	.765

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Porosity before Grouting with AlFeSiO4 - Porosity after Grouting with AlFeSiO4	.3588400	.0538351	.0240758	.2919948	.4256852	14.905	4	.000
Pair 2	Porosity before Grouting with NaSiO4 - Porosity after Grouting with NaFeSiO4	.36150	.05353	.02394	.29504	.42796	15.102	4	.000
Pair 3	Porosity before Grouting with CaCl - Porosity after Grouting with CaCl	.27364	.04714	.02108	.21510	.33218	12.979	4	.000
Pair 4	Porosity before Grouting with CaOH - Porosity after Grouting with CaOH	.28376	.05825	.02605	.21143	.35609	10.893	4	.000

Source: **Author's SPSS Analysis**

This table is used to to get among other information, the mean, standard deviations and p–values of the porosities before and after grouting with each of the four listed chemicals.

We will first explore the p – values and what they imply. We already know that when the p–value is less than 0.05, it means that what was tested for is significant, while if otherwise, it implies insignificance of the test. For all the four comparisons, the p–values are 0.000, less than 0.05. what it means is that the porosities before and after grouting are significantly different in each of the four chemicals; that is for example, the porosity before grouting with CaCl is significantly different from the porosity after grouting with CaCl; the same applies to all the other three chemicals.

From the standard deviations, which when take their square roots we obtain the variances; we will be able to use the variances to know which chemical that its porosities had the highest before and after grouting variation and which had the lowest. The lower the variance, the better the chemical.

So from the little explanation, the standard deviations and variances of the chemicals are as follows:

a. $AlFeSiO_4$ has standard deviation of 0.0538351 and variance of 0.23202392,

b. $NaSiO_4$ has standard deviation of 0.05353 and variance of 0.0.231365511,

c. CaCl has standard deviation of 0.04714 and variance of 0.217747560,

d. CaOH has standard deviation 0.05825 and variance of 0.2413503677.

From here, we can now arrange the chemicals in their order of magnitude starting with the one that has least variance thus: CaCl, $NaSiO_4$, $AlFeSiO_4$, and CaOH.

T-Test

Table 5.23Resualt of T-test Analysis for hypothses 3 (permeability) Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Permeability before Grouting with AlFeSiO4	77.0000	5	11.00000	4.91935
	Permeability after Grouting with AlFeSiO4	25.4500	5	9.40023	4.20391
Pair 2	Permeability before Grouting with NaFeSiO4	77.0000	5	11.00000	4.91935
	Permeability after Grouting with NaFeSiO4	30.2140	5	5.64113	2.52279
Pair 3	Permeability before Grouting with CaCl	77.0000	5	11.00000	4.91935
	Permeability after Grouting with CaCl	17.5620	5	12.06430	5.39532
Pair 4	Permeability before Grouting with CaOH	77.0000	5	11.00000	4.91935
		16.2800	5	11.61115	5.19267

Table 5.24Paired Sample Correlation Analysis

		N	Correlation	Sig.
Pair 1	Permeability before Grouting with AlFeSiO4 & Permeability after Grouting with AlFeSiO4	5	-.006	.993
Pair 2	Permeability before Grouting with NaFeSiO4 & Permeability after Grouting with NaFeSiO4	5	.140	.822
Pair 3	Permeability before Grouting with CaCl & Permeability after Grouting with CaCl	5	.320	.600
Pair 4	Permeability before Grouting with CaOH & Permeability after Grouting with CaOH	5	.149	.811

Table 5.25 Generated from SPSS Analysis

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Permeability before Grouting with AlFeSiO4 - Permeability after Grouting with AlFeSiO4	51.55000	14.50911	6.48867	33.53456	69.56544	7.945	4	.001
Pair 2	Permeability before Grouting with NaFeSiO4 - Permeability after Grouting with NaSiO4	46.78600	11.63862	5.20495	32.33475	61.23725	8.989	4	.001
Pair 3	Permeability before Grouting with CaCl - Permeability after Grouting with CaCl	59.43800	13.48007	6.02847	42.70029	76.17571	9.860	4	.001
Pair 4	Permeability before Grouting with CaOH - Permeability after Grouting with CaOh	60.72000	14.76004	6.60089	42.39299	79.04701	9.199	4	.001

Source: **Author's SPSS Analysis**

This table was used to to get among other information, the mean, standard deviations and p – values of the permeabilities before and after grouting with each of the four listed chemicals.

We will first explore the p – values and what they imply. We already know that when the p–value is less than 0.05, it means that what was tested for is significant, while if otherwise, it implies insignificance of the test. For all the four comparisons, the p–values are 0.001, less than 0.05. what it means is that the permeabilities before and after grouting are significantly different in each of the four chemicals; that is for example, the permeability before grouting with CaCl is significantly different from the permeability after grouting with CaCl; the same applies to all the other three chemicals.

From the standard deviations, we took their square roots to obtain the variances; the variances will show the chemical with the highest permeabilities before and after grouting variation and the one with the lowest. The lower the variance, the better the chemical.

So from the little explanation, the standard deviations and variances of the chemicals are as follows:

a. $AlFeSiO_4$ has standard deviation of 14.50911 and variance of 3.809082567,
b. $NaSiO_4$ has standard deviation of 11.63862 and variance of 3.411542173,
c. CaCl has standard deviation of 13.48007 and variance of 3.671521483,
d. CaOH has standard deviation 14.76004 and variance of 3.841879748.

From here, we can now arrange the chemicals in their order of magnitude starting with the one that has least variance thus: $NaSiO_4$, CaCl, $AlFeSiO_4$, and CaOH.

The summary of the test of hypothesis 3 which states that there is significant difference between the physical characteristics of the rock samples collected, answered objective 5 which is to determine the relationship between pre-grouting and post-grouting porosities and permeabilities of the rocks of the rock samples collected.

Hypothesis 4

H_0: There is no significant difference between the pre-grouting and the post grouting erodibilities of the samples collected.

Station One

Statement: The mean weight of soil from station one collected after grouting is 428.55.

Statistical Tool: One sample T – Test

Reason for using one sample T – Test: one level of observation was collected; (that is the Al, Fe Silicate, Na Silicate, CaCl and CaOH as collected individually) from station one.

Decision Rule: Accept the statement if the p – value is greater than or equal to 0.05, otherwise reject it.

Degrees of freedom: 5

Test proper:

Table 5.26: One SampleT-test Result for hypotheses 4 (Station 1)

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Al, Fe Silicate of station 1	6	86.2700	33.86037	13.82344
Na silicate of station 1	6	108.1017	39.42840	16.09658
CaCl of station 1	6	148.2117	64.96105	26.52024
CaOH of station 1	6	161.1017	55.36283	22.60178

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Al, Fe Silicate of station 1	6.241	5	.002	86.27000	50.7357	121.8043
Na silicate of station 1	6.716	5	.001	108.10167	66.7241	149.4792
CaCl of station 1	5.589	5	.003	148.21167	80.0392	216.3841
CaOH of station 1	7.128	5	.001	161.10167	103.0019	219.2014

Source: **Author's SPSS Analysis**

Decision and Reason for Decision: Looking at the table, the averages of all the four substances (Al, Fe Silicate, Na Silicate, CaCl, and CaOH) are significantly below 428.55, this is because each of their p – values is less than 0.05; but Al, Fe Silicate has the lowest average (86.2700) compared with all the others in station one.

Station Two

Statement: The mean weight of soil from station two collected after grouting is 449.46.

Statistical Tool: One sample T – Test

Reason for using one sample T – Test: one level of observation was collected; (that is the Al, Fe Silicate, Na Silicate, CaCl and CaOH as collected individually) from station two.

Decision Rule: Accept the statement if the p – value is greater than or equal to 0.05, otherwise reject it.

Degrees of freedom: 5

Test Proper:

Table 5.27: One SampleT-test Result for Hypotheses 4 (Station 2)

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Al, Fe Silicate of station 2	6	76.7417	37.59341	15.34744
Na silicate of station 2	6	111.6167	37.59769	15.34919
CaCl of station 2	6	136.0367	77.19129	31.51321
CaOH of station 2	6	162.9150	57.60680	23.51788

Source: **Author's SPSS Analysis**

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Al, Fe Silicate of station 2	5.0	5	.004	76.74167	37.2898	116.1935
Na silicate of station 2	7.2	5	.001	111.61667	72.1603	151.0730
CaCl of station 2	4.3	5	.008	136.03667	55.0294	217.0440
CaOH of station 2	6.9	5	.001	162.91500	102.4604	223.3696

Source: **Author's SPSS Analysis**

Decision and Reason for Decision: Looking at the table, the averages of all the four substances (Al, Fe Silicate, Na Silicate, CaCl, and CaOH) are significantly below 449.46, this is because each of their p – values is less than 0.05; but Al, Fe Silicate has the lowest average (76.74167) compared with all the others in station two.

Station Three

Statement: The mean weight of soil from station three collected after grouting is 590.16.

Statistical Tool: One sample T – Test

Reason for using one sample T – Test: one level of observation was collected; (that is the Al, Fe Silicate, Na Silicate, CaCl and CaOH as collected individually) from station three.

Decision Rule: Accept the statement if the p – value is greater than or equal to 0.05, otherwise reject it.

Degrees of freedom: 5

Table 5.28: One SampleT-test Result for hypotheses 4 (Station 3)

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Al, Fe Silicate of station 3	6	91.7683	26.88033	10.97385
Na silicate of station 3	6	102.7617	35.06621	14.31572
CaCl of station 3	6	124.1200	59.10278	24.12861
CaOH of station 3	6	146.9883	75.09336	30.65674

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Al, Fe Silicate of station 3	8.362	5	.000	91.76833	63.5592	119.9775
Na silicate of station 3	7.178	5	.001	102.76167	65.9619	139.5614
CaCl of station 3	5.144	5	.004	124.12000	62.0954	186.1446
CaOH of station 3	4.795	5	.005	146.98833	68.1827	225.7940

Source: **Author's SPSS Analysis**

Decision and Reason for Decision: Looking at the table, the averages of all the four substances (Al, Fe Silicate, Na Silicate, CaCl, and CaOH) are significantly below 590.16, this is because each of their p – values is less than 0.05; but Al, Fe Silicate has the lowest average (91.76833) compared with all the others in station three.

Station Four

Statement: The mean weight of soil from station four collected after grouting is 611.22.

Statistical Tool: One sample T – Test

Reason for using one sample T – Test: one level of observation was collected; (that is the Al, Fe Silicate, Na Silicate, CaCl and CaOH as collected individually) from station four.

Decision Rule: Accept the statement if the p – value is greater than or equal to 0.05, otherwise reject it.

Degrees of freedom: 5

Table 5.29:One SampleT-test Result for hypotheses 4 (Station 4)

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Al, Fe Silicate of station 4	6	81.6400	30.59381	12.48987
Na silicate of station 4	6	94.4850	29.06401	11.86533
CaCl of station 4	6	135.7983	57.12969	23.32310
CaOH of station 4	6	141.9767	65.12841	26.58856

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Al, Fe Silicate of station 4	6.536	5	.001	81.64000	49.5338	113.7462
Na silicate of station 4	7.963	5	.001	94.48500	63.9842	124.9858
CaCl of station 4	5.822	5	.002	135.79833	75.8444	195.7523
CaOH of station 4	5.340	5	.003	141.97667	73.6286	210.3247

Source: **Author's SPSS Analysis**

Decision and Reason for Decision: Looking at the table, the averages of all the four substances (Al, Fe Silicate, Na Silicate, CaCl, and CaOH) are significantly below 611.22, this is because each of their p – values is less than 0.05; but Al, Fe Silicate has the lowest average (81.640000) compared with all the others in station four.

Station Five

Statement: The mean weight of soil from station three collected after grouting is 519.85.

Statistical Tool: One sample T – Test

Reason for using one sample T – Test: one level of observation was collected; (that is the $AlFeSiO_4$, $NaSiO_4$, CaCl and CaOH as collected individually) from station five.

Decision Rule: Accept the statement if the p – value is greater than or equal to 0.05, otherwise reject it.

Degrees of freedom: 5

Table 5.30: One SampleT-test Result for hypotheses 4 (Station 5)

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Al, Fe Silicate of station 5	6	61.8467	28.47861	11.62634
Na silicate of station 5	6	73.9400	19.66030	8.02628
CaCl of station 5	6	114.9883	53.19471	21.71665
CaOH of station 5	6	145.8833	76.76824	31.34050

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Al, Fe Silicate of station 5	5.320	5	.003	61.84667	31.9602	91.7331
Na silicate of station 5	9.212	5	.000	73.94000	53.3078	94.5722
CaCl of station 5	5.295	5	.003	114.98833	59.1639	170.8128
CaOH of station 5	4.655	5	.006	145.88333	65.3200	226.4467

Author's SPSS Analysis

Decision and Reason for Decision: Looking at the table, the averages of all the four chemicals ($AlFeSiO_4$, $NaSiO_4$, CaCl, and CaOH) are significantly below 519.85, this is because each of their p–values is less than 0.05; but $AlFeSiO_4$ has the lowest average (61.84667) compared with all the others in station three.

Summary of Test of Hypothesis 4

Hypothesis: There is no significant difference between the pre-grouting and the post grouting erodibilities of the samples collected.

Statistical Tool: One sample T – Test

Reason for using one sample T – Test: one level of observation was collected; (that is the $AlFeSiO_4$, $NaSiO_4$, CaCl and CaOH as collected individually) from each station.

Decision Rule: Accept the null hypothesis if the p – value is greater than or equal to 0.05, otherwise reject it.

Degree of freedom: as contained in the results of the five stations.

Test proper: as contained in the results of the five stations

Decision and Reason for Decision: From the result of the five stations analyzed, it is clear that there is significant difference between the pre-grouting and post-grouting erodibilities of samples collected. Furthermore, on the grounds of having the ability to reduce erodibility, $AlFeSiO_4$ is the best grouting chemical among the four, since it recorded the lowest post grouting averages when compared to others.

The above result of the test of hypothesis 4 which showed clearly that there is significant difference between the pre-grouting and post-grouting erodibilities of the samples collected, answered objective 6 which is to compare the pre-grouting and post-grouting erodibilities of the rock samples collected.

Hypothesis 5

H_0: There is no significant difference between the water samples collected before and after grouting exercise.

Statistical Tool: One sample T – Test

Reason for using one sample T – Test: one level of observation was collected; (that is the $AlFeSiO_4$, $NaSiO_4$, CaCl and CaOH as collected individually) from each station comparing the results of elemental composition of water after grouting with the elemental composition of water before grouting. The elements/parameters were considered individually, but considering that we have already proven that the chemical composition of the samples are significantly the same across the stations, the mean values of the stations were computed in this test to avoid repeatition of the tests across the stations.

Table 5.31: Summary of the T-Test Results for $AlFeSiO_4$ and Original Water Quality (OWQ)

Parameters Analysed	OWQ	Mean	Mean difference	P – value	Decision
pH	6.77	5.6680	-0.83200	0.003	Mean is significantly below OWQ
Hardness mg/l	64	247.800	177.800	0.003	Mean is significantly above OWQ.
Turbidity NTU	0.01	124.800	-125.200	0.00	Mean is significantly below OWQ.
Conductivity us/cm	141.80	322.600	-177.400	0.049	Mean is significantly below OWQ.
Nitrate mg/l	0.3070	1.7404	-3.2596	0.002	Mean is significantly below OWQ.
Phosphate mg/l	0.274	1.774	-3.226	0.005	Mean is significantly below OWQ.
Sodium ((ppm))	0.112	9.2522	4.2522	0.014	Mean is significantly above OWQ.
Calcium (ppm)	0.00	4.4708	-5.5292	0.000	Mean is significantly below OWQ.
Lead (ppm)	0.07	0.3096	0.2596	0.021	Mean is significantly above OWQ.
Silver (ppm)	0.05	0.1260	0.07600	0.288	Mean is above OWQ, but not significant.
Copper (ppm)	0.013	0.0442	-0.25580	0.00	Mean is significantly below OWQ.
Manganese	0.697	0.4224	0.12240	0.006	Mean is above OWQ, and significant.
Mercury (ppm)	0.338	0.2226	0.19260	0.016	Mean is significantly above OWQ.
Chloride mg/l	5.00	146.4	26.4	0.131	Mean is above OWQ, but not significant.
Magnesium (ppm)	3.386	7.1972	-2.80280	0.029	Mean is significantly below OWQ.
Cadmium (ppm)	0.004	0.027	-0.273	0.00	Mean is significantly below OWQ.
Chromium (ppm)	0.00	0.0542	-0.2458	0.00	Mean is significantly below OWQ.
Potassium (ppm)	1.186	5.7302	0.7302	0.444	Mean is significantly above OWQ.
Zinc (ppm)	0.028	0.1906	-0.1094	0.04	Mean is significantly below OWQ.
Iron (ppm)	0.02	37.9430	37.643	0.00	Mean is significantly above OWQ.

Source: Generated from the summary of authors statistical analyses comparing the result of AAS for the Original water and that of the water after grouting on each parameter.

From Table 5.31, it is clear that the addition of $AlFeSiO_4$ to the soil sample increased the content of 9 of the whole parameters measured to above OWQ. It is therefore concluded that the addition of $AlFeSiO_4$, significantly impacts the ground water.Considering the nature of most of these parameters it is discernable that though $AlFeSiO_4$ is a sound grouting agent as proven with its very high ability to reduce erodibility, its impact on the ground water might make it unsafe for human consumption due to the excessive presence of elements like lead, mecury and manganese (table 5.31)

Table 5.32: Summary of the T-Test Results for $NaSiO_4$ and OWQ

Parameters Analysed	OWQ	Mean	Mean difference	P – value	Decision
pH	6.77	6.054	-0.716	0.001	Mean is significantly below the OWQ.
Hardness mg/l	64	164.4	100.4	0.034	Mean is significantly above the OWQ.
Turbidity NTU	0.01	112.20000	112.190	0.001	Mean is significantly above the OWQ.
Conductivity us/cm	141.80	524.4	382.6	0.001	Mean is significantly above the OWQ.
Nitrate mg/l	0.3070	1.2616	0.9546	0.93	Mean is not significantly above OWQ.
Phosphate mg/l	0.274	1.4254	1.1514	0.001	Mean is significantly above the OWQ.
Sodium (ppm)	0.112	23.3688	23.2568	0.00	Mean is significantly above the OWQ.
Calcium (ppm)	0.00	.4.5166	4.5166	0.00	Mean is significantly above the OWQ.
Lead (ppm)	0.07	0.3124	0.2424	0.009	Mean is not significantly above OWQ.
Silver (ppm)	0.053	0.009	-0.044	0.008	Mean is not significantly below OWQ.
Copper (ppm)	0.013	0.1212	0.1082	0.008	Mean is above the OWQ, but not significant.
Manganese	0.697	0.53	-0.167	0.214	Mean is below the OWQ, but not significant.
Mercury (ppm)	0.338	0.0936	-0.2444	0.002	Mean is significantly below OWQ.
Chloride mg/l	5	137.4	132.4	0.00	Mean is significantly above the OWQ.
Magnesium (ppm)	3.386	7.7246	4.3386	0.001	Mean is significantly above the OWQ.
Cadmium (ppm)	0.004	0.0194	-0.02060	0.001	Mean is significantly below OWQ.
Chromium (ppm)	0.00	0.0956	0.0956	0.003	Mean is significantly above the OWQ.
Potassium (ppm)	1.186	5.5594	4.3734	0.002	Mean is significantly above the OWQ.
Zinc (ppm)	0.028	0.1892	0.1612	0.012	Mean is significantly above the OWQ.
Iron (ppm)	0.02	4.834	4.814	0.001	Mean is significantly above the OWQ.
Silicon	85.278	72.2242	-13.0498	0.073	Mean is not significantly below OWQ

Source: Generated from the summary of authors statistical analyses comparing the result of AAS for the Original water and that of the water after grouting on each parameter.

From table 5.32, it is clear that the addition of $NaSiO_4$ to the soil sample increased the content of 12 of the whole parameters measured to above OWQ, it is therefore concluded that though $NaSiO_4$ which has been confirmed to be a good grouting agent from the erodibility test, will significantly impact the ground water.

Table 5.33: Summary of the T-Test Results for CaOH and OWQ

Parameters Analysed	OWQ	Mean	Mean difference	P – value	Decision
pH	6.77	6.004	-0.766	0.004	Mean is significantly below the OWQ.
Hardness mg/l	64	212.2	148.2	0.146	Mean is not significantly above the OWQ.
Turbidity NTU	0.01	64.2	64.19	0.001	Mean is significantly above the OWQ.
Conductivity us/cm	141.80	427.2	285.4	0.001	Mean is significantly above the OWQ.
Phosphate mg/l	0.274	2.0554	1.7814	0.001	Mean is significantly above the OWQ.
Sodium (ppm)	0.112	17.28320	17.1712	0.002	Mean is significantly above the OWQ.
Calcium (ppm)	0.00	.157.6488	157.6488	0.005	Mean is significantly above the OWQ.
Lead (ppm)	0.07	0.5688	0.4988	0.052	Mean is not significantly above OWQ.
Silver (ppm)	0.053	0.0318	-0.0212	0.471	Mean is not significantly below OWQ.
Copper (ppm)	0.013	0.0162	0.0032	0.675	Mean is above OWQ, but not significant.
Manganese	0.697	0.398	-0.29900	0.00	Mean is significantly below the OWQ.
Chloride mg/l	5	0.948	89.8	0.000	Mean is sigificantly above OWQ.
Cobalt (ppm)	0.048	0.0248	-0.0232	0.367	Mean is below OWQ, but not significant.
Magnesium (ppm)	3.386	16.7778	13.3918	0.000	Mean is significantly above the OWQ.
Cadmium (ppm)	0.004	0.0172	-0.0228	0.071	Mean is not significantly below OWQ.
Chromium (ppm)	0.00	0.053	0.053	0.004	Mean is significantly above OWQ.
Potassium (ppm)	1.186	28.5874	27.4014	0.001	Mean is significantly above the OWQ.
Zinc (ppm)	0.028	0.4142	0.3862	0.001	Mean is significantly above the OWQ.
Iron (ppm)	0.02	1.8414	1.8214	0.01	Mean is significantly above the OWQ.

Source: Generated from the summary of authors statistical analyses comparing the result of AAS for the Original water and that of the water after grouting on each parameter.

From Table 5.33, it is clear that the addition of CaOHto the soil sample increased the content of 12 of the whole parameters measured to above OWQ, it is therefore concluded that the addition of CaOH to the soil as a grouting agent, will have significant impact on the ground water.

Table 5.34: Summary of the T-Test Results for CaCl and OWQ

Parameters Analysed	**OWQ**	**Mean**	**Mean difference**	**P – value**	**Decision**
pH	6.77	1.82840	-4.941600	0.000	Mean is significantly below OWQ.
Hardness mg/l	64	2.33360	-61.6664000	0.000	Mean is significantly below OWQ.
Turbidity NTU	0.01	1.82840	1.818400	0.007	Mean is significantly above OWQ.
Conductivity us/cm	141.80	2.33360	-139.46640	0.000	Mean is significantly below OWQ.
Nitrate mg/l	0.3070	1.82840	1.521400	0.014	Mean is significantly above OWQ.
Phosphate mg/l	0.274	2.33360	2.059600	0.002	Mean is significantly above OWQ.
Sodium (ppm)	0.112	20.81580	20.703800	0.000	Mean is significantly above OWQ.
Calcium (ppm)	0.00	207.69000	207.69000	0.003	Mean is significantly above OWQ.
Lead (ppm)	0.07	0.69540	0.625400	0.005	Mean is significantly above OWQ.
Copper (ppm)	0.013	0.03100	0.018000	0.154	Mean is above OWQ, but not significant.
Manganese	0.697	0.89540	0.198400	0.538	Mean is above OWQ, but not significant.
Mercury (ppm)	0.338	0.12660	-0.211400	0.000	Mean is significantly below OWQ.
Chloride mg/l	5.00	562.800	557.80000	0.169	Mean is above OWQ, but not significant.
Cobalt (ppm)	0.048	0.01220	-0.035800	0.009	Mean is significantly below OWQ.
Magnesium (ppm)	3.386	318.99160	315.605600	0.356	Mean is above OWQ, but not significant.

Cadmium (ppm)	0.004	0.00580	0.001800	0.505	Mean is above OWQ, but not significant.
Chromium (ppm)	0.00	0.06200	0.062000	0.004	Mean is significantly above OWQ.
Potassium (ppm)	1.186	26.04740	24.861400	0.005	Mean is significantly above OWQ.
Zinc (ppm)	0.028	0.62460	0.596600	0.000	Mean is significantly above OWQ.
Iron (ppm)	0.02	2.17620	2.156200	0.016	Mean is significantly above OWQ.

Source: Generated from the summary of authors statistical analyses comparing the result of AAS for the Original water and that of the water after grouting on each parameter.

From table 5.34, it is clear that the addition of CaClto the soil sample increased the content of 9 of the whole parameters measured to above OWQ, it is therefore concluded that the addition of CaCl to the soil as a grouting agent, will have significant impact on the ground water.

It should be noted that the four chemicals tested all have impact on the water quality which is significant with varying parameters. The nature of these parameters and their potential health effects becomes an issue for strict consideration in selecting the best grouting chemical among the four.

Hypothesis 6

H_0: The effects of the grouting chemicals on water vary significantly.

Statistical Tool: One sample T – Test

Reason for using one sample T – Test: one level of observation was collected; (that is the $AlFeSiO_4$, $NaSiO_4$, CaCl and CaOH as collected individually) from each station comparing the results of elemental composition of water after grouting with the elemental composition of water before grouting. The elements /parameters were considered individually, but considering that we have already proven that the chemical composition of the samples are significantly the same across the stations, the mean values of the stations were computed in this test to avoid repeatition of the tests across the stations.

Table 5.35: Summary of the T-Test Results for $AlFeSiO_4$and WHO Standard

Parameters Analysed	WHO Standard	Mean	Mean difference	P value	Decision
pH	6.5-7.5	5.6680	-0.83200	0.003	Mean is significantly below WHO standard.
Hardness mg/l	70	247.800	177.800	0.003	Mean is significantly above WHO standard.
Turbidity NTU	250	124.800	-125.200	0.00	Mean is significantly below WHO standard.
Conductivity us/cm	500	322.600	-177.400	0.049	Mean is significantly below WHO standard.
Nitrate mg/l	5.0	1.7404	-3.2596	0.002	Mean is significantly below WHO standard.
Phosphate mg/l	5.0	1.774	-3.226	0.005	Mean is significantly below WHO standard.
Sodium (ppm)	5.0	9.2522	4.2522	0.014	Mean is significantly above WHO standard.
Calcium (ppm)	10.0	4.4708	-5.5292	0.000	Mean is significantly below WHO standard.
Lead (ppm)	0.05	0.3096	0.2596	0.021	Mean is significantly above WHO standard.
Silver (ppm)	0.05	0.1260	0.07600	0.288	Mean is above WHO standard, but not significant.
Copper (ppm)	0.3	0.0442	-0.25580	0.00	Mean is significantly below WHO standard.
Manganese	0.3	0.4224	0.12240	0.006	Mean is above WHO standard,and significant.
Mercury (ppm)	0.03	0.2226	0.19260	0.016	Mean is significantly above WHO standard.
Chloride mg/l	5.00	146.4	26.4	0.131	Mean is above WHO standard, but not significant.
Cobalt (ppm)	0.05				Mean is below WHO standard, but not significant.
Magnesium (ppm)	10.0	7.1972	-2.80280	0.029	Mean is significantly below WHO standard.
Cadmium (ppm)	0.3	0.027	-0.273	0.00	Mean is significantly below WHO standard.
Chromium (ppm)	0.3	0.0542	-0.2458	0.00	Mean is significantly below WHO standard.
Potassium (ppm)	5.0	5.7302	0.7302	0.444	Mean is significantly above WHO standard.
Zinc (ppm)	0.3	0.1906	-0.1094	0.04	Mean is significantly below WHO standard.
Iron (ppm)	0.3	37.9430	37.643	0.00	Mean is significantly above WHO standard.

Source: Generated from the summary of authors statistical analyses comparing the result of AAS for the water after grouting on each parameter and the WHO Standard.

From Table 5.35, it is clear that 8 of the measure parameters are significantly above WHO standards for portable water. Therefore it is concluded that the addition of $AlFeSiO_4$ impacts the water portability. This agrees with the comparison done earlier with OWQ.

Table 5.36: Summary of the T-Test Results for $NaSiO_4$ and WHO Standard

Parameters Analysed	WHO Standard	Mean	Mean difference	P – value	Decision
pH	6.5-7.5	6.05400	-0.446	0.004	Mean is significantly below WHO standard.
Hardness mg/l	70	164.4	94.4	0.041	Mean is significantly above WHO standard.
Turbidity NTU	250	112.2	-137.8	0.000	Mean is significantly below WHO standard.
Conductivity us/cm	500	524.4	24.4	0.593	Mean is above WHO standard, but not significant.
Nitrate mg/l	5.0	1.2616	-3.738400	0.001	Mean is significantly below WHO standard.
Phosphate mg/l	5.0	1.42540	-3.5746	0.000	Mean is significantly below WHO standard.
Sodium (ppm)	5.0	23.3688	18.3688	0.001	Mean is significantly above WHO standard.
Calcium (ppm)	10.0	4.5166	-5.4834	0.000	Mean is significantly above WHO standard.
Lead (ppm)	0.05	0.3124	0.2624	0.007	Mean is not significantly above WHO standard.
Silver (ppm)	0.05	0.009	-0.041	0.01	Mean is significantly below WHO standard.
Copper (ppm)	0.3	0.1212	-0.1788	0.108	Mean is below WHO standard, but not significant.
Manganese	0.3	0.53	0.23	0.112	Mean is above WHO standard, but not significant.
Mercury (ppm)	0.03	0.0936	0.0636	0.129	Mean is not significantly above WHO standard.
Chloride mg/l	5.00	0.01374	17.4	0.081	Mean is above WHO standard, but not significant.
Cobalt (ppm)	0.05				Mean is below WHO standard, but not significant.
Magnesium (ppm)	10.0	7.7246	-2.2754	0.014	Mean is below WHO standard, and significant.
Cadmium (ppm)	0.3	0.0194	-0.2806	0.000	Mean is significantly below WHO standard.
Chromium (ppm)	0.3	0.0956	-0.2044	0.00	Mean is significantly below WHO standard.
Potassium (ppm)	5.0	5.5594	0.5594	0.393	Mean is above WHO standard, but not significant.
Zinc (ppm)	0.3	0.1892	-0.1108	0.041	Mean is significantly above WHO standard.
Iron (ppm)	0.3	4.834	4.534	0.001	Mean is significantly above WHO standard.

Source: Generated from the summary of authors statistical analyses comparing the result of AAS for the water after grouting on each parameter and the WHO Standard.

From table 5.36, it is clear that 5 of the measure parameters are significantly above WHO standards for portable water. Therefore it is concluded that the addition of $NaSiO_4$ impacts the water portability. This also agrees with the comparison done earlier with OWQ.

Table 5.37:Summary of the T-Test Results for CaOH and WHO Standard

Parameters Analysed	WHO Standard	Mean	Mean difference	P – value	Decision
pH	6.5-7.5	6.00400	.0.496000	0.018	Mean is significantly below WHO standard.
Hardness mg/l	70	212.2000	142.20000	0.159	Mean is above WHO standard, but not significant.
Turbidity NTU	250	64.20000	-185.80000	0.000	Mean is significantly below WHO standard.
Conductivity us/cm	500	427.200	-72.800000	0.112	Mean is below WHO standard, but not significant.
Nitrate mg/l	5.0				Mean is significantly below WHO standard.
Phosphate mg/l	5.0	2.05540	-2.944600	0.000	Mean is significantly below WHO standard.
Sodium (ppm)	5.0	17.28320	12.283200	0.007	Mean is significantly above WHO standard.
Calcium (ppm)	10.0	157.64880	147.64880	0.006	Mean is significantly above WHO standard.
Lead (ppm)	0.05	0.56880	0.518800	0.047	Mean is significantly above WHO standard.
Silver (ppm)	0.05	0.03180	-0.018200	0.532	Mean is below WHO standard, but not significant.
Copper (ppm)	0.3	0.01620	-0.283800	0.000	Mean is significantly below WHO standard.
Manganese	0.3	0.39800	0.098000	0.434	Mean is above WHO standard, but not significant.
Mercury (ppm)	0.03	0.26920	0.239200	0.219	Mean is not significantly above WHO standard.
Cobalt (ppm)	0.05	0.02480	-0.025200	0.332	Mean is below WHO standard, but not significant.
Magnesium (ppm)	10.0	16.77780	6.777800	0.003	Mean is above WHO standard, but not significant.
Cadmium (ppm)	0.3	0.1720	-0.282800	0.000	Mean is significantly below WHO standard.
Chromium (ppm)	0.3	0.05300	-0.247000	0.000	Mean is significantly below WHO standard.
Potassium (ppm)	5.0	28.58740	23.5874	0.001	Mean is significantly above WHO standard.
Zinc (ppm)	0.3	0.41420	0.114200	0.078	Mean is not significantly above WHO standard.
Iron (ppm)	0.3	1.84140	1.5414	0.018	Mean is significantly above WHO standard.

Source: Generated from the summary of authors statistical analyses comparing the result of AAS for the water after grouting on each parameter and the WHO Standard.

From table 5.37, it is clear that 5 of the measure parameters are significantly above WHO standards for portable water. Therefore it is concluded that the addition of CaOH impacts the water portability. This is also in agreement with the comparison done earlier with OWQ.

Table 5.38: Summary of the T-Test Results for CaCl and WHO Standard

Parameters Analyzed	WHO Standard	Mean	Mean difference	P – value	Decision
pH	6.5-7.5	1.82840	-4.671600	0.000	Mean is significantly below WHO standard.
Hardness mg/l	70	2.33360	-67.666400	0.000	Mean is significantly below WHO standard.
Turbidity NTU	250	1.82840	-248.171600	0.000	Mean is significantly below WHO standard.
Conductivity us/cm	500	2.33360	-497.666400	0.000	Mean is significantly below WHO standard.
Nitrate mg/l	5.0	1.82840	-3.171600	0.001	Mean is significantly below WHO standard.
Phosphate mg/l	5.0	2.33360	-2.666400	0.001	Mean is significantly below WHO standard.
Sodium (ppm)	5.0	20.81580	15.815800	0.000	Mean is significantly above WHO standard.
Calcium (ppm)	10.0	207.69000	197.690000	0.003	Mean is significantly above WHO standard.
Lead (ppm)	0.05	0.69540	0.645400	0.004	Mean is significantly above WHO standard.
Copper (ppm)	0.3	0.03100	-0.269000	0.000	Mean is significantly below WHO standard.
Manganese	0.3	0.89540	0.595400	0.114	Mean is above WHO standard, but not significant.
Mercury (ppm)	0.03	0.12660	0.096600	0.001	Mean is significantly above WHO standard.
Chloride mg/l	5.00	562.800	442.800000	0.254	Mean is above WHO standard, but not significant.
Cobalt (ppm)	0.05	0.01220	-0.037800	0.007	Mean is significantly below WHO standard.
Magnesium (ppm)	10.0	318.99160	308.991600	0.365	Mean is above WHO standard, but not significant.
Cadmium (ppm)	0.3	0.00580	-0.294200	0.000	Mean is significantly below WHO standard.
Chromium (ppm)	0.3	0.06200	-0.238000	0.000	Mean is significantly below WHO standard.
Potassium (ppm)	5.0	26.04740	21.047400	0.009	Mean is significantly above WHO standard.
Zinc (ppm)	0.3	0.62460	0.324600	0.002	Mean is significantly above WHO standard.
Iron (ppm)	0.3	2.17620	1.876200	0.025	Mean is significantly above WHO standard.

Source: Generated from the summary of authors statistical analyses comparing the result of AAS for the water after grouting on each parameter and the WHO Standard.

From Table 5.38, it is evident that 7 of the measure parameters are significantly above WHO standards for portable water. Therefore it is concluded that the addition of CaCl impacts the water portability. This is also in agreement with the comparison done earlier with OWQ.

The results of the test of hypotheses 5 and 6 which shows that the application of the grouting chemicals impacted the water quality, answered objective 7 which is to examine the impact of the grouting chemicals on water quality.

5.5.1 Test for the Overall Best Grouting Chemical

Having confirmed the best chemical amongst the four adopted in each characteristic parameter measured, (change in porosity, change in permeability, variation with WHO standard and original water quality and erodibility. There is need to combine all these criteria and derive the average best which will be most recommended for grouting chemical in the area. To this end, the two way ANOVA was adopted as follows:

Table 5.39: Table for Two-Way ANOVA Test for the Overall Best Grouting Chemical

Between-Subjects Factors

		Value Label	N
Chemicals used for grouting	1	CaCl	180
	2	CaOH	180
	3	NaSiO4	180
	4	AlFeSiO4	170
Characteristics Measured	1	Permeability	40
	2	Porosity	40
	3	WHO and water quality	510
	4	Erodibility	120

Source: Author's SPSS Analysis

Levene's Test of Equality of Error Variances[a]

Dependent Variable:Data

F	df1	df2	Sig.
1.514	15	694	.094

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Chemicals + Measured Characteristics + Chemicals * Measured Characteristic

Table 5.40: SPSS Table for Tests of Between-Subjects Effects

Dependent Variable:Data

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	744914.966[a]	15	49660.998	3.371	.000
Intercept	708916.585	1	708916.585	48.125	.000
Chemicals	10723.824	3	3574.608	.243	.867
Characteristics	645736.515	3	215245.505	14.612	.000
Chemicals * Characteristics	82677.016	9	9186.335	.624	.777
Error	1.022E7	694	14730.596		
Total	1.289E7	710			
Corrected Total	1.097E7	709			

Source: Author's SPSS Analysis

a. R Squared = .068 (Adjusted R Squared = .048)

From the table, we discover that the chemicals used are significantly the same; though the Post HOC test can still be used to check which of them is higher that the other. As for the actions taken with these chemicals, they significantly differ. There is no significant interaction between the chemicals and the actions taken with them. Having established that there is no significant difference amongst the chemicals, but by actions taken with these chemicals, they differ significantly. Post HOC test was adopted for ranking of these chemicals that appear to be the same but are not. Using the Post HOC test which is used in statistical hypothesis for classification, two treatments/items are said to have almost the same characteristic if the significance value is greater than 0.05 and the higher the value the closer the items in classification.

Post Hoc Tests of Chemicals used for grouting

Table 5.41: SPSS Generated Table for Post HOC Test

Multiple Comparisons

Data

LSD

(I) Chemicals used for grouting	(J) Chemicals used for grouting	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
CaCl	CaOH	.130476	12.7934863	.992	-24.988103	25.249055
	NaSiO4	9.633341	12.7934863	.452	-15.485238	34.751919
	AlFeSiO4	8.859571	12.9802624	.495	-16.625722	34.344864
CaOH	CaCl	-.130476	12.7934863	.992	-25.249055	24.988103
	NaSiO4	9.502865	12.7934863	.458	-15.615714	34.621444
	AlFeSiO4	8.729095	12.9802624	.501	-16.756198	34.214388
NaSiO4	CaCl	-9.633341	12.7934863	.452	-34.751919	15.485238
	CaOH	-9.502865	12.7934863	.458	-34.621444	15.615714
	AlFeSiO4	-.773770	12.9802624	.952	-26.259063	24.711523
AlFeSiO4	CaCl	-8.859571	12.9802624	.495	-34.344864	16.625722
	CaOH	-8.729095	12.9802624	.501	-34.214388	16.756198
	NaSiO4	.773770	12.9802624	.952	-24.711523	26.259063

Source: Author's SPSS Analysis

Based on observed means, the error term is Mean Square(Error) = 14730.596. From the table above, the chemicals were ranked thus from highest to lowest: $NaSiO_4$, $AlFeSiO_4$, CaOH and CaCl.

Table 5.42: Table for Homogeneous SubsetsActions taken

Multiple Comparisons

Data
LSD

(I) Actions taken	(J) Actions taken	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Permeability	Porosity	49.439567	2.7139083E1	.069	-3.844985	102.724120
	WHO and water qual	8.276015	1.9928583E1	.678	-30.851529	47.403558
	Erodibility	-65.671333*	2.2158968E1	.003	-109.177988	-22.164678
Porosity	Permeability	-49.439567	2.7139083E1	.069	-102.724120	3.844985
	WHO and water qual	-41.163553*	1.9928583E1	.039	-80.291096	-2.036009
	Erodibility	-115.110901*	2.2158968E1	.000	-158.617556	-71.604246
WHO and water quality	Permeability	-8.276015	1.9928583E1	.678	-47.403558	30.851529
	Porosity	41.163553*	1.9928583E1	.039	2.036009	80.291096
	Erodibility	-73.947348*	1.2314158E1	.000	-98.124820	-49.769876
Erodibility	Permeability	65.671333*	2.2158968E1	.003	22.164678	109.177988
	Porosity	115.110901*	2.2158968E1	.000	71.604246	158.617556
	WHO and water qual	73.947348*	1.2314158E1	.000	49.769876	98.124820

Source: Author's SPSS Analysis

Based on observed means, the error term is Mean Square (Error) = 14730.596. The mean difference is significant at the .05 level.

5.6 Discussion of Findings

5.6.1 General Discussions of Results of the Analyses

The efforts of governmental and non-governmental agencies in erosion control is unquantifiable, but erosion being a natural hazard cannot be stopped but can be better controlled/managed. Some control measures have prevailed in the past, majority of which are civil engineering construction of gutters, culverts, and other waterway channels. Most recently, the NEWMAP have widely practiced a combination of these civil engineering structures and bioremediation (Appendix Ia-1f). Most of these control measures look beautiful at the onset but shortly will start failing with resultant huge economic loss emanating from their failure (appendix 2a – 2f). this was therefore drilled into evaluation of grouting as a way of soil stabilization, which will not only make the soil stable and in-erodible but will also make the civil engineering structure constructed on them to stand the taste of time.

From the result of the analysis, it is clear that the study area which is the area of Anambra State underlain by Nanka sand geologic unit of Ameki formation, is highly gully prone (section 5.1 & figure 5.1). The analysis of the soil samples proved that the Nanka sand geologic unit is made up of higher percentage of sand than clay. This sandy nature supports its porosity and permeability recorded in Table 5.3 and 5.4 and the high porosity and permeability with friable nature of the soil noticed during field survey supports its high erodibility obtained from the laboratory analysis this finding is inline with the findings (Egboka *et al*. 2006 and Igbokwe *et al,* 2008). This also agrees with the responses of the two professionals interviewed at National Geoharzard Centre Awka.

The result of the test on erodibility especially with the introduction of a varying slopes makes it evident that slope (topography) is a factor of the soil erodibility, these agrees with the findings of several literature reviewed. A close look at the erodibility results in tables 5.5.1-5.5.5 shows a constant increase in erodibility with increase in slope that is all things being equal slope is directly proportional to erodibility. It is also evident that there is increase in erodibility with increase in the flow rate except for few outliers. This also agrees with the finding in literature which considered rainfall as the major agent of erosion in the study area. Considering the grouting chemicals, after grouting, the least erodible on the average was $AlFeSO_4$ followed by $NaSiO_4$, CaCl and finally CaOH. This trend continued throughout the five stations but for few outliers. It should be noted that while $AlFeSO_4$ was the best considering erodibility,$NaSiO_4$, and CaCl had lesser impact on porosity, on permeability and on water quality. Thus the outcome of the univariate analysis which has it that there is no significant difference in the chemicals used for grouting, though surprising, is true. Considering the physical and chemical characteristics of these grouting chemicals, which were analyzed to have no lucid variations, the application of the Post HOC test ranked $NaSiO_4$, best on the average amongst the whole chemicals used.

It is noteworthy that the affirmation in literature that the geology/characteristics of soil which is a major causative factor of gullying in the study area has been partially considered and not given the merited attention, was confirmed by the response of the professionals interviewed at the National Geohazard Centre Awka; who confirmed that the centre has not engaged in any chemical or geochemical analysis of the study area but are limited to geotechnical analysis and parameters of the study area. In fact in their own words "we don't have a chemical laboratory for elemental composition of soil and water". This calls for serious attention especially considering the fact contained in the findings of this work.

Finally, having confirmed the weak and friable nature of the Nanka sand unit of the Ameki formation underlying a large area surface of Anambra state, there is need to advance this research into developing a soil stabilization model for this weak zone to avert potential gully development and growth.

5.6.2 Discussions on the Environmental Implications of the Findings

The physical and solid characteristics of $NaSiO_4$ ranked the best of the four grouting chemicals tested, agreed with the opinion Reuben (2003) on what a chemical grouting material should be (a powder readily soluble in water, inexpensive, stable at all anticipated storage conditions, non-toxic, non-corrosive, non-explosive, low viscosity, able to withstand appreciable dilution with water and unaffected by chemicals normally found in groundwater. Also according to the Nigerian Industrial Standard (NIS, 2007), in their Nigeria Standard for Drinking Water Quality, sodium which is among the element that are significantly higher than WHO standard and original water quality in the grouting test with $NaSiO_4$, was confirmed to have no health effect (NIS, 2007).

There are lots of works on the implications of addition of silicon and sodium which are the main excesses of the application of $NaSiO_4$ as a grouting agent in the soil. In the words of Moayedi, Huat, Moayedi, Asadi and Parsaie (2011), "Soft clay soil can be stabilized by the adding of small percentages, by weight, of sodium silicate, thereby producing an improved construction material and enhancing many of the engineering properties of the soil without causing danger to the environment". In order to explain this, they subjected one of the most frequently occurring minerals in clay deposits, namely, kaolinite, to a series of tests. As sodium silicate stabilization is most often used in relation to construction, the tests were chosen with this in mind. As results, addition of 5mol/L sodium silicate showed the highest unconfined compressive strength (UCS) results. However the effect of chemical molarities on UCS become less and less, with longer curing time. This was also supported by the work of Fang and Daniel (2006).

Jian (2011) found that although silicon (Si) has not been recognized as an essential element for plant growth, the beneficial effects of Si have been observed in a wide variety of plant species. The beneficial effects of Si are usually expressed more clearly in Si-accumulating plants under various abiotic and biotic stress conditions. Silicon is effective in controlling various pests and diseases caused by both fungi and bacteria in different plant species. Silicon also exerts alleviative effects on various abiotic stresses including salt stress, metal toxicity, drought stress, radiation damage, nutrient imbalance, high temperature, freezing and so on. These beneficial effects are mainly attributed to the high accumulation of silica on the tissue stirface although other mechanisms have also been proposed. To obtain plants resistant to multiple stresses, genetic modification of the root ability to take up Si has been proposed by Jian.

Also, Kermani, Hassani, Aflaki, Benzaazoua and Nokken (2015), supported the adoption of $NaSiO_4$ as a grouting agent stating that it is more ecofriendly than other silicates. To this end the findings of this study has been buttressed and justified.

5.7 Development of a Project Management Framework for Execution of Grouting as Gully Erosion Control Measure in Anambra State.

This section discussed the development of a project management framework for execution of grouting as gully erosion control measure in Anambra State. It detailed what was developed, why it was developed, how it was developed and for whom it was developed.

5.7.1 How was the Framework Developed?

The figure 5.2, being the framework for application of grouting in gully erosion control projects as was developed by this study, was structured in line with the basic stages of a project management plan as was stipulated in PMI (2013) and buttressed in the works of Arif ud (2016) and Mhando, Mlinga, & Alinaitwe (2017) to include the following stages: Initiation Stage, Planning Stage, Execution Stage, Monitoring and Evaluation Stage and finally the Conclusion Stage or Project Closure for terminal projects. This format was adopted and modified by the researcher in developing the framework for managing grouting as a gully erosion control measure because every gully erosion control procedure is a project of its own and grouting is not an exception. Also this format has been adopted by the International Project Management Professionals as the basic stages of any project management plan. The researcher therefore infused all the processes were undergone to establish the practicability of grouting in the evaluation conducted into these five basic stages of a project management plan to arrive at this framework.

5.7.2 How does the Framework Operate?

The foremost action of any project is its initiation. In the same vein, the first stage set in the framework developed is the Initiating Stage, followed by the Planning Stage, Execution Stage, Monitoring and Evaluation Stage and finally the Conclusion Stage.

The Initiating stage has three vital actions or steps which includes: Step 1 - Project Justification ; here the agency in-charge uses any convenient method to establish that the gully erosion control project is a need gap, tentatively through sourcing the opinion of the general public and other stakeholders and the review of earlier similar projects. Step 2 - Project confirmation; this is merely the confirmation of this established need gap by the contracting agency or the client. Step 3 - TOR Development; is the agreement (Terms of Reference) reached by the client and the executing agency on what should be and what should not be part of the project.

The Planning Stage is the stage that shoulders the largest chunk of the work. From the framework, there are six vital actions or steps enlisted here Step 1 - Mapping of the affected area to determine the area coverage to be treated. Step 2 - Analyses of the physical and chemical composition of rock(s) to determine their physical and chemical characteristics. Step 3 - Enlistment of possible grouting chemicals and determining their concentration and amount(s) to be used for the grouting proper. Step 4 - Impact Analyses; the essence of this is to ascertain the potential impacts of the grouting process and the grouting chemicals on the environment and to strengthen the decision to carry-on with the project and the enlisted chemicals. Step 5 - Adoption of a possible method of application there are many available grouting methods like, pore injection, open spray, jet injection and compaction grouting. It should be noted that this step was not really considered strictly in this research project because everything was done in the laboratory, the researcher made use of available techniques and affordable space such that the chemicals were administered as open spray. But ordinarily the executor should while planning consider critically the type of chemical selected, the physical and chemical characteristics of the area to be treated and the available fund and instruments in determining the grouting method to be adopted. Step 6 - Cost-Benefit Analyses; here the executor of the project considers the cost and the benefits to finally decide to either go to site for the execution proper or to quite.

Executing Stage is the stage where the selected and confirmed chemical grout is applied to the mapped out area in the stipulated volume and concentration using the most appropriate method. Two vital action or steps were enlisted in the framework: Step 1 - Preparing the chemicals and moving the equipments to site; and Step 2 – Commencement of the application of the chemicals proper.

Monitoring and Evaluation Stage is just a test of accuracy or level of success of the already executed grouting process. Here three vital actions or steps were enlisted, which includes: Step 1 - ensuring that the entire area is covered. Step 2 - checking the level of improvement achieved tentatively through erodibility variation test(s) and finally Step 3 – weighing the clients satisfaction through stakeholders feedback examination(s). If the total area is covered with significant increase in resistance of the rocks, decrease in erodibilities and good client satisfaction; the process is considered sound the executor concludes. Where it is not sound, he returns to the planning and execution stages again.

Conclusion Stage is the final stage of any project. For a grouting of gully erosion project three vital steps were enlisted as follows: Step 1 – Determining the method(s) of sustaining the achieved success, possibly by educating the inhabitants of the grouted area or periodically reapplying the chemicals and any other methods to be determined by the executor. Step 2 - Keeping records of all the proceedings of the project and finally Step 3 - Conclude the Project, most time by leaving the site, moving out of equipments used, commissioning of project by the client agency and other processes of project conclusion the executor may deem necessary.

5.7.3 Summary of Framework and its Link to the Present Research Project

In summary, the framework can be juxtaposed with the present research project/study as each stage depicts a stage in the research project. While the initiation stage is involved the suggestion of the topic by the researcher and subsequent establishment of the need gap through the literature review; the planning stage is actually the proposal stage were the researcher says it all about his scope, aim and objectives and the methods adopted to pursue them; the execution stage is the field and laboratory works proper; the monitoring is by the research project supervisor and the evaluation is the intermittent presentations and subsequent corrections at the Departmental and Faculty levels with the client feedback and satisfaction being the comments and corrections of the examiners; the conclusion is the final presentation and submission of the updated and corrected dissertation. The vital steps of each stage must be strictly observed to ensure a result oriented execution.

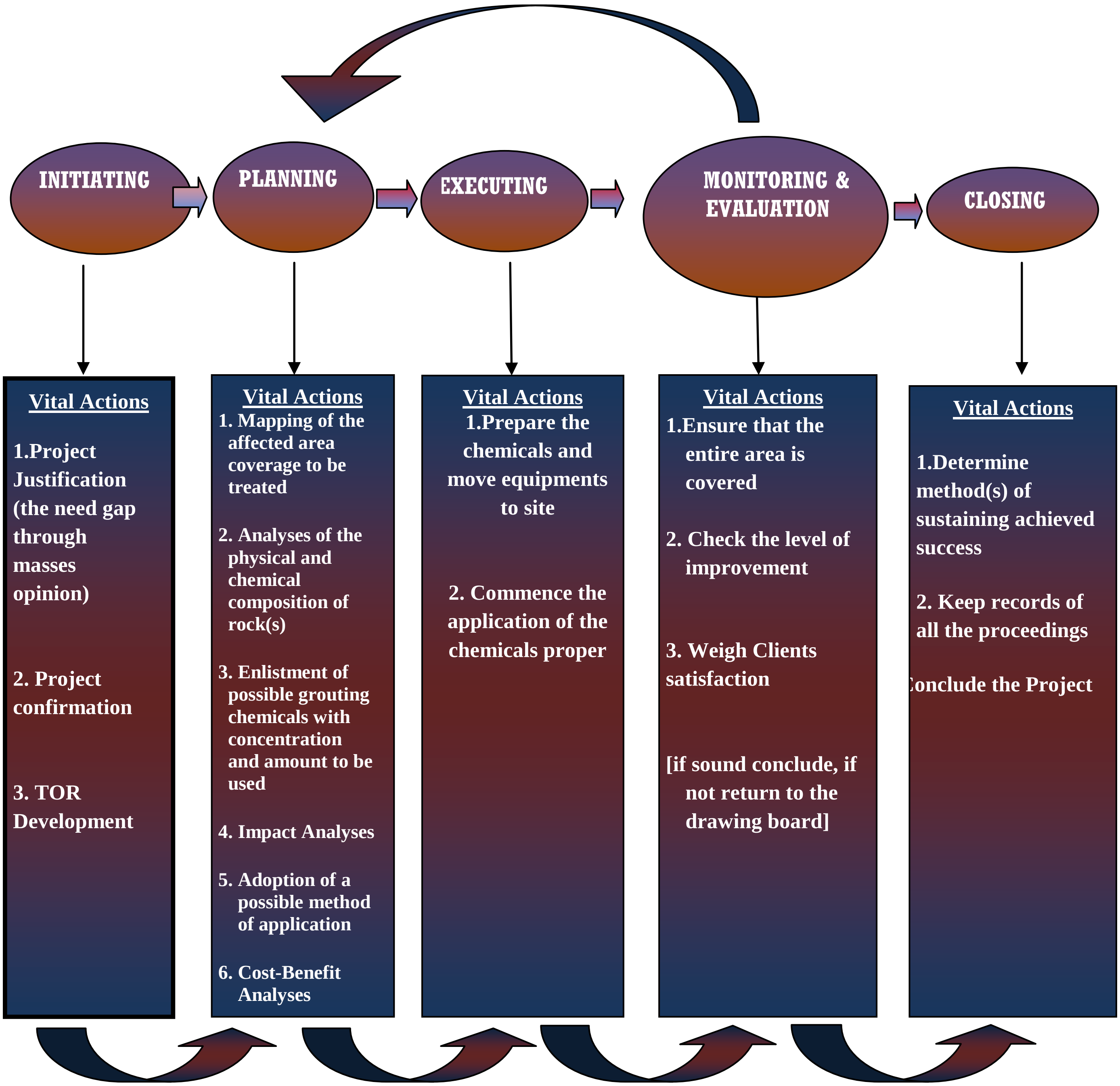

Fig. 5.2 : Project Management Framework for Execution of Grouting as a Gully Erosion Control Measure in Anambra State.

The figure 5.2 is the developed project management framework for execution of grouting as gully erosion control measure in Anambra State. This is one of the main objectives of this whole study, the eighth and last objective of this study as stipulated in section 1.3 of chapter one. This framework was developed to assist the governmental and non-governmental agencies who are into gully erosion control and who may be interested in adopting grouting as a control measure. It will also act as an instrument to reckon with for researchers seeking to advance the course of grouting in gully erosion control.

5.8 Review of Objectives of the Study

A critical consideration of the objectives of this study as stated earlier in chapter one was thoroughly carried out and these objectives were accomplished as follows:

- Objective one was achieved in section 5.1 of the data presentation and analyses, with detailscontained in table5.1 and figure 5.1, where the active gully sites within the study area (Nanka Sands Geologic Unit of Anambra State) were identified and shown in a map.
- Objective two was achieved in section 5.2 with details contained in table 5.2. The chemical composition of the samples collected from the sampling stations were determined and summarized in a table.
- Objective three was answered by the testing o f hypothesis 1. It was found that there is no significant difference in the chemical composition of the soils of the gully erosion sites sampled within Nanka Sands geologic unit in Anambra State.
- Objective four was answered by the testing of hypothesis 2. It was found that there is no significant difference in the physical characteristics of the soils of the gully erosion sites sampled within Nanka Sands geologic unit in Anambra State.
- Objective five was answered by the testing of hypothesis 3. It was found that there is significant difference between the pre-grouting and post-grouting porosities and permeabilities of the rocks of the area.
- Objective six was answered by the testing of hypothesis 4. It was found that there is significant difference between pre-grouting and post-grouting erodibilities, that is grouting affects erodibiility (reduces erodbility and increases resistance).
- Objective seven was answered by the testing of hypotheses 5 and 6. It was found that the grouting chemicals impacted the water quality as there were significant differences between the water quality after grouting and the water quality before grouting. The water quality after grouting also varied with the WHO standard of portable water.
- Objective Eight was answered by the framework developed in section 5.7 of the work.

- Finally, the aim of the study which is to evaluate grouting with a view of identifying the best chemical to adopted for stabilization of Nanka sand geologic unit was accomplished in section5.7 with Sodium Silicate being recommended as the best of the four chemicals analyzed for grouting in the study area

CHAPTER SIX

SUMMARY, RECOMMENDATION AND CONCLUSION

This chapter presents the summary of all the findings of this study, highlighted the contribution(s) to the already existing body of knowledge, made some recommendations and drew conclusion from the findings. Also highlighted were suggested areas of further study.

6.1 Summary

The following summaries were drawn from the results of the field survey, laboratory analyses and statistical analyses in the course of the study:

The findings from the field survey has it that Nanka sand which is a major geologic unit dominating the Ameki formation in the study area harbors majority of the gully sites in Anambra State due to its friable geology, in a wet climate zone with irregular topography as can be confirmed from literature. This finding is in tandem with the findings of the earlier researchers as contained in the literature review which is one of the major reasons why this study concentrated on Nanka sand.

Responses from the inhabitants of the gully prone areas and the professionals interviewed at the National Geoharzard Centre Awka, showed that most times the government and non governmental agencies over look gullies when they are still young and small but that is when they are supposed to be suppressed and controlled. They only respond when these gullies have grown so big and the attendant effects on the masses have been pronounced. At this stage the fund needed to solve the problem becomes possibly huge and sometimes too cumbersome for the government alone to handle.

From the results of the water analyses after grouting with the various chemicals, it became obvious that the addition of $AlFeSiO_4$ increases the hardness and conductivity of the water percolating through it. The addition of $NaSi0_4$ as a grouting chemical increases the hardness, turbidity and conductivity of the water percolating through it. The addition of CaCl as a grouting chemical reduces the hardness and conductivity of the water infiltrating through it but acidifies the water more. In addition to expect increase in calcium content, the application of CaOH as a grouting chemical increases hardness, turbidity and conductivity of the water infiltrating through it.

There is significant difference in the pre-grouting porosity, permeability, erodibility, and water quality and the post-grouting porosity, permeability, erodibility, and water quality.
There is significant impact of the four grouting chemicals evaluated on the water quality leading to its great variation with the WHO standard.

6.2 **Contribution to Knowledge**

This study from its findings and conclusion has contributed to the already existing body of knowledge in the following ways:

1. The study proved through laboratory analyses of variation in erodibility that use of chemical grouting reduces the erodibility of the rocks of Nanka Sands.
2. Under favourable topography and climatic conditions (gentle slopes and low rainfall intensity), the application of chemicals like $NaSiO_4$, $AlFeSiO_4$, CaCl and CaOH significantly reduce the erodibility of the soil, as shown in the erodibility test results.
3. Following the water quality test results, sodium silicate ($NaSiO_4$) was proven by this study to be the best grouting chemical amongst the four chemicals tested ($NaSiO_4$, $AlFeSiO_4$, CaCl and CaOH). This is because it has a high ability to hold the soils together, increase its resistance and reduce its erodibility with limited impact on the water quality.
4. The application of chemical grouts ($NaSiO_4$, $AlFeSiO_4$, CaOH and CaCl), was also found by this study to reduce significantly the porosity and permeability of the rock samples.
5. Through the result of the variation of the angle of slope for the erodibility test, it was proven by this study that topography is a very critical factor in the growth of gullies on Nanka Sandsgeologic unit in Ameki Formation of Anambra state as the erodibility of the samples significantly increased with increase in angle of slope.
6. The comparative analyses of the chemical and physical characteristics of the rock samples done in this study found that the chemical and physical characteristics of Nanka Sands do not differ significantly with changes in location.

7. The test for water quality before and after grouting done in this study, found that the application of $NaSiO_4$, $AlFeSiO_4$, CaOH and CaClfor soil grouting and stabilizationsignificantly impacts the water quality.

8. The study developed a project management framework for execution of grouting as a gully erosion control measure in Anambra State.

6.3 **Recommendation**

The study made the following recommendations:

1. The governmental and non governmental agencies like NEWMAP, National Geohazards, among others, who are into gully erosion control should embrace chemical grouting method for effective gully erosion control in Anambra State.

2. Haven proven the suitability of grouting as a gully erosion control method, areas with high proximity to severely gullied sites should be grouted in order to prevent gullying in the State.

3. In selecting chemicals for grouting in gully control projects, those that totally reduce porosity and permeability of the soil should not be adopted to avoid causing flooding and other problems.

4. Timely response should be ensured in gully erosion control. Also the masses in any area of gully occurrence should be educated to report to appropriate agencies for immediate intervention.

5. The construction of gully control structures should be done and completed within a stipulated time to avoid excavating and leaving the excavated soils open, thereby causing more gullies.

6. The developed project management framework be strictly followed and all the vital actions strictly adhered to for successful grouting process to be ensured.

6.4 Conclusion

For the findings of the study made above, the study concludes that chemical grouting though a new method in this part of the world increases resistance of the soil, reduces erodibility and should be encouraged within and outside the study area to better manage gully erosion.

The adoption of chemical grouting as a control measure to gully erosion should be done with utmost care and sensitivity, especially in the area of selecting the grouting chemicals as it has been proven from this study that these chemicals may impact the groundwater.

Also to be considered is the concentration to the precipitating chemicals to be used. This is because dome of thee chemicals when not well dissolved may over precipitateand after drying block all the interstitial spaces thereby drastically reducing porosity and permeability which may result flooding.

Finally, the study concluded that amongst the four grouting chemicals used for the experiment, the best on the average is $NaSiO_4$.

6.5Areas of Further Study

This study is not a terminal research work but just the starting of a new area in erosion control within the study area. Therefore more work needs to be done to improve, support or disprove the findings of this study. To this end, the following areas of further study were suggested by the researcher:

1. The study should be done in a larger scale and or site not in the laboratory to ascertain the feasibility of insitu chemical grouting as a control measure.

2. There should be a thorough cost-benefit analysis on this chemical method of gully erosion control.

3. There is need to analyze with other chemicals, silicates, fly ash, etc especially the fly ash which is already a waste from thermal plants and will form a ready raw material to be used for this process if proven.

4. A detailed work on the impacts of chemical methods of grouting is worth doing to establish a model for any type of chemical to be used to avoid facing the challenges of flooding due to extreme reduction in porosity and permeability.

5. Research into slope stabilization is necessary as this is essential for effective grouting to take place

References

Abdulfatai, I. A. , Okunlola, I. A. , Akande, W. G. , Momoh, L. O. , & Ibrahim, K. O. (2014). Review of Gully Erosion in Nigeria: Causes, Impacts and Possible Solutions. *Journal of Geosciences and Geomatics,* 2(3), 125-129.

Adrian, W. J. (1973). *A Comparison of a Wet Pressure Digestion Method With Other Commonly Used Wet And Dry–Ashing Methods.*16th, Edition, United States of America, Baltimore, Maryland.Analyst 98,213.

Afigbo, A.E. (1981). *Ropes of sand; Studies in Igbo history and culture, Nsukka:* University of Nigeria press.

Ajaero, C.K. & Mozie, A.T. (2011). The Agulu-Nanka gully erosion menace In Nigeria. What does the future hold for population at risk? Institute for environment and human security: United Nations: University Munich.

Akpokodje, E.G., Tse Akaha, C.& Ekeocha, N. (2010). "Gully erosion Geo-hazards in Southeastern Nigeria and management implications" *Scientia Africana.*9(1), 20 – 36.

Albert, A. A., Samson, A. A., Peter, O. O. & Olufunmilayo, A. O. (2006)."An Assessment of the Socio Economic Impacts of Soil Erosion in South-EasternNigeria, Shaping the Change".*FIG. 23 Congress Munich*, Germany, 12.

American Public Health Association (1995).*Cold–Vapour Atomic Absorption Spectrometric Method, Standard Methods for the Examination of Water and Wastewater (3112B)*, 20th Edition, APHA, AWWA,WEF.

Anagnostopoulos, C. A. & Chatziangelou, M. (2008). "Compressive Strength of Cement Stabilized Soils, a New Statistical Model", *The Electron. J. Geotech. Eng.,* 13, Bund. B.

Arif ud, D. (2016).Evaluation of Project Failure Causes in a Community- Based Organization: a Case Study in Pakistan. PM World Journal 5(4) 1-9. April 2016 www.pmworldjournal.net

Babalola,O., Jimba,J.C., Maduakolam,O. & Dada, O.A. (2003). Use of vetiver grass for soil and water conservation in Nigeria.*Proc. Third Intern. Conf. on Vetiver and Exhibition, Guangzhou, China,* October 2003. 293-309.

Baffour, N. K.; Attakora, E. T.; Ofori, E. & Antwi, B.O., (2012).Estimationof Soil erodibility and rainfall erosivity for the Biemso basin, Ghana.

Bezdicek, D.F., Papendick, R.I.& Lal, R. (1996). Introduction: Importance of soil quality to health and sustainable land management. In Doran, J.W.and Jones, A.J. (eds.): *Methods for Assessing Soil Quality*. SSSA Spec. Publ. 49. SSSA, Madison, WI, 1-8.

Bromes, B. B.; Holm, G. & Bredenberg, H. (1999).“Dry Mix Method for Deep Soil stabilization”, Rotterdam, *Balkema*, ISBN 90 5809 108 2.

Bruce, D. A. (2000).*An Introduction in Deep soil Mixing Method as uses in Geotechnical application.*US department transportation Federal Highway Administration.

Brussaard, L. (1994). Interrelationships between biological activities, soil properties and soil management. In Greenland, D.J.and Szabolcs, I. (eds.). *Soil Resilience and Sustainable Land Use.* CAB Int., Wallingford, Oxon, UK, 309-352.

Bryan, R. B. (2000). The Concept of Soil Erodibility and some problems of assessment and Application. *Catena.*16:393-412.

Bund, H.; Ingles, O. G. & Metcalf, J. B. (1973).“*Soil Stabilization*”, John Wiley and Sons, New York.

Calcium Chloride Institute, (1953).*Calcium Chloride for Stabilization of Bases and Wearing Courses.*Report CM-1.

Cavey, B. (2006). Gully erosion: *Department of National Resources and water Fact Sheets* L81. 1–4.

Committee on Grouting (1980). Preliminary glossary of terms related to grouting, *J Geotech. Eng.* Div. ASCE, 106(GT7):803–805.

Dalrymple, T. (1976).Flood frequency Analysis.*Nigeria Geological Survey*

Davenport, D. W., Breshears, D. D., Wilcox, B. P. & Allen, C. D. (1998). Viewpoint: Sustainability of pinon-juniper ecosystems-A unifying perspective of soil erosion thresholds. *Journal of Range Management.* 51:231-240.

David-Chyddy, E. (2016). *At a time when other states are reclaiming land from the sea, Anambra is losing* its landmass to erosion.*This Day News Oline*.https://www.thisdaylive.com/index.php/2016/10/31/the-menace-of-erosion-in-anambra-2/

Edil, T. B. (2003). Recent advances in geotechnical characterization and construction over peat and organic soils.*Proceedings 2nd International Conference on Advances in Soft Soil Engineering and Technology*. (Eds). Huat et al. Malaysia: Putrajaya, 3-25.

Egboka, B. C. E.; Nfor, B. N. & Banlanjo, E. W. (2006): Water Budget Analysis of Agulu Lake in Anambra State, Nigeria. *Journal of Applied Sciences and Environmental Management*. 10 (3): 27 – 30.

Egboka, B. C. E.; Nwankwor, G. I. (1985). The hydrogeological and geotechnical parameters as agents for gully type erosion in the Rain-Forest Belt of Nigeria . *Journal of African Earth Sciences,* 3(4): 47-425.

Egboka, B.C. E. (1985).*Water Resources problems of Enugu area, Anambra State Nigeria,* IAHS Publishers 153: 96 – 106.

Egboka, B.C.E. & Nwankwo, G.I. (1985).The hydro geological and geotechnical parameters and agents for expansion of Agulu-Nanka Gully, Anambra State Nigeria.*Journal of African Earth Science,* Vol.3 No.4 pp. 417 – 425.

Egboka, B.C.E. & Okpoko, C. I. (1984).*Gully erosion in Agulu-Nanka Region of Anambra State Nigeria*. IAHS Publishers.

Egboka, B.C.E. & Okpoko, E.I. (1984): *Gully Erosion in the Agulu-Nnaka region of Anambra State, Nigeria.Challenges in African Hydrology and Water Resources* (Proceedings of the Harare Symposium, July 1984). IAHS Publications.no.

Egboka, B.C.E. &Okpoko, E.I.(1984). Gully erosion in the Agulu-Nanka region of Anambra State, Nigeria. *Proceedings of the Harare Symposium,* Publication number *144, July, 1984.*

Egboka, B.C.E. (1993). *The raging war, erosion, gullies and landslides ravage Anambra State,* Awka: God's Time Printing and Publishing Co.

Egboka, B.C.E. (2004). Distress call and plea to Senate Committee for urgent Actions against Floods: Soil/Gully Erosion/Landslides Disaster in the South East. *Paper presented to the Senate Committee on Environment, Roads/Erosion Senate Delegation to the South East*.

Egboka, B.C.E.(1993). Types and Causes of Soil Erosion, paper presented at the Workshop of Soil Erosion, Nigeria Society of Engineers, Enugu.

Egboka, B.C.E., Orajaka, I.P. & Nwosu, V.C. (1985).Redox activities as additional causative factors in generation of Gully Erosion in Agulu-Nanka area of Nigeria.*Science of total Environment (stoten)*. 53(3): 217 – 232.

Ehiorobo J.O & Izinyon O.C (2011).Measurement and documentation for Flood and Erosion Monitoring and control in the Niger Delta States of Nigeria, FIG working week 2011.

Ezezika O.C & Adetona O, (2011).Resolving the gully erosion problem in Southeastern Nigeria: Innovation through public awareness and community-based approaches. Journal of Soil Science and Environmental Management 2(10): 286-291, 25 October, 2011.

Fang, H. Y. & Daniels, J. L. (2006).*Introductory Geotechnical Engineering.An environmentalperspective.* Taylor and Francis, pp. 75-114.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L. & Holling, C.S. (2004). Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. *Annual Review of Ecology, Evolution, and Systematics*35: 557–581. doi:10.1146/annurev.ecolsys.35.021103.105711.

Folke, C., Carpenter,S., Elmqvist, T., Gunderson, L., Holling C.S., & Walker, B. (2002). Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. *Ambio*31 (5): 437–440. doi:10.1639/0044-7447(2002)031[0437:rasdba]2.0.co;2. PMID 12374053.

Forman, R. T. T. & Godron, M..(1986). *Landscape Ecology*. John Wiley & Sons, New York.

Fufa, S. D.; Strauss, P. & Schneider, W. (2002).Comparisonof Erodibility of Some Hararghe Soils Using Rainfall Simulation. Community Soil Science Plant Analyses 33(3&4):333-3348.

Giordano, A., Bonfils, P., & Briggs, D. J. (1991).Menezes de Sequeira E., Roquero D.L.C., Yassoglou A. the methodological approach to soil erosion and important land resources evaluation of the European community.*Soil Technology* (4), 65-77.

Gonzáles-Hidalgo J. C., Peňa-Monné J. L. &de Luis, M. (2007).A review of daily soil erosion in W estern Mediterranean areas.CATENA, Elsevier 71(2007):193-199.

Gunderson, L.H. (2000). Ecological Resilience in Theory and Application.*Annual Review of Ecology &Systematics*31(1), 425. doi:10.1146/annurev.ecolsys.31.1.425.

Hashim, R. & Islam, S. (2008a).Properties of stabilized peat by soil cement column method" *Electron. J. Geotech. Eng.*, 13,

Hashim, R. & Islam, S. (2008b).Stabilized Peat by Deep Mixing Method: A Critical Review of the State of Practice.*The Electronic J. Geotech.Eng.*, 13.

Herrick, J. E., & Wander, M. M. (1998). Relationships between soil organic carbon and soil quality in cropped and rangeland soils: The importance of distribution, composition and soil biological activity. In:*Soil Processes and the Carbon Cycle. R.*

http://links.onlinenigeria.com/anambraadv.asp?blurb=195

http://newmap.gov.ng/newmap-tackling-erosion-and-improving-lives-using-the-watershed-concept/

Hudson N (1995).Soil Conservation.Third Edition. B.T. Batsford Limited. U.K. pp. 290.

Igbokwe, J.I., Akinyede, J.O., Dang, B., Alaga, T., Ono, M.N.; Nnodu, V.C. & Aneke, L. O. (2008). Mapping and Monitoring of the Impact of Gully Erosion in Southeastern Nigeria; with Satellite Remote Sensing and Geographic Information System.*The International Archives of the*

Photogrammetry Remote Sensing and Spatial Information Science,Beijing 2008.37(*88*), 865 – 871.

Igbokwe, J.I., Akinyede, J.O., Dang, B.A., Alaga, A.T., Nnodu, V.C., Ojiako, J.C., Obienusi, E.A., & Onwuka, S.U. (2008): Estimating Soil Loss in Gully Erosion in Southeastern Nigeria from Remotely sensed Imageries.*Nigeria Journ. of Space research*, (5), 135-151.

Igbokwe, J.I., Ojiako, J.C., & Nnodu, V.C. (2003). Monitoring, Characterization and controlling of flood water erosion using remote sensing techniques. *Proceedings of the Technical Session of the 38th Annual General Meeting and Conference of Nigerian Institute of Surveyors, Lokoja*.

Igbozurike, U.M. (1977). Socio-economic Impact of Soil: Paper presented at *The National Seminar on Erosion ravages in South Eastern Nigeria; Quest for Solution*, Owerri.

Igwe, C. A. & Stahr, K. (2004). Water-stable aggregates of flooded inceptisols from southeastern Nigeria in relation to mineralogy and chemical properties. *Australian Journal of Soil Research* (42): 171-179.

Igwe, C. A. (1999). Land use and soil conservation strategies for potentially highly erodible soils of central-eastern Nigeria. *Land Degradation Development* (10): 425-434.

Igwe, C. A., Akamigbo, F. O. R. & Mbagwu, J. S. C. (1999).Chemical and mineralogical properties of soils in southeastern Nigeria in relation to aggregate stability.*Geoderma* (92): 111-123.

Igwe, C. A., Zarei, M. & Stahr, K. (2009). Colloidal stability in some tropical soils of southeastern Nigeria as affected by iron and aluminium oxides. *Catena*, 2009(77): 232-237.

Igwe, C.A. (2005). Erodibility in relation to water-dispersible clay for some soils of eastern Nigeria. Land Degradation and Development, 2005(16), 87-96.

Izinyon, O.C.; Ehiorobo, J.O. & Adedeji, A.C. (2013).Appraisal of Structural and Non-Structural Approaches to Gully Erosion Control a Case Study of Queen Ede Gully Site in Benin City.*Gully Erosion Control*. *Pp.* http://cayac.blogspot.com.ng/2013/02/gully-erosion-control.html

Jian, F. M. (2011).Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses.*Soil Science and Plant Nutrition*.50 (1), 11-18.

Karlen, D. L., Mausbach, M.J., Doran, J. W., Cline, R. G., Harris, R. F. & Schuman, G. E. (1997). Soil quality: A concept, definition, and framework for evaluation. *Soil Science Society Am. Journal* 61:4-10.

Karol, R. H. & Dekker, M. (1983).*Chemical Grouting*. USA: New York and Basel Inc.

Karol, R. H. (1959).Soils Engineering Research-Creep Tests, Nov. 30, 1959, American Cyanamid Co., Wayne, N.J.

Kazemian, S. (2009).Assessment and Comparison of Grouting and Injection Methods in Geotechnical Engineering, *Eur. J. Sci. Res*. ISSN 1450-216X, 27(2): 234-247.

Keller, K. (2009). Ground improvement Techniques.*Geotechnical Construction*,Retrieved on 12 Sept 2009 at www.haywardbaker.com

Kermani, M.;Hassani, F. P.; Aflaki, E.; Benzaazoua, M. &Nokken, M. (2015). Evaluation of the effect of sodium silicate addition to mine backfill, Gelfill − Part 1.Journal of Rock Mechanics and Geotechnical Engineering.7 (3), 266-272.

Lal, R. & Elliot, W. (1994).Erodibility and Erosivity.in Lal, R. (ed.). 1994. Soil Erosion Research Methods. St. Lucie Press, Delray Beach, FL. Lal R, Steward BA (1994). Soil Processes and Water Quality: Lewis. p. 370.

Mabbutt, J.A. (1984). A new global assessment of the status and trends of Desertification.*Journal of Environmental Conservation*, 11 (2), 106.

Magill, D. & Berry, R. (2006).*Comparison of Chemical Grout Properties*Avanti International and Rembco Geotechnical Contractors.

Mhando, Y. B.; Mlinga, R. S. & Alinaitwe, H. M. (2017). Perspectives of the Causes of Variations in Public Building Projects in Tanzania, *International Journal of Construction Engineering and Management* , Vol. 6 No. 1, 2017, pp. 1-12. doi: 10.5923/j.ijcem.20170601.01.

Miller, G.T. (1990). Living in the environment.*An Introduction to Environmental Science 6th Edition,* Wadsworth Publishing Co. Belmont (10), 224 – 225.

Mitchell, J. K. (1993). *Fundamental of soil behaviour*, John Wiley and Sons, New York.

Mitchell, J. M. & Jardine, F. M. (2002).*A guide to ground treatment* CIRIA C573, ISBN 0 86017 5731.

Moayedi, H.; Huat, B.; Moayedi, F.; Asadi, A.& Parsaie, A. (2011). Effect of Sodium Silicate on Unconfined Compressive Strength of Soft Clay.*Electronic Journal of Geotechnical Engineering*. 16, 289-295. https://www.researchgate.net/publication/245586849_Effect_of_Sodium_Silicate_on_Unconfined_Compressive_Strength_of_Soft_Clay

Morgan, R. P. C. (1995). Soil Erosion and Conservation.Second Edition. LongmanGroup Ltd. U.K..pp. 290.

Morgan, R. P. C. (2001). A simple approach to soil loss prediction: a revised Morgan-Morgan-Finney model. *Catena* 44(4): 305-22.

Morgan, R.P.C. (1986). *Soil Erosion and Conservation* in Davidson, D.A. (eds.) Longman Scientific and Technical Studies London; 29 – 33.

Morgan, R.P.C. (2001). A simple approach to soil loss prediction: a revised Morgan-Morgan-Finney model. *Catena* 44(4), 305-22.

Moseley, M. P. & Kirsch, K. (2004). *Ground Improvement*, 2nd edition Spon Press in an imprint of Taylor and Francis group, U. K.

Moseley, M. P. (2000). "*Ground Improvement*" CRC Press, Inc ISBN 0 7514 0073 4.

Murat, R.C. (1972). Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In: T.F.J. Dessauvagie and A.J. Whiteman (eds.). *African Geology*, University of Ibadan press, Nigeria. 251- 266.

National Geohazards Centre Awka, (2017).Geologic Map of Anambra State Showing Nanka Sand and other formations underlying the State.

National PopulationCommission(2006). 2006 Census National Population Commission, Federal Republic of Nigeria.

Nearing, M. A. (1991).A probability model of soil detachment by shallow turbulent flow.*Trans. ASAE* (34) 81-85.

Nigerian Industrial Standard (2007).Nigerian Standard for Drinking Water Quality. NIS (554:2007), 16-17.

Niger-Techno (1978).*Soil Erosion Control in Imo and Anambra States*.

Nonveiller, E. (1989). *Grouting Theory and Practice*, Elsevier Science Publication Company, Inc., New York, US.

Nwajide, C.S. & Hoque, M. (1979). Trace Fossils from the Nanka Formation South Eastern Nigeria. Geologic on Myibown (58), 85-88.

Nwajide, C.S. (1977). The Stratigraphy and Sedementology of the Nanka Sand (Unpublished M. Phil. Thesis) University of Nigeria Nsukka.

Nwajide, C.S. (1980). Eocene tidal Sedimentation in the Anambra Basin, Southern Nigeria.Sedimentary geology. (25), 189-207.

Nwajide, C.S. (2005). Anambra Basin of Nigeria: Synoptic Basic Analysis as basis for hydrocarbon prospectively. In: C.O. Okogbue (ed). Hydrocarbon potential of the Anambra Basin. Great Ap Express, Nigeria. 1-46.

Nwajide, S.C. & Hogue, M. (1979).Gulling Processes in South EasternNigeria.*Nigerian field Journal* 44(2), 64 – 74.

Nyakatawa, E. Z.; Reddy, K. C.; & Lemunyon, J. L. (2001).Predicting soil erosion in conservation tillage cotton production systems using the revised universal soil loss equation (RUSLE).*Soil and Tillage Res*. 57(4): 213-24.

Obiadi, I.I., Nwosu, C.M., Ajaegwu, N.E., Anakwuba, E.K., Onuigbo, N.E.; Akpunonu, E.O. & Ezim, O.E. (2011). Gully erosion in Anambra State, South East, Nigeria, Issues and Solutions. *International Journal of Environmental Science* 2(2), 795 – 805.

Obidimma, C. E. & Olorunfemi, A (2011). Resolving the Gully Erosion Problem in Southeastern Nigeria: Innovation Through Public Awareness and Community–Based Approaches.*Journal of Soil Science and Environmental Management,*286-287.

Ofomata, G. E. K. (1975). Soil erosion.*Nigeria in maps, Eastern States*, Ethiope Publishing House, Benin City Nigeria.

Ofomata, G. E. K. (1981a). The Management of Soil Erosion Problems in Nigeria. Paper presented at the *24ih Annual Conference of the Nigerian Geographical Association,* Kano, April 6-10, 1981 (In Press).

Ofomata, G. E. K. (1981b). Actual and Potential erosion in Nigeria and measures for control.*Soil Science Society of Nigeria Special Monograph*, (1): 151-165.

Ofomata, G.E.K. (1964). Soil Erosion in the Enugu Region of Nigeria.*African Soils,* 4(2): 289-348.

Ofomata, G.E.K. (1965). Factors of Soil Erosion in Enugu Area of Nigeria, *Nigerian Geographical Journal*, (8): 45 – 59.

Ofomata, G.E.K. (1967). Some observations sur. I'eboulement d'Agwu, *Nigeria Oriental Bulletin* de I'IFAN Series A: XXVIII Pp. 433 to 443.

Ofomata, G.E.K. (1973); Village erosion at Ozuitem, East Central State of Nigeria.*Ikenga*.11(1): 64-74.

Ofomata, G.E.K. (1985). Soil erosion in Nigeria: the Views of a Geo-morphologist. *University of Nigeria Inaugural Lecture Series (7)*.

Ofomata, G.E.K.(2002). Soils and soil erosion. In: Ofomata, G.E.K(Ed): *A survey of the Igbo nation*. Africana First Publishers Ltd, Onitsha. 99-116.

Ojha, G. & Shrestha, R. (2007).Bio-Engineering Measures for Stabilizing Cut-Slopes of Dipayal-Mellekh road, Far Western Nepal. *Bulletin of Department of Geology, Tribhuvan University,* Kathmandu, Nepal, (10), 79-88.

Okagbue, C.O. (1988). Landslide in Agulu-Nanka, South Eastern Nigeria; University of Nigeria Press, University of Nigeria Nsukka, 29 – 38.

Okagbue, C.O., & Ezechi, J.I. (1988).Geo-technical characteristics of soil Susceptible to erosion in Eastern Nigeria; *Bulletin Int. Asso.of Eng. Geology,* (38) 111–118.

Okonkwo, C.O. (2002). Depositional Environment of Eocene Nanka; Nanka Sand Stone, Anambra Basin South-eastern Nigeria: Paper presented at the *Environmental Geo-Sciences Convention* Colorado, U.S.A.

Okorie, P.E. (1995). Ecological disaster Research, Gully Erosion Aforestation Project: *Unpublished terminal Report* 122.

Okorie, P.E. (1997). Use of Dacryodes edulis in Erosion control in Agricultural Lands in Nigeria, In Kapan, C. And Kayem, G.A. (eds.): Proc. of 2nd *International Workshop on African Poor Improvement and other newsources of vegetable oil.* Ngoendre Cameroon; 35 – 44.

Okoye, C. O., Emengini, E. J. & Onwuzuligbo, C. U. (2014).Environmental Sensitivity Index Mapping and Assessment of Gully Erosion Sites in Anambra State, Nigeria.*Journal of Environment and Earth Science* 4(10):

Onuoha, D. C. & Onwuka, S. U. (2014):The Place of Soil Geotechnical Characteristics in Road Failure, a Study of the Onitsha-Enugu Expressway, Southeastern Nigeria.*Journal of Civil and Environmental Research.* IISTE, USA. 6(1), 55-67.

Onwuka, S.U. (2009) Vertical Velocity of Pollutants through Porous Rocks: Implications for Water Resources Management in Anambra State: A Ph.D. Dissertation (Unpublished).

Orji, E. C. & Bhatt, G.P. (1990). Survey of trees in Girei district and its relevance to Technical Development of the area in Proc. *Third World Strategies for Tech. Development* 1(59), 435 – 458

Orji, E.C. (1995). Deforestation, bush burning and Bio-diversity frame work for effective control. In: Adina, E. N. and Odunukwe, G. C. *Towards Environmental Management Policy for sustainable Development in Anambra State*.

Osadebe, C. C. & Enuvie, G. (2008).Factor Analysis of Soil Spatial Variability in Gully Erosion Area of southeastern Nigeria: A Case Study of Agulu-Nanka- Oko Area.*Scientia Africana,* 7 (2): 45.

Panagos, P., Ballabid, C., Borrelli, P., Meusberger, K., Klik, A., Rousseva, S., Melita, P., T.,Michaelides, S., Hrabalikova, M.,Olsen, P., Aalta, J., Lakatos, M.,Rymszewicz, A.,Dumitrescu, A., Begueria, S. & Alewell, C. (2015).Rainfall erosivity in Europe.Science Total Environment 511(2015) pp.801-814.

Peterson, G., Allen, C.R. & Holling, C.S. (1998).Ecological Resilience, Biodiversity, and Scale.*Ecosystems*1(1): 6–18. doi:10.1007/s100219900002.

Pimm, S. L. (1984). The complexity and stability of ecosystems.*Nature* (30): 321-326.

Poesen, J., Nachtergaele, J., Verstraeten, G. & Valentin, C. (2003).Gully erosion and environmental change: importance and research needs.*Catena*, 50 (2-4), 91-133.

Project Management Institute (PMI). (2013). *A guide to the project management body of knowledge*.5th edition, Project Management Institute, Newtown Square, PA.

Raison, C. A. (2004).*Ground improvement method*, Thomas Telford, 1 Heron Quay, London. ISBN: 0 72773170.

Rapp, A. (1976). Soil Conservation and Management in developing countries, *F.A.O. Soil bulletin* (33): 123 – 132.

Rawlings, C. G.; Hellawell, E. E. & Kilkenny, W. M. (2000).*Grouting for ground engineering*, CIRIA C 514, ISBN 0 86017 514 6.

Relf, D. (2001). Reducing erosion and runoff.*Virginia Cooperative Extension, Publication* No. 426-722, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA.

Renard, K. G., Foster, G. R., Weesies, G. A., Mc Cool, D. K., & Yoder, D. C. (1997). Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation.U.S. Department of Agriculture, *Agriculture Handbook*, (703): 384.

Reuben, H. K. (2003). *Chemical Grouting and Soil Stabilization.*Third Edition, Revised and Expanded.Rutgers UniversityNew Brunswick, New Jersey,U.S.A.

Reyment, R.A. (1965):.*Aspects of the Geology of Nigeria*. Ibadan Univ. Press, 133.

Ristic, R., Kasarin-Grubin, M., Radic, B., Mikic, Z. & Vasi ljevic, N. (2012).Land degradation at the Stara planina Ski resort.*Environmental Management International formal for Decision Makers, Scientists and Environmental assessors.* 580 – 592.

Rozanov, B. G. (1994). Stressed soil systems and soil resilience in drylands.*In Proc. 15th World Cong. of soil Sci.*, Acapulco, Mexico, July 10-16, 1994,

Shealiker, J. R. (1987). *Introduction of Flood proofing: An outline of Principles and Methods:* University of Chicago, Centre of Urban Studies.

Shroff, A. V. & Shah, D. L. (1999).*Grouting Technology in Tunnelling and Dam Construction*, (2nd edition), A.A Balkema Publishers.

Simpson, F. (2010).Prevention and control of Gullying Processes in Diverse Climatic Settings: Lessons for the age of global climate change. *2nd Joint Federal Interagency Conference*, Las Vegas, NV.

Sina, K. & Maassoumeh, B. (2012). Review of soft soils stabilization by grouting and injection methods with different chemical binders. *Scientific Research and Essays.* 7 (24): 2104-2111. http://www.academicjournals.org/SRE DOI: 10.5897/SRE11.1186

Singh, M. J. & Khera, K. L. (2009).Nomographic estimation and evaluation of soil erodibility under simulated and natural rainfall conditions.*Land Degradation and Development* Vol.20, pp.471-480. http://www.iuss.org/19th%20WCSS/Symposium/pdf/0166.pdf

Tilman, D., & Downing, J. A. (1994).Biodiversity and stability in grasslands.*Nature* 367:363-365.

U.S. Department of the Interior, Bureau of Reclamation (1984). *Policy Statement for Grouting*, Denver, Colorado.

UN-HABITAT (2002) State of world cities report.

UN-HABITTAT (2009) Structure plan for Awka and Satellite towns. http://w.w.w-unhabitat.org.

US Army Corps of Engineers (1995).*Chemical Grouting*, Manual No. 1110-1-3500, Washington, DC, USA.

Valentin, C., Poesen,J. &Li, Y. (2005). Gully Erosion: A Global Issue ; "Impacts, factors and control" *CATENA*,63(2–3): 132–153.

Vrieling, A., Hoedjes, J. C. B. & Velde,M. vander,2014.Towards large scale monitoring of soil erosion in Africa: accounting for the dynamics of rainfall erosivity. *Global Planet Change*5(115),pp.33-43.

Walker, B., Holling, C. S., Carpenter, S. R. &Kinzig, A. (2004).Resilience, adaptability and transformability in social–ecological systems.*Ecology and Society*,9 (2): 5.

Wall, G.; Baldwin, C.S.; & Shelton, I. J. (1987).*Soil erosion - causes and effects*.Ontario Ministry of Agriculture and Food Factsheet Agdex # 572, Canada.

Williams, J., & Chartres, C. J. (1991).Sustaining productive pastures in the tropics 1.Managing the soil resource.*Tropical Grassl*. 25: 73-84.

Yonckura, R. & Kaga, M. (1992).Current Chemical Grout Engineering in Japan,*GeotechnicalSpecial Publication* 30(l): 725–736, ASCE, Reston, VA.

APPENDICES

APPENDIX 1 (Plates Showing Some NEWMAP Gully Erosion Control Projects within and outside Anambra State).

1a. Site Inspection by the Honourable Minister at the newly completed Channelization Project by NEWMAP at Amachalla Awka.

1b. Part of the Amachalla Gully before the NEWMAP Project Commenced.

1c.Queen Ede Gully Site Edo State before intervention of NEWMAP.

1d.Queen Ede after intervention by NEWMAP.

1e.Civil works mixed with bioremediation in one of the Auchi Gully fingers reclaimed by NEWMAP

1f .Devastating effect of erosion in Nkot Nkebere-Cross River State where NEWMAP has presently commenced action

1g.Atakpa Site Cross River State Before Intervention

1h. Atakpa Site Now

APPENDIX 2 (Plates showing failed Control Measures)

2a. Gabbions after construction by Rhino at Nanka Erosion Site (Researcher's Field Work Pictures)

2b. Gabbions after construction by Rhino at Nanka Erosion Site (Researcher's Field Work Pictures)

2c. Gabbions showing signs of failure a short while after construction at Nanka Erosion Site (Researcher's Field Work)

2d. Sandbag Check Dams showing signs of fairlure shortly after construction by Rhino at Nanka Erosion Site (Researcher's Field Work)

2e. Sandbag Check Dams showing signs of fairlure shortly after construction by Rhino at Nanka Erosion Site (Researcher's Field Work)

2f. Failed Gully Erosion Channelization at Oraukwu

2g. Failed Gully Erosion Channelization at Neni

APPENDIX 3 (Result of Laboratory Analyses)

1. Results of the Laboratory Analyses of Water

Springboard Research Laboratories
Rd 3, House 1, Udoka Housing Estate,
Awka Anambra State.
08100382601, 046844587, 08022087994
springboardlab@yahoo.com

Name of Customer:Mr.Onuoha David
Sample :Soil
Test Required: Physiochemical/Heavy Metal
Date Received:30th June, 2017.

Samples	Station 1 tag 1 CAOH	Station tag 3 CAOH	Station 4 tag 9 CAOH	Station 3 tag 4B CAOH	Station 10 tag 5 CAOH	Station 10 tag 5 Cacl	Station 4 tag 9 Cacl	Station 3 tag 4B Cacl	Station 2 tag 3 Cacl	Station 1 tag 1 Cacl
Copper (ppm)	0.040	0.024	0.011	0.003	0.003	0.033	0.003	0.035	0.065	0.019
Iron (ppm)	2.320	2.939	0.605	1.916	1.427	2.640	1.280	0.547	3.207	3.207
Cadmium (ppm)	0.017	0.018	0.00	0.00	0.051	0.012	0.00	0.008	0.00	0.009
Chromium (ppm)	0.030	0.049	0.038	0.074	0.074	0.088	0.080	0.039	0.039	0.064
Nickel (ppm)	0.00	0.00	0.00	0.00	0.139	0.061	0.00	0.00	0.00	0.00
Zinc (ppm)	0.430	0.370	0.596	0.337	0.338	0.476	0.585	0.630	0.736	0.696
Lead (ppm)	0.153	0.157	0.869	1.052	0.613	0.820	1.010	0.440	0.445	0.762
Manganese (ppm)	0.216	0.287	0.585	0.161	0.741	1.410	1.781	0.363	0.332	0.591
Potassium (ppm)	32.247	28.167	20.256	37.184	25.083	12.247	38.167	31.156	27.384	21.283

Arsenic (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium (ppm)	12.787	16.646	17.625	17.591	19.240	18.036	18.005	11.831	17.086	1530
Sodium (ppm)	11.695	13.819	15.007	21.271	24.624	24.161	24.393	18.750	19.033	17.742
Cobalt (ppm)	0.00	0.008	0.00	0.00	0.116	0.00	0.032	0.00	0.029	0.00
Silver (ppm)	0.137	0.00	0.022	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium (ppm)	`135.77	109.40	97.014	217.77	228.36	169.15	262.90	114.81	204.50	287.09
Aluminium (ppm)	0.059	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenium (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mercury (ppm)	0.924	0.145	0.108	0.085	0.084	0.131	0.110	0.100	0.166	0.126
Vanadium (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pH	6.20	6.10	5.50	6.09	6.13	6.13	5.94	5.41	5.46	5.32
Turbidity NTU	041	081	60	69	070	081	031	58	45	42
Conductivity us/cm	492	453	395	493	303	202	242	265	416	573
Hardness mg/kg	94	480	330	90	67	104	668	170	202	200
Chloride mg/kg	118	88	100	78	90	136	255	1888	215	320
Nitrate mg/kg	1.863	`1.428	1.786	1.421	1.056	1.948	2.292	2.863	1.011	1.028

Phosphorous mg/kg	2.362	2.086	2.194	2.249	1.386	1.291	2.422	2.593	2.499	2.863
Density g/ml	1.6899	1.7513	1.7596	1.6807	1.6344	1.653	1.7107	1.7769	1.7729	1.7002
Porosity us/cm	0.1454	0.1339	0.1229	0.1150	0.1060	0.1053	0.181	0.1155	0.1366	0.1354
Permeability	30.61	7.60	5.11	11.34	26.74	29.84	11.85	6.38	8.40	31.34

Okeke David Okechukwu *Signature Of Analayst*

(B.Sc, M.Sc, MIPAN)

Public Analyst

Springboard Research Laboratories
Rd 3, House 1, Udoka Housing Estate,
Awka Anambra State.
08100382601, 046844587, 08022087994
springboardlab@yahoo.com

Name of Customer: David Onuoha

Test Required: Physiochemical analysis
Date Received:15th July, 2017.

Parameters	Station 1 tag 1 NaSi0_4	Station 2 tag 3 NaSi0_4	Station 4 tag9 NaS1$0_4$	Station 3 tag4b NaSi0_4	Station10 tag 5 NaSi0_4	Station 1 tag 1 FeAlSi0_4	Station 2 tag 3 FeAlSi0_4	Station 4 tag9 FeAlS1 0_4	Station 3 tag4b FeAlSi0_4	Station 10 tag 5 FeAlSi0_4
pH	6.10	6.08	5.92	5.88	6.29	5.87	5.29	5.46	5.74	5.98
Turbidity NTU	88	92	108	127	146	122	121	122	107	152
Conductivity us/cm	489	506	638	592	397	108	322	498	377	308
Hardness mg/l	124	108	146	157	287	307	322	198	224	188
Chloride mg/l	120	122	146	139	160	144	108	127	166	187
Nitrate mg/l	0.435	0.267	1.569	1.367	2.67	1.463	3.538	1.072	1.432	1.197
Phosphorus mg/l	1.936	1.473	1.063	1.367	1.288	1.023	3.972	1.637	1.265	0.973
Copper	0.056	0.467	0.028	0.036	0.019	0.035	0.018	0.044	0.098	0.026

(ppm)										
Iron (ppm)	3.986	4.972	3.937	4.738	6.537	32.648	44.673	32.762	38.279	41.353
Cadmium (ppm)	0.012	0.025	0.018	0.022	0.020	0.012	0.014	0.026	0.072	0.011
Chromium (ppm)	0.108	0.116	0.035	0.102	0.117	0.026	0.037	0.059	0.084	0.065
Nickel (ppm)	0.016	0.027	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zinc (ppm)	0.286	0.167	0.107	0.119	0.267	0.156	0.267	0.119	0.289	0.122
Lead (ppm)	0.467	0.297	0.153	0.289	0.356	0.482	0.193	0.227	0.168	0.478
Manganese (ppm)	0.464	0.378	0.564	0.298	0.946	0.463	0.453	0.462	0.361	0.373
Potassium (ppm)	6.474	7.363	4.638	5.038	4.284	8.648	6.478	4.299	5.383	3.843
Arsenic (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium (ppm)	9.474	7.564	6.748	8.373	6.464	5.297	5.363	7.278	8.574	9.474
Sodium (ppm)	18.464	22.474	28.164	20.288	27.454	11.194	7.453	6.183	11.197	10.234
Cobalt (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Silver (ppm)	0.00	0.00	0.00	0.00	0.045	0.022	0.19	0.013	0.34	0.065
Aluminum (ppm)	1.163	1.662	1.073	1.443	2.063	39.474	47.354	31.464	42.654	48.474
Calcium (ppm)	4.365	5.363	4.373	4.193	4.289	5.376	5.299	4.742	3.749	3.188
Mercury (ppm)	0.036	0.045	0.037	0.178	0.172	0.372	0.112	0.147	0.289	0.193
Silicon (ppm)	89.732	78.363	58.373	67.291	67.362	98.342	85.278	91.473	80.189	72.383
Molybdenum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bulk density g/ml	1.197	1.189	1.192	1.187	1.165	1.128	1.188	1.168	1.167	1.189
pore density g/ml	1.089	1.099	1.176	1.128	1.158	1.108	1.122	1.119	1.108	1.092
Porosity	0.0902	0.0756	0.013	0.0497	0.00601	0.0177	0.0556	0.0419	0.051	0.0816
permeability	35	28.40	22.18	29.30	36.19	40.23	19.19	20.22	18.19	29.42

Okeke, David O.
B.Sc, M.Sc, MIPAN
Analyst

Results of Soil Analyses

Springboard Research Laboratories
Rd 3, House 1, Udoka Housing Estate,
Awka Anambra State.
08100382601, 046844587, 08022087994
springboardlab@yahoo.com

Name of Customer: David Onuoha
Sample: Soil
Test Required: Complete Analysis
Date Received:22nd Feb, 2017.

Parameters/ Minerals	1 tag 1	2 tag 3
Copper (ppm)	0.525	0.158
Cobalt (ppm)	0.119	0.018
Lead (ppm)	0.729	0.502
Mercury (ppm)	0.00	0.00
Chromium (ppm)	0.085	0.016
Nickel (ppm)	0.574	0.264
Aluminium	12.783	16.637
Manganese (ppm)	3.629	1.283
Iron (ppm)	44.948	43.101
Zinc (ppm)	3.509	1.480
Silver (ppm)	0.117	0.087
Cadmium (ppm)	0.101	0.176
Calcium (ppm)	0.066	0.044
Magnesium (ppm)	2.387	2.291
Sodium (ppm)	6.633	6.744
Tin (ppm)	0.012	0.011
Molybdenium (ppm)	0.633	0.382
Arsenic (ppm)	0.00	0.00
Selenium (ppm)	0.067	0.047
Barium (ppm)	0.003	0.00
Potassium (ppm)	7.033	8.125
Ca (mol/kg	0.00016	0.00011
Na (mol/kg	0.01441	0.01466

Mg (mol/kg	0.00994	0.00693
Total Base	0.02451	0.0217
Exchangeable Acidity mg/kg	11.2	7.2
Cation Exchange Capacity mg/kg	11.2101	7.20704
Sulphur %	9.219	6.585
Phenolic Content mg/kg	0.9150	0.7189
Total Nitrogen %	1.176	0.504
Particulate Matter mg/kg	1.15	0.95
% clay	24.83	30.6
% silt	44.77	47.8
% Sand	30.4	21.6
Total Organic Carbon %	0.0290	0.05517
Organic Matter %	1.6	1.253
Moisture Content %	0.45	0.4
pH in water	7.80	5.66
pH in CaCl	5.10	5.38
Phosphorous mg/kg	13.1120	6.3112
Ca. Hardness mg/kg	20	20
Total Hardness mg/kg	82	64
Chloride mg/kg	164	204
Alkalinity mg/l	15	12.5
Conductivity us/cm	164	146
Nitrite mg/l	0.3703	0.3050
Resistivity cm/us	0.006097	0.00685
Bulk Density g/ml	1.087	1.083
Pore Density g/ml	1.037	1.033
Porosity	0.0460	0.046

PARAMETERS	St 3 tag 4B	St 4 tag 9	St b5 tag10
Copper (ppm)	2.101	4.043	1.296
Iron (ppm)	20.145	21.484	21.410
Chromium (ppm)	0.083	0.584	0.424
Nickel (ppm)	0.314	1.454	0.845
Lead (ppm)	3.527	0.820	0.615
Manganese (ppm)	1.728	6.167	14.169
Cobalt (ppm)	0.094	1.822	0.092
Zinc (ppm)	4.067	8.407	9.706
Cadmium (ppm)	0.655	0.453	0.154
Mercury (ppm)	0.742	0.484	0.138
Silver (ppm)	2.281	0.840	0.490
Potassium (ppm)	12.67	11.231	8.223
Calcium (ppm)	12.867	9.256	8.258
Magnesium (ppm)	15.801	15.985	17.548
Sodium (ppm)	2.474	30.8642	32.3722
Molybdenium (ppm)			
Selenium pm			
Silicon (ppm)	12.22		
Ca (mol/kg)	0.0322	0.02314	0.020645
Mg (mol/kg)	0.0658	0.0660	0.07311
Na (mol/kg)	0.0054	0.06709	0.07037
Total Base	0.1034	0.15623	0.164125
Cation Exchange Capacity	6.498	3.28914	7.293755
Base Saturation	1.5081	2.71013	1.28541
pH in Water	4.48	5.43	6.07
pH in chloride	4.64	5.21	5.84
Conductivity mg/kg	168	173	217
Chloride mg/kg	214	160`	143

Total Hardness mg/kg	14	68	80
Calcium Hardness mg/kg	6.8	46	32
Phosphorous mg/kg	13.4385	11.7519	10.6637
Exchangeable Acidity mg/kg	6.4	3.2	7.2
Total Organic Carbon %	0.0513	0.0181	0.0354
% Sand	58.7	67.6	56.8
% Silt	34.7	25.3	29.7
% Clay	6.6	7.1	13.5
Nitrogen %	0.672	0.336	0.448
Phenol mg/kg	0.6754	1.0021	1.111
Sulphur %	10.96	11.853	19.755
Organic Matter %	1.45	1.05	1.95
Moisture Content %	0.35	0.25	0.45
Alkalinity mg/kg	17.5	20	30
Bulk Density mg/kg	1.214	1.318	1.324
Nitrite mg/kg	0.1931	0.1394	0.2038
Resistivity cm/us	0.0059	0.0057	0.0046
Density g/ml	1.024	1.2402	1.218
Porosity g/ml	0.1566	0.0540	0.0800
Particulate Matter %	2.8	2.15	3.55

3. WHO Standard for Portable Water and Original Water Quality Before the Introduction of Grouting Chemicals

Parameter	Concentration (ppm)	WHO 2005 standard
pH	6.77	6.5-7.8
Hardness mg/l	64	70max
Turbidity NTU	0.01	250max
Conductivity us/cm	141.80	500max
Temperature ^{0}C	28	-
Taste	Unobjectionable	Unobjectionable
Odour	Odourless	Odourless
Colour	Colourless	Colourless
Nitrate mg/l	0.3070	5.0max
Phosphate mg/l	0.274	5.0max
Total Dissolved Solid mg/l	3.76	500max
Total Suspended Solid mg/l	0.54	500max
Sodium (ppm)	0.112	5.0max
Calcium (ppm)	0.00	10.0max
Lead (ppm)	0.07	0.05max
Copper (ppm)	0.013	0.3max
Manganese	0.697	0.3max
Coliform count	Nil	Nil
Mercury (ppm)	0.338	0.03max
Acidity mg/l	22.5	-
Alkalinity mg/l	8.00	-
Total solid mg/l	4.30	250max
Chloride mg/l	5.00	120max
Silver (ppm)	0.053	0.05max
Cobalt (ppm)	0.048	0.05max

Magnesium (ppm)	3.386	10max
Selenium (ppm)	0.00	0,1max
Arsenic (ppm)	0.00	0.00max
Cadmium (ppm)	0.004	0.3max
Chromium (ppm)	0.00	0.3max
Cobalt (ppm)	0.205	0.03max
Potassium (ppm)	1.186	5.00max
Aluminium (ppm)	0.00	0.00
Zinc (ppm)	0.028	0.3max
Molybdenum (ppm)	0.00	0.00
Tin (ppm)	0.00	0.00
Vanadium	0.00	0.00
Iron (ppm)	0.02	0.3max

APPENDIX 4 (Questionnaire)

Department of Environmental
Management,
Faculty of Environmental
science,
Nnamdi Azikiwe University,
P.M.B 5025, Awka,
Nigeria.

Dear Sir/Madam,

I am a Ph.D student of the aforementioned institution. I am presently carrying out a research on "Evaluation of Grouting as a Measure for Controlling Gully Erosion in Nanka Sands Geologic Unit in Anambra State, Nigeria". Consequently, I crave your indulgence in answering the questions herein attached as your candid response is expedient for the completion of this research work.

Be confident that this research is purely for academic purposes and the information to be provided herein will be treated as private and confidential.

Thanks for your anticipated co-operation and kind consideration.

Yours faithfully

Onuoha, David Chijioke.

Section A: Personal Information

1	**YOUR AGE BRACKET**	**Frequency of Responses by Respondents**
	18 – 25	
	26 – 40	
	41 – 64	
	65 and above	
2	**YOUR GENDER**	
	Female	
	Male	
3	**FOR HOW LONG HAVE YOU LIVED AROUND THIS GULLY PRONE AREA?**	
	Less than one year	
	More than one year but less than five years	
	More than five years	
	From birth	
4	**WHAT IS YOUR HIGHEST ACADEMIC QUALIFICATION?**	
	First School Leaving Cert.	
	WAEC, GCE, NECO	
	NCE, OND	
	HND, B.Sc	
	M.Sc	
	Ph.D	
5	**DO YOU BELONG TO ANY PROFESSIONAL BODY THAT DEALS**	

	ON GULLY EROSION CONTROL OR ENVIRONMENTA MANAGEMENT?	
	Yes	
	No	

Keys:
SA = Strongly Agree
A = Agree
N = No Option
D = Disagree
SD = Strongly Disagree

SECTION B:

Responses of the Respondents on What are the Causes of the Gully Erosion in the area?		**SA**	**A**	**N**	**D**	**SD**
1	High intensity of rainfall / climatic factors					
2	Friable Geology and loose soil type/Characteristics					
3	Topography / Geomorphology of the area					
4	Agricultural Activities/Farming/Deforestation					
5	Soil excavation and sand mining					
6	Building constructions					
7	Corruption of the agencies saddled with the responsibilities of gully control					

8	Poor water Channelization/Drainage system					
9	Wrong government policies on erosion control					
10	Inefficiency in the project management by the manager or leader					
11	Wrong control measures					
12	Developmental activities					
13	Zero or low involvement of the affected communities to control the gullies at young stage					
14	Political factors, change of governments, lack of interest in control projects					
15	Late intervention to gully cases					
16	Delays in accessing funds for control					
17	Ignorance of the masses on their role in gully control					
18	Poor information of bad communication link between the affected communities and agencies saddled with the responsibility of gully erosion control					
19	Poor planning of control measures					
20	Control project abandonment /Haphazard Construction					

What are the Effects of Gully Erosion in the area?		SA	A	N	D	SD
1	Siltation of nearby rivers/streams					
2	Loss of lives					
3	Low food production					
4	Inaccessibility of affected area					
5	Loss of communal heritage and monuments					
6	Boundary dissections					
7	Loss of properties and farmlands					
8	Emotional and psychological trauma					
9	Economical losses					
10	Relocation problems					
11	Creation of bad lands					
12	Increased health challenges like high blood pressure etc.					

SECTION C:

What should be done to better control Gully Erosion in the Area?		SA	A	N	D	SD
1	Early intervention to control emerging gullies					
2	Project continuity by new governments					
3	Construction of sound and wide drainage channels					
4	Reduction in the rate of soil excavation					
5	Prompt information to the agencies involved with gully control of newly developed gullies					
6	Soil stabilization through chemical means like grouting					
7	Prompt release of fund by the government and agencies involved in controlling gullies					
8	Adoption of sound project management policies for gully erosion control project to be successful Superiority Issues					
9	Combination of both civil engineering control strategies and chemical stabilization methods					
10	Control of Agricultural activities					
11	Improved community involvement / public participation					
12	Encouraging sound developmental control practices that will not expose the environment to gullying					
13	Enlistment of climatologists, geologist and soil scientists in the team controlling the gullies to widen the knowledge about the area					
14	Extensive planning and proper implementation of gully erosion control measures					
15	Education of the inhabitants of the affected areas					

APPENDIX 5 (SPSS Generated Outputs for Statistical Analyses)

Hypothesis 1

Notes

Output Created		10-Jul-2017 16:46:07
Comments		
Input	Data	C:\Documents and Settings\ZINOX\Desktop\Mr David\Hyp one.sav
	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	210
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on cases with no missing data for any variable in the analysis.
Syntax		ONEWAY Data BY Group /MISSING ANALYSIS.
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.031

Hypothesis 2

```
ONEWAY Hyp2 BY Group_Hyp2
  /MISSING ANALYSIS.
```

Oneway

Notes

Output Created		10-Jul-2017 16:52:14
Comments		
Input	Data	C:\Documents and Settings\ZINOX\Desktop\Mr David\Hyp one.sav
	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	210
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on cases with no missing data for any variable in the analysis.
Syntax		ONEWAY Hyp2 BY Group_Hyp2 /MISSING ANALYSIS.
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.000

Hypothesis 3

T-
TEST PAIRS=Porosity_b4_Al VAR00001 VAR00005 VAR00009 WITH Porosity_after_Al VAR00002 VAR00006 VAR00
010 (PAIRED)
/CRITERIA=CI(.9500)
/ISSING=ANALYSIS.

T-Test

Notes

Output Created		24-Jul-2017 20:58:54
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Permeability_Porosity.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST PAIRS=Porosity_b4_Al VAR00001 VAR00005 VAR00009 WITH Porosity_after_Al VAR00002 VAR00006 VAR00010 (PAIRED) /CRITERIA=CI(.9500) /MISSING=ANALYSIS.
Resources	Processor Time	00:00:00.062
	Elapsed Time	00:00:00.031

[DataSet1] C:\Users\USER\Desktop\Mr_David\Permeability_Porosity.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Porosity before Grouting with AlFeSiO4	.408400	5	.0533507	.0238592
	Porosity after Grouting with AlFeSiO4	.049560	5	.0231239	.0103413
Pair 2	Porosity before Grouting with NaFeSiO4	.4084	5	.05335	.02386
	Porosity after Grouting with NaFeSiO4	.0469	5	.03717	.01662
Pair 3	Porosity before Grouting with CaCl	.4084	5	.05335	.02386
	Porosity after Grouting with CaCl	.1348	5	.02907	.01300
Pair 4	Porosity before Grouting with CaOH	.4084	5	.05335	.02386
	Porosity after Grouting with CaOH	.1246	5	.01549	.00693

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Porosity before Grouting with AlFeSiO4 & Porosity after Grouting with AlFeSiO4	5	.196	.752
Pair 2	Porosity before Grouting with NaFeSiO4 & Porosity after Grouting with NaFeSiO4	5	.344	.571
Pair 3	Porosity before Grouting with CaCl & Porosity after Grouting with CaCl	5	.474	.420
Pair 4	Porosity before Grouting with CaOH & Porosity after Grouting with CaOH	5	-.186	.765

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Porosity before Grouting with AlFeSiO4 - Porosity after Grouting with AlFeSiO4	.3588400	.0538351	.0240758	.2919948	.4256852	14.905	4	.000
Pair 2	Porosity before Grouting with NaFeSiO4 - Porosity after Grouting with NaFeSiO4	.36150	.05353	.02394	.29504	.42796	15.102	4	.000
Pair 3	Porosity before Grouting with CaCl - Porosity after Grouting with CaCl	.27364	.04714	.02108	.21510	.33218	12.979	4	.000
Pair 4	Porosity before Grouting with CaOH - Porosity after Grouting with CaOH	.28376	.05825	.02605	.21143	.35609	10.893	4	.000

```
T-
TEST PAIRS=Permeability_b4_Al VAR00003 VAR00007 VAR00011 WITH Permeability_after_Al VAR00004 VAR00008 VAR00012 (
PAIRED)

 /CRITERIA=CI(.9500)

 /MISSING=ANALYSIS.
```

T-Test

Notes

Output Created		24-Jul-2017 21:01:39
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Permeability_Porosity.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST PAIRS=Permeability_b4_Al VAR00003 VAR00007 VAR00011 WITH Permeability_after_Al VAR00004 VAR00008 VAR00012 (PAIRED) /CRITERIA=CI(.9500) /MISSING=ANALYSIS.
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.016

[DataSet1] C:\Users\USER\Desktop\Mr_David\Permeability_Porosity.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Permeability before Grouting with AlFeSiO4	77.0000	5	11.00000	4.91935
	Permeability after Grouting with AlFeSiO4	25.4500	5	9.40023	4.20391
Pair 2	Permeability before Grouting with NaFeSiO4	77.0000	5	11.00000	4.91935
	Permeability after Grouting with NaFeSiO4	30.2140	5	5.64113	2.52279
Pair 3	Permeability before Grouting with CaCl	77.0000	5	11.00000	4.91935
	Permeability after Grouting with CaCl	17.5620	5	12.06430	5.39532
Pair 4	Permeability before Grouting with CaOH	77.0000	5	11.00000	4.91935
	Permeability after Grouting with CaOh	16.2800	5	11.61115	5.19267

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Permeability before Grouting with AlFeSiO4 & Permeability after Grouting with AlFeSiO4	5	-.006	.993
Pair 2	Permeability before Grouting with NaFeSiO4 & Permeability after Grouting with NaFeSiO4	5	.140	.822
Pair 3	Permeability before Grouting with CaCl & Permeability after Grouting with CaCl	5	.320	.600
Pair 4	Permeability before Grouting with CaOH & Permeability after Grouting with CaOh	5	.149	.811

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interv Difference				
		Mean	Std. Deviation	Std. Err	Low	Upper			
Pair 1	Permeability before Grouting with AlFeSiO4 - Permeability after Grouting with AlFeSiO4	51.55000	14.50911	6.48867	33.53456	69.56544	7.945	4	.001
Pair 2	Permeability before Grouting with NaFeSiO4 - Permeability after Grouting with NaFeSiO4	46.78600	11.63862	5.20495	32.33475	61.23725	8.989	4	.001
Pair 3	Permeability before Grouting with CaCl - Permeability after Grouting with CaCl	59.43800	13.48007	6.02847	42.70029	76.17571	9.860	4	.001
Pair 4	Permeability before Grouting with CaOH - Permeability after Grouting with CaOh	60.72000	14.76004	6.60089	42.39299	79.04701	9.199	4	.001

Hypothesis 4

The test was done considering the various chemicals (4) used for grouting, station by station.

T-Test

Notes

Output Created		12-Jul-2017 16:00:37
Comments		
Input	Data	C:\Documents and Settings\ZINOX\Desktop\Mr David\Hypothesis 4.sav
	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	6
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0 /MISSING=ANALYSIS /VARIABLES=Station1_Al Station1_Na Station1_CaCl Station1_CaOH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.062
	Elapsed Time	00:00:00.297

Author's SPSS Analysis

```
T-TEST
 /TESTVAL=0
 /MISSING=ANALYSIS
 /VARIABLES=Station2_Al Station2_Na Station2_CaCl Station2_CaOH
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		12-Jul-2017 16:01:42
Comments		
Input	Data	C:\Documents and Settings\ZINOX\Desktop\Mr David\Hypothesis 4.sav
	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	6
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0 /MISSING=ANALYSIS /VARIABLES=Station2_Al Station2_Na Station2_CaCl Station2_CaOH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.031

Author's SPSS Analysis

```
T-TEST
 /TESTVAL=0
 /MISSING=ANALYSIS
 /VARIABLES=Station3_Al Station3_Na Station3_CaCl Station3_CaOH
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		12-Jul-2017 16:02:17
Comments		
Input	Data	C:\Documents and Settings\ZINOX\Desktop\Mr David\Hypothesis 4.sav
	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	6
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0 /MISSING=ANALYSIS /VARIABLES=Station3_Al Station3_Na Station3_CaCl Station3_CaOH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.187
	Elapsed Time	00:00:00.188

Author's SPSS Analysis

```
T-TEST
 /TESTVAL=0
 /MISSING=ANALYSIS
 /VARIABLES=Station4_Al Station4_Na Station4_CaCl Station4_CaOH
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		12-Jul-2017 16:02:55
Comments		
Input	Data	C:\Documents and Settings\ZINOX\Desktop\Mr David\Hypothesis 4.sav
	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	6
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0 /MISSING=ANALYSIS /VARIABLES=Station4_Al Station4_Na Station4_CaCl Station4_CaOH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.031

Author's SPSS Analysis

```
T-TEST
  /TESTVAL=0
  /MISSING=ANALYSIS
  /VARIABLES=Station5_Al Station5_Na Station5_CaCl Station5_CaOH
  /CRITERIA=CI(.9500).
```

T-Test **Notes**

Output Created		12-Jul-2017 16:03:37
Comments		
Input	Data	C:\Documents and Settings\ZINOX\Desktop\Mr David\Hypothesis 4.sav
	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	6
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0 /MISSING=ANALYSIS /VARIABLES=Station5_Al Station5_Na Station5_CaCl Station5_CaOH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.109
	Elapsed Time	00:00:00.109

Author's SPSS Analysis

Hypothesis 5(AlFeSiO_4)

The elements /parameters were considered individually.

```
T-TEST
 /TESTVAL=6.5
 /MISSING=ANALYSIS
 /VARIABLES=pH
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:09:43
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=6.5 /MISSING=ANALYSIS /VARIABLES=pH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.007

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
pH	5	5.6680	.28700	.12835

One-Sample Test

	Test Value = 6.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
pH	-6.482	4	.003	-.83200	-1.1884	-.4756

```
T-TEST
  /TESTVAL=70
  /MISSING=ANALYSIS
  /VARIABLES=Hardness
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:10:25
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=70 /MISSING=ANALYSIS /VARIABLES=Hardness /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.042

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hardness mg/l	5	247.8000	62.51560	27.95783

One-Sample Test

	Test Value = 70					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hardness mg/l	6.360	4	.003	177.80000	100.1766	255.4234

```
T-TEST
 /TESTVAL=250
 /MISSING=ANALYSIS
 /VARIABLES=Turbidity
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:10:51
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=250 /MISSING=ANALYSIS /VARIABLES=Turbidity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.011

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Turbidity NTU	5	124.8000	16.48332	7.37157

One-Sample Test

	Test Value = 250					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity NTU	-16.984	4	.000	-125.20000	-145.6668	-104.7332

```
T-TEST
  /TESTVAL=500
  /MISSING=ANALYSIS
  /VARIABLES=Conductivity
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:11:14
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=500 /MISSING=ANALYSIS /VARIABLES=Conductivity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.011

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Conductivity us/cm	5	322.6000	141.41358	63.24207

One-Sample Test

	Test Value = 500					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Conductivity us/cm	-2.805	4	.049	-177.40000	-352.9881	-1.8119

```
T-TEST
  /TESTVAL=5.0
  /MISSING=ANALYSIS
  /VARIABLES=Nitrate Phosphate Sodium Pottasium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:12:27
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=5.0 /MISSING=ANALYSIS /VARIABLES=Nitrate Phosphate Sodium Pottasium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.013

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Nitrate mg/l	5	1.7404	1.01802	.45527
Phosphate mg/l	5	1.7740	1.25645	.56190
Sodium (ppm)	5	9.2522	2.30075	1.02893
Potassium (ppm)	5	5.7302	1.92374	.86032

One-Sample Test

	Test Value = 5.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Nitrate mg/l	-7.160	4	.002	-3.25960	-4.5236	-1.9956
Phosphate mg/l	-5.741	4	.005	-3.22600	-4.7861	-1.6659
Sodium (ppm)	4.133	4	.014	4.25220	1.3954	7.1090
Potassium (ppm)	.849	4	.444	.73020	-1.6584	3.1188

```
T-TEST
 /TESTVAL=10.0
 /MISSING=ANALYSIS
 /VARIABLES=Calcium Magnesium
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:13:40
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=10.0 /MISSING=ANALYSIS /VARIABLES=Calcium Magnesium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.010

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Calcium (ppm)	5	4.4708	.96765	.43275
Magnesium (ppm)	5	7.1972	1.87490	.83848

One-Sample Test

	Test Value = 10.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Calcium (ppm)	-12.777	4	.000	-5.52920	-6.7307	-4.3277
Magnesium (ppm)	-3.343	4	.029	-2.80280	-5.1308	-.4748

```
T-TEST
  /TESTVAL=0.05
  /MISSING=ANALYSIS
  /VARIABLES=Lead Silver
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:16:29
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.05 /MISSING=ANALYSIS /VARIABLES=Lead Silver /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.017

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lead (ppm)	5	.3096	.15696	.07020
Silver (ppm)	5	.1260	.13892	.06213

One-Sample Test

	Test Value = 0.05					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Lead (ppm)	3.698	4	.021	.25960	.0647	.4545
Silver (ppm)	1.223	4	.288	.07600	-.0965	.2485

```
T-TEST
 /TESTVAL=0.3
 /MISSING=ANALYSIS
 /VARIABLES=Copper Manganese Cadmium Chromium Zinc Iron
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:17:56
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3 /MISSING=ANALYSIS /VARIABLES=Copper Manganese Cadmium Chromium Zinc Iron /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.015

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Copper (ppm)	5	.0442	.03161	.01414
Manganese	5	.4224	.05090	.02276
Cadmium (ppm)	5	.0270	.02587	.01157
Chromium (ppm)	5	.0542	.02302	.01029
Zinc (ppm)	5	.1906	.08147	.03643
Iron (ppm)	5	37.9430	5.28946	2.36552

One-Sample Test

	Test Value = 0.3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper (ppm)	-18.095	4	.000	-.25580	-.2950	-.2166
Manganese	5.377	4	.006	.12240	.0592	.1856
Cadmium (ppm)	-23.601	4	.000	-.27300	-.3051	-.2409
Chromium (ppm)	-23.881	4	.000	-.24580	-.2744	-.2172
Zinc (ppm)	-3.003	4	.040	-.10940	-.2106	-.0082
Iron (ppm)	15.913	4	.000	37.64300	31.0753	44.2107

```
T-TEST
 /TESTVAL=0.03
 /MISSING=ANALYSIS
 /VARIABLES=Mercury
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:18:55
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.03 /MISSING=ANALYSIS /VARIABLES=Mercury /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.016

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Mercury (ppm)	5	.2226	.10672	.04772

One-Sample Test

	Test Value = 0.03					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Mercury (ppm)	4.036	4	.016	.19260	.0601	.3251

```
T-TEST
  /TESTVAL=120
  /MISSING=ANALYSIS
  /VARIABLES=Chloride
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:19:19
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=120 /MISSING=ANALYSIS /VARIABLES=Chloride /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.017

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Chloride mg/l	5	146.4000	31.18173	13.94489

One-Sample Test

	Test Value = 120					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Chloride mg/l	1.893	4	.131	26.40000	-12.3172	65.1172

```
T-TEST
 /TESTVAL=0.00
 /MISSING=ANALYSIS
 /VARIABLES=Aluminum
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:20:00
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Aluminum /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.062

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Aluminium (ppm)	5	41.8840	6.86160	3.06860

One-Sample Test

	Test Value = 0.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Aluminium (ppm)	13.649	4	.000	41.88400	33.3642	50.4038

```
T-TEST
  /TESTVAL=98.342
  /MISSING=ANALYSIS
  /VARIABLES=Silicon
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:20:25
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=98.342 /MISSING=ANALYSIS /VARIABLES=Silicon /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.000

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Silicon ((ppm))	5	85.5330	10.01124	4.47716

One-Sample Test

	Test Value = 98.342					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Silicon ((ppm))	-2.861	4	.046	-12.80900	-25.2396	-.3784

<u>Hypothesis 5 ($NaSiO_4$)</u>

```
T-TEST
  /TESTVAL=6.77
  /MISSING=ANALYSIS
  /VARIABLES=pH
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:16:29
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=6.77 /MISSING=ANALYSIS /VARIABLES=pH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.020

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
pH	5	6.05400	.163340	.073048

One-Sample Test

	Test Value = 6.77					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
pH	-9.802	4	.001	-.716000	-.91881	-.51319

```
T-TEST
 /TESTVAL=64
 /MISSING=ANALYSIS
 /VARIABLES=Hardness
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:17:58
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=64 /MISSING=ANALYSIS /VARIABLES=Hardness /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.009

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hardness mg/l	5	164.40000	71.128756	31.809747

One-Sample Test

	Test Value = 64					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hardness mg/l	3.156	4	.034	100.400000	12.08198	188.71802

```
T-TEST
  /TESTVAL=0.01
  /MISSING=ANALYSIS
  /VARIABLES=Turbidity
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:18:17
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.01 /MISSING=ANALYSIS /VARIABLES=Turbidity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.063
	Elapsed Time	00:00:00.056

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Turbidity NTU	5	112.20000	24.355697	10.892199

One-Sample Test

	Test Value = 0.01					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity NTU	10.300	4	.001	112.190000	81.94841	142.43159

```
T-TEST
  /TESTVAL=141.80
  /MISSING=ANALYSIS
  /VARIABLES=Conductivity
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:18:47
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=141.80 /MISSING=ANALYSIS /VARIABLES=Conductivity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.203
	Elapsed Time	00:00:00.203

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Conductivity us/cm	5	524.40000	93.937745	42.010237

One-Sample Test

	Test Value = 141.80					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Conductivity us/cm	9.107	4	.001	382.600000	265.96088	499.23912

```
T-TEST
  /TESTVAL=0.3070
  /MISSING=ANALYSIS
  /VARIABLES=Nitrate
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:19:16
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3070 /MISSING=ANALYSIS /VARIABLES=Nitrate /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.010

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Nitrate mg/l	5	1.26160	.969754	.433687

One-Sample Test

	Test Value = 0.3070					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Nitrate mg/l	2.201	4	.093	.954600	-.24951	2.15871

```
T-TEST
  /TESTVAL=0.274
  /MISSING=ANALYSIS
  /VARIABLES=Phosphate
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:19:47
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.274 /MISSING=ANALYSIS /VARIABLES=Phosphate /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.094
	Elapsed Time	00:00:00.034

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Phosphate mg/l	5	1.42540	.322723	.144326

One-Sample Test

	Test Value = 0.274					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Phosphate mg/l	7.978	4	.001	1.151400	.75069	1.55211

```
T-TEST
  /TESTVAL=0.112
  /MISSING=ANALYSIS
  /VARIABLES=Sodium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:20:12
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.112 /MISSING=ANALYSIS /VARIABLES=Sodium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.187
	Elapsed Time	00:00:00.320

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Sodium (ppm)	5	23.36880	4.302088	1.923952

One-Sample Test

	Test Value = 0.112					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Sodium (ppm)	12.088	4	.000	23.256800	17.91505	28.59855

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Calcium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:20:28
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Calcium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.014

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Calcium (ppm)	5	4.51660	.478674	.214070

One-Sample Test

	Test Value = 0.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Calcium (ppm)	21.099	4	.000	4.516600	3.92225	5.11095

```
T-TEST
 /TESTVAL=0.07
 /MISSING=ANALYSIS
 /VARIABLES=Lead
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:20:53
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.07 /MISSING=ANALYSIS /VARIABLES=Lead /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.020

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lead (ppm)	5	.31240	.114012	.050988

One-Sample Test

	Test Value = 0.07					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Lead (ppm)	4.754	4	.009	.242400	.10084	.38396

```
T-TEST
  /TESTVAL=0.013
  /MISSING=ANALYSIS
  /VARIABLES=Copper
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:21:13
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.013 /MISSING=ANALYSIS /VARIABLES=Copper /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.031

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Copper (ppm)	5	.12120	.193790	.086666

One-Sample Test

	Test Value = 0.013					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper (ppm)	1.248	4	.280	.108200	-.13242	.34882

```
T-TEST
  /TESTVAL=0.697
  /MISSING=ANALYSIS
  /VARIABLES=Manganese
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:21:31
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.697 /MISSING=ANALYSIS /VARIABLES=Manganese /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.010

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Manganese	5	.53000	.252733	.113026

One-Sample Test

	Test Value = 0.697					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Manganese	-1.478	4	.214	-.167000	-.48081	.14681

```
T-TEST
  /TESTVAL=0.338
  /MISSING=ANALYSIS
  /VARIABLES=Mercury
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:22:00
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.338 /MISSING=ANALYSIS /VARIABLES=Mercury /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.010

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Mercury (ppm)	5	.09360	.074420	.033282

One-Sample Test

	Test Value = 0.338					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Mercury (ppm)	-7.343	4	.002	-.244400	-.33680	-.15200

```
T-TEST
 /TESTVAL=5.00
 /MISSING=ANALYSIS
 /VARIABLES=Chloride
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:22:20
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=5.00 /MISSING=ANALYSIS /VARIABLES=Chloride /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.032
	Elapsed Time	00:00:00.016

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Chloride mg/l	5	137.40000	16.786900	7.507330

One-Sample Test

	Test Value = 5.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Chloride mg/l	17.636	4	.000	132.400000	111.55631	153.24369

```
T-TEST
  /TESTVAL=0.053
  /MISSING=ANALYSIS
  /VARIABLES=Silver
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:22:47
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.053 /MISSING=ANALYSIS /VARIABLES=Silver /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.094
	Elapsed Time	00:00:00.046

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Silver (ppm)	5	.00900	.020125	.009000

One-Sample Test

	Test Value = 0.053					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Silver (ppm)	-4.889	4	.008	-.044000	-.06899	-.01901

```
T-TEST
  /TESTVAL=3.386
  /MISSING=ANALYSIS
  /VARIABLES=Magnesium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:23:31
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=3.386 /MISSING=ANALYSIS /VARIABLES=Magnesium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.188
	Elapsed Time	00:00:00.162

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Magnesium (ppm)	5	7.72460	1.229784	.549976

One-Sample Test

	Test Value = 3.386					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Magnesium (ppm)	7.889	4	.001	4.338600	2.81162	5.86558

```
T-TEST
  /TESTVAL=0.04
  /MISSING=ANALYSIS
  /VARIABLES=Cadmium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:23:54
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.04 /MISSING=ANALYSIS /VARIABLES=Cadmium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.020

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Cadmium (ppm)	5	.01940	.004879	.002182

One-Sample Test

	Test Value = 0.04					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Cadmium (ppm)	-9.442	4	.001	-.020600	-.02666	-.01454

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Chromium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:24:34
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Chromium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.188
	Elapsed Time	00:00:00.145

[DataSet1] C:\Uers\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Chromium (ppm)	5	.09560	.034428	.015397

One-Sample Test

	Test Value = 0.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Chromium (ppm)	6.209	4	.003	.095600	.05285	.13835

```
T-TEST
  /TESTVAL=1.186
  /MISSING=ANALYSIS
  /VARIABLES=Potassium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:24:59
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=1.186 /MISSING=ANALYSIS /VARIABLES=Potassium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.011

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Potassium (ppm)	5	5.55940	1.307378	.584677

One-Sample Test

	Test Value = 1.186					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Potassium (ppm)	7.480	4	.002	4.373400	2.75008	5.99672

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Aluminum
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:25:24
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Aluminum /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.031

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Aluminium (ppm)	5	1.48080	.400161	.178958

One-Sample Test

	Test Value = 0.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Aluminium (ppm)	8.275	4	.001	1.480800	.98393	1.97767

```
T-TEST
  /TESTVAL=0.028
  /MISSING=ANALYSIS
  /VARIABLES=Zinc
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:25:47
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.028 /MISSING=ANALYSIS /VARIABLES=Zinc /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.063
	Elapsed Time	00:00:00.067

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Zinc (ppm)	5	.18920	.083067	.037149

One-Sample Test

	Test Value = 0.028					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Zinc (ppm)	4.339	4	.012	.161200	.05806	.26434

```
T-TEST
  /TESTVAL=0.02
  /MISSING=ANALYSIS
  /VARIABLES=Iron
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:26:06
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.02 /MISSING=ANALYSIS /VARIABLES=Iron /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.014

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Iron (ppm)	5	4.83400	1.055010	.471815

One-Sample Test

	Test Value = 0.02					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Iron (ppm)	10.203	4	.001	4.814000	3.50403	6.12397

```
T-TEST
  /TESTVAL=85.274
  /MISSING=ANALYSIS
  /VARIABLES=Silicon
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:26:32
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=85.274 /MISSING=ANALYSIS /VARIABLES=Silicon /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.022

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Silicon ((ppm))	5	72.22420	12.083471	5.403893

One-Sample Test

	Test Value = 85.274					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Silicon ((ppm))	-2.415	4	.073	-13.049800	-28.05341	1.95381

Hypothesis 5 (CaOH)

```
T-TEST
  /TESTVAL=6.77
  /MISSING=ANALYSIS
  /VARIABLES=pH
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:57:53
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=6.77 /MISSING=ANALYSIS /VARIABLES=pH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.032
	Elapsed Time	00:00:00.021

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
pH	5	6.00400	.285009	.127460

One-Sample Test

	Test Value = 6.77					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
pH	-6.010	4	.004	-.766000	-1.11989	-.41211

```
T-TEST
  /TESTVAL=64
  /MISSING=ANALYSIS
  /VARIABLES=Hardness
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:58:09
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=64 /MISSING=ANALYSIS /VARIABLES=Hardness /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.156
	Elapsed Time	00:00:00.121

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hardness mg/l	5	212.20000	184.106491	82.334926

One-Sample Test

	Test Value = 64					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hardness mg/l	1.800	4	.146	148.200000	-80.39840	376.79840

```
T-TEST
  /TESTVAL=0.01
  /MISSING=ANALYSIS
  /VARIABLES=Turbidity
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:58:26
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.01 /MISSING=ANALYSIS /VARIABLES=Turbidity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.078
	Elapsed Time	00:00:00.065

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Turbidity NTU	5	64.20000	14.956604	6.688797

One-Sample Test

	Test Value = 0.01					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity NTU	9.597	4	.001	64.190000	45.61892	82.76108

```
T-TEST
 /TESTVAL=141.80
 /MISSING=ANALYSIS
 /VARIABLES=Conductivity
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:59:19
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=141.80 /MISSING=ANALYSIS /VARIABLES=Conductivity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.020

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Conductivity us/cm	5	427.20000	80.088701	35.816756

One-Sample Test

	Test Value = 141.80					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Conductivity us/cm	7.968	4	.001	285.400000	185.95674	384.84326

```
T-TEST
  /TESTVAL=0.274
  /MISSING=ANALYSIS
  /VARIABLES=Phosphate
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:59:37
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.274 /MISSING=ANALYSIS /VARIABLES=Phosphate /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.094
	Elapsed Time	00:00:00.032

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Phosphate mg/l	5	2.05540	.387210	.173166

One-Sample Test

	Test Value = 0.274					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Phosphate mg/l	10.287	4	.001	1.781400	1.30061	2.26219

```
T-TEST
  /TESTVAL=0.112
  /MISSING=ANALYSIS
  /VARIABLES=Sodium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:00:02
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.112 /MISSING=ANALYSIS /VARIABLES=Sodium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.010

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Sodium (ppm)	5	17.28320	5.435983	2.431045

One-Sample Test

	Test Value = 0.112					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Sodium (ppm)	7.063	4	.002	17.171200	10.42154	23.92086

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Calcium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:00:19
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Calcium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.140
	Elapsed Time	00:00:00.132

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Calcium (ppm)	5	157.64880	61.442876	27.478089

One-Sample Test

	Test Value = 0.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Calcium (ppm)	5.737	4	.005	157.648800	81.35739	233.94021

```
T-TEST
  /TESTVAL=0.07
  /MISSING=ANALYSIS
  /VARIABLES=Lead
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:00:53
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.07 /MISSING=ANALYSIS /VARIABLES=Lead /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.009

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lead (ppm)	5	.56880	.408664	.182760

One-Sample Test

	Test Value = 0.07					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Lead (ppm)	2.729	4	.052	.498800	-.00862	1.00622

```
T-TEST
  /TESTVAL=0.013
  /MISSING=ANALYSIS
  /VARIABLES=Copper
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:01:31
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.013 /MISSING=ANALYSIS /VARIABLES=Copper /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.017

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Copper (ppm)	5	.01620	.015834	.007081

One-Sample Test

	Test Value = 0.013					
					95% Confidence Interval of the Difference	
	t	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper (ppm)	.452	4	.675	.003200	-.01646	.02286

```
T-TEST
  /TESTVAL=0.697
  /MISSING=ANALYSIS
  /VARIABLES=Manganese
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:01:56
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.697 /MISSING=ANALYSIS /VARIABLES=Manganese /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.011

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Manganese	5	.39800	.252107	.112746

One-Sample Test

	Test Value = 0.697					
					95% Confidence Interval of the Difference	
	t	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Manganese	-2.652	4	.057	-.299000	-.61203	.01403

```
T-TEST
  /TESTVAL=0.338
  /MISSING=ANALYSIS
  /VARIABLES=Mercury
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:02:14
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.338 /MISSING=ANALYSIS /VARIABLES=Mercury /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.078
	Elapsed Time	00:00:00.083

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Mercury (ppm)	5	.26920	.366880	.164074

One-Sample Test

	Test Value = 0.338					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Mercury (ppm)	-.419	4	.697	-.068800	-.52434	.38674

```
T-TEST
  /TESTVAL=5.00
  /MISSING=ANALYSIS
  /VARIABLES=Chloride
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:02:34
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=5.00 /MISSING=ANALYSIS /VARIABLES=Chloride /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.038

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Chloride mg/l	5	9.48000E1	15.139353	6.770524

One-Sample Test

	Test Value = 5.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Chloride mg/l	13.263	4	.000	89.800000	71.00201	108.59799

```
T-TEST
  /TESTVAL=0.053
  /MISSING=ANALYSIS
  /VARIABLES=Silver
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:02:59
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.053 /MISSING=ANALYSIS /VARIABLES=Silver /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.046
	Elapsed Time	00:00:00.030

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Silver (ppm)	5	.03180	.059575	.026643

One-Sample Test

	Test Value = 0.053					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Silver (ppm)	-.796	4	.471	-.021200	-.09517	.05277

```
T-TEST
  /TESTVAL=0.048
  /MISSING=ANALYSIS
  /VARIABLES=Cobalt
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:03:17
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.048 /MISSING=ANALYSIS /VARIABLES=Cobalt /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.045

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Cobalt (ppm)	5	.02480	.051100	.022853

One-Sample Test

	Test Value = 0.048					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Cobalt (ppm)	-1.015	4	.367	-.023200	-.08665	.04025

```
T-TEST
  /TESTVAL=3.386
  /MISSING=ANALYSIS
  /VARIABLES=Magnesium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:03:39
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=3.386 /MISSING=ANALYSIS /VARIABLES=Magnesium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.031

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Magnesium (ppm)	5	16.77780	2.417919	1.081326

One-Sample Test

	Test Value = 3.386					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Magnesium (ppm)	12.385	4	.000	13.391800	10.38956	16.39404

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Arsenic
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:04:14
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Arsenic /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.011

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

Warnings

The One-Sample Test table is not produced.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Arsenic (ppm)	5	.00000	.000000[a]	.000000

a. t cannot be computed because the standard deviation is 0.

```
T-TEST
  /TESTVAL=0.04
  /MISSING=ANALYSIS
  /VARIABLES=Cadmium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:05:01
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.04 /MISSING=ANALYSIS /VARIABLES=Cadmium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.032

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Cadmium (ppm)	5	.01720	.020825	.009313

One-Sample Test

	Test Value = 0.04					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Cadmium (ppm)	-2.448	4	.071	-.022800	-.04866	.00306

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Chromium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:05:21
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Chromium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.008

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Chromium (ppm)	5	.05300	.020322	.009088

One-Sample Test

	Test Value = 0.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Chromium (ppm)	5.832	4	.004	.053000	.02777	.07823

```
T-TEST
  /TESTVAL=1.186
  /MISSING=ANALYSIS
  /VARIABLES=Potassium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:06:30
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=1.186 /MISSING=ANALYSIS /VARIABLES=Potassium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.013

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Potassium (ppm)	5	28.58740	6.503153	2.908298

One-Sample Test

	Test Value = 1.186					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Potassium (ppm)	9.422	4	.001	27.401400	19.32667	35.47613

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Aluminum
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:06:46
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Aluminum /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.094
	Elapsed Time	00:00:00.094

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Aluminium (ppm)	5	.01180	.026386	.011800

One-Sample Test

	Test Value = 0.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Aluminium (ppm)	1.000	4	.374	.011800	-.02096	.04456

```
T-TEST
  /TESTVAL=0.028
  /MISSING=ANALYSIS
  /VARIABLES=Zinc
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:07:08
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.028 /MISSING=ANALYSIS /VARIABLES=Zinc /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.020

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Zinc (ppm)	5	.41420	.108421	.048488

One-Sample Test

	Test Value = 0.028					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Zinc (ppm)	7.965	4	.001	.386200	.25158	.52082

```
T-TEST
  /TESTVAL=0.02
  /MISSING=ANALYSIS
  /VARIABLES=Iron
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 15:07:49
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.02 /MISSING=ANALYSIS /VARIABLES=Iron /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.011

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Iron (ppm)	5	1.84140	.885969	.396217

One-Sample Test

	Test Value = 0.02					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Iron (ppm)	4.597	4	.010	1.821400	.72132	2.92148

a. Hypothesis 6 ($AlFeSiO_4$)

```
T-TEST
 /TESTVAL=6.5
 /MISSING=ANALYSIS
 /VARIABLES=pH
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:09:43
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=6.5 /MISSING=ANALYSIS /VARIABLES=pH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.007

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
pH	5	5.6680	.28700	.12835

One-Sample Test

	Test Value = 6.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
pH	-6.482	4	.003	-.83200	-1.1884	-.4756

```
T-TEST
 /TESTVAL=70
 /MISSING=ANALYSIS
 /VARIABLES=Hardness
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:10:25
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=70 /MISSING=ANALYSIS /VARIABLES=Hardness /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.042

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hardness mg/l	5	247.8000	62.51560	27.95783

One-Sample Test

	Test Value = 70					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hardness mg/l	6.360	4	.003	177.80000	100.1766	255.4234

```
T-TEST
 /TESTVAL=250
 /MISSING=ANALYSIS
 /VARIABLES=Turbidity
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:10:51
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=250 /MISSING=ANALYSIS /VARIABLES=Turbidity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.011

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Turbidity NTU	5	124.8000	16.48332	7.37157

One-Sample Test

	Test Value = 250					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity NTU	-16.984	4	.000	-125.20000	-145.6668	-104.7332

```
T-TEST
  /TESTVAL=500
  /MISSING=ANALYSIS
  /VARIABLES=Conductivity
  /CRITERIA=CI(.9500).
```

T-Test

otes

Output Created		23-Jul-2017 12:11:14
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=500 /MISSING=ANALYSIS /VARIABLES=Conductivity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.011

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Conductivity us/cm	5	322.6000	141.41358	63.24207

One-Sample Test

	Test Value = 500					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Conductivity us/cm	-2.805	4	.049	-177.40000	-352.9881	-1.8119

```
T-TEST
  /TESTVAL=5.0
  /MISSING=ANALYSIS
  /VARIABLES=Nitrate Phosphate Sodium Pottasium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:12:27
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=5.0 /MISSING=ANALYSIS /VARIABLES=Nitrate Phosphate Sodium Pottasium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.013

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Nitrate mg/l	5	1.7404	1.01802	.45527
Phosphate mg/l	5	1.7740	1.25645	.56190
Sodium (ppm)	5	9.2522	2.30075	1.02893
Potassium (ppm)	5	5.7302	1.92374	.86032

One-Sample Test

	Test Value = 5.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Nitrate mg/l	-7.160	4	.002	-3.25960	-4.5236	-1.9956
Phosphate mg/l	-5.741	4	.005	-3.22600	-4.7861	-1.6659
Sodium (ppm)	4.133	4	.014	4.25220	1.3954	7.1090
Potassium (ppm)	.849	4	.444	.73020	-1.6584	3.1188

```
T-TEST
 /TESTVAL=10.0
 /MISSING=ANALYSIS
 /VARIABLES=Calcium Magnesium
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:13:40
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=10.0 /MISSING=ANALYSIS /VARIABLES=Calcium Magnesium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.010

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Calcium (ppm)	5	4.4708	.96765	.43275
Magnesium (ppm)	5	7.1972	1.87490	.83848

One-Sample Test

	Test Value = 10.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Calcium (ppm)	-12.777	4	.000	-5.52920	-6.7307	-4.3277
Magnesium (ppm)	-3.343	4	.029	-2.80280	-5.1308	-.4748

```
T-TEST
  /TESTVAL=0.05
  /MISSING=ANALYSIS
  /VARIABLES=Lead Silver
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:16:29
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.05 /MISSING=ANALYSIS /VARIABLES=Lead Silver /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.017

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lead (ppm)	5	.3096	.15696	.07020
Silver (ppm)	5	.1260	.13892	.06213

One-Sample Test

	Test Value = 0.05					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Lead (ppm)	3.698	4	.021	.25960	.0647	.4545
Silver (ppm)	1.223	4	.288	.07600	-.0965	.2485

```
T-TEST
  /TESTVAL=0.3
  /MISSING=ANALYSIS
  /VARIABLES=Copper Manganese Cadmium Chromium Zinc Iron
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:17:56
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3 /MISSING=ANALYSIS /VARIABLES=Copper Manganese Cadmium Chromium Zinc Iron /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.015

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Copper (ppm)	5	.0442	.03161	.01414
Manganese	5	.4224	.05090	.02276
Cadmium (ppm)	5	.0270	.02587	.01157
Chromium (ppm)	5	.0542	.02302	.01029
Zinc (ppm)	5	.1906	.08147	.03643
Iron (ppm)	5	37.9430	5.28946	2.36552

One-Sample Test

	Test Value = 0.3					
					95% Confidence Interval of the Difference	
	t	df	Sd)	Mean Difference	Lower	Upper

Copper (ppm)	-18.095	4	.000	-.25580	-.2950	-.2166
Manganese	5.377	4	.006	.12240	.0592	.1856
Cadmium (ppm)	-23.601	4	.000	-.27300	-.3051	-.2409
Chromium (ppm)	-23.881	4	.000	-.24580	-.2744	-.2172
Zinc (ppm)	-3.003	4	.040	-.10940	-.2106	-.0082
Iron (ppm)	15.913	4	.000	37.64300	31.0753	44.2107

```
T-TEST
 /TESTVAL=0.03
 /MISSING=ANALYSIS
 /VARIABLES=Mercury
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:18:55
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.03 /MISSING=ANALYSIS /VARIABLES=Mercury /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.016

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Mercury (ppm)	5	.2226	.10672	.04772

One-Sample Test

	Test Value = 0.03					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Mercury (ppm)	4.036	4	.016	.19260	.0601	.3251

```
T-TEST
 /TESTVAL=120
 /MISSING=ANALYSIS
 /VARIABLES=Chloride
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:19:19
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=120 /MISSING=ANALYSIS /VARIABLES=Chloride /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.017

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Chloride mg/l	5	146.4000	31.18173	13.94489

One-Sample Test

	Test Value = 120					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Chloride mg/l	1.893	4	.131	26.40000	-12.3172	65.1172

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Aluminum
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:20:00
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Aluminum /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.062

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Aluminium (ppm)	5	41.8840	6.86160	3.06860

One-Sample Test

	Test Value = 0.00					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Aluminium (ppm)	13.649	4	.000	41.88400	33.3642	50.4038

```
T-TEST
  /TESTVAL=98.342
  /MISSING=ANALYSIS
  /VARIABLES=Silicon
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 12:20:25
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=98.342 /MISSING=ANALYSIS /VARIABLES=Silicon /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.000

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with FeAlSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Silicon ((ppm))	5	85.5330	10.01124	4.47716

One-Sample Test

	Test Value = 98.342					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Silicon ((ppm))	-2.861	4	.046	-12.80900	-25.2396	-.3784

b. Hypothesis 6 ($NaSiO_4$)

```
T-TEST
  /TESTVAL=6.5
  /MISSING=ANALYSIS
  /VARIABLES=pH
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 13:58:25
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=6.5 /MISSING=ANALYSIS /VARIABLES=pH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.016

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
pH	5	6.05400	.163340	.073048

One-Sample Test

	Test Value = 6.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
pH	-6.106	4	.004	-.446000	-.64881	-.24319

```
T-TEST
 /TESTVAL=70
 /MISSING=ANALYSIS
 /VARIABLES=Hardness
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 13:58:43
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=70 /MISSING=ANALYSIS /VARIABLES=Hardness /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.011

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hardness mg/l	5	164.40000	71.128756	31.809747

One-Sample Test

	Test Value = 70					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference Lower	Upper
Hardness mg/l	2.968	4	.041	94.400000	6.08198	182.71802

```
T-TEST
 /TESTVAL=250
 /MISSING=ANALYSIS
 /VARIABLES=Turbidity
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 13:58:58
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=250 /MISSING=ANALYSIS /VARIABLES=Turbidity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.032
	Elapsed Time	00:00:00.021

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Turbidity NTU	5	112.20000	24.355697	10.892199

One-Sample Test

	Test Value = 250					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity NTU	-12.651	4	.000	-137.800000	-168.04159	-107.55841

```
T-TEST
 /TESTVAL=500
 /MISSING=ANALYSIS
 /VARIABLES=Conductivity
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 13:59:29
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=500 /MISSING=ANALYSIS /VARIABLES=Conductivity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.032
	Elapsed Time	00:00:00.008

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Conductivity us/cm	5	524.40000	93.937745	42.010237

One-Sample Test

	Test Value = 500					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Conductivity us/cm	.581	4	.593	24.400000	-92.23912	141.03912

```
T-TEST
 /TESTVAL=5.0
 /MISSING=ANALYSIS
 /VARIABLES=Nitrate Phosphate Sodium Potassium
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:00:29
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=5.0 /MISSING=ANALYSIS /VARIABLES=Nitrate Phosphate Sodium Potassium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.021

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

		Mean	Std. Deviation	Std. Error Mean
Nitrate mg/l	5	1.26160	.969754	.433687
Phosphate mg/l	5	1.42540	.322723	.144326
Sodium (ppm)	5	23.36880	4.302088	1.923952
Potassium (ppm)	5	5.55940	1.307378	.584677

One-Sample Test

	Test Value = 5.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Nitrate mg/l	-8.620	4	.001	-3.738400	-4.94251	-2.53429
Phosphate mg/l	-24.768	4	.000	-3.574600	-3.97531	-3.17389
Sodium (ppm)	9.547	4	.001	18.368800	13.02705	23.71055
Potassium (ppm)	.957	4	.393	.559400	-1.06392	2.18272

```
T-TEST
 /TESTVAL=10.0
 /MISSING=ANALYSIS
 /VARIABLES=Calcium Magnesium
 /CRITERIA=CI(.9500).
```

T-Test

otes

Output Created		23-Jul-2017 14:01:23
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=10.0 /MISSING=ANALYSIS /VARIABLES=Calcium Magnesium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.032
	Elapsed Time	00:00:00.013

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Calcium (ppm)	5	4.51660	.478674	.214070
Magnesium (ppm)	5	7.72460	1.229784	.549976

One-Sample Test

	Test Value = 10.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Calcium (ppm)	-25.615	4	.000	-5.483400	-6.07775	-4.88905
Magnesium (ppm)	-4.137	4	.014	-2.275400	-3.80238	-.74842

```
T-TEST
  /TESTVAL=0.05
  /MISSING=ANALYSIS
  /VARIABLES=Lead Silver
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:03:19
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.05 /MISSING=ANALYSIS /VARIABLES=Lead Silver /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.013

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lead (ppm)	5	.31240	.114012	.050988
Silver (ppm)	5	.00900	.020125	.009000

One-Sample Test

	Test Value = 0.05					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Lead (ppm)	5.146	4	.007	.262400	.12084	.40396
Silver (ppm)	-4.556	4	.010	-.041000	-.06599	-.01601

```
T-TEST
  /TESTVAL=0.3
  /MISSING=ANALYSIS
  /VARIABLES=Copper Manganese Cadmium Chromium Zinc
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:05:09
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3 /MISSING=ANALYSIS /VARIABLES=Copper Manganese Cadmium Chromium Zinc /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.014

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Copper (ppm)	5	.12120	.193790	.086666
Manganese	5	.53000	.252733	.113026
Cadmium (ppm)	5	.01940	.004879	.002182
Chromium (ppm)	5	.09560	.034428	.015397
Zinc (ppm)	5	.18920	.083067	.037149

One-Sample Test

	Test Value = 0.3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper (ppm)	-2.063	4	.108	-.178800	-.41942	.06182
Manganese	2.035	4	.112	.230000	-.08381	.54381
Cadmium (ppm)	-128.613	4	.000	-.280600	-.28666	-.27454
Chromium (ppm)	-13.276	4	.000	-.204400	-.24715	-.16165
Zinc (ppm)	-2.983	4	.041	-.110800	-.21394	-.00766

```
T-TEST
  /TESTVAL=0.03
  /MISSING=ANALYSIS
  /VARIABLES=Mercury
  /CRITERIA=CI(.9500).
```

T-Test

otes

Output Created		23-Jul-2017 14:06:34
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.03 /MISSING=ANALYSIS /VARIABLES=Mercury /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.011

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Mercury (ppm)	5	.09360	.074420	.033282

One-Sample Test

	Test Value = 0.03					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Mercury (ppm)	1.911	4	.129	.063600	-.02880	.15600

```
T-TEST
  /TESTVAL=120
  /MISSING=ANALYSIS
  /VARIABLES=Chloride
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:07:01
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=120 /MISSING=ANALYSIS /VARIABLES=Chloride /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.296
	Elapsed Time	00:00:00.359

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Chloride mg/l	5	1.37400E2	16.786900	7.507330

One-Sample Test

	Test Value = 120					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Chloride mg/l	2.318	4	.081	17.400000	-3.44369	38.24369

```
T-TEST
  /TESTVAL=98.342
  /MISSING=ANALYSIS
  /VARIABLES=Silicon
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:07:54
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=98.342 /MISSING=ANALYSIS /VARIABLES=Silicon /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.078
	Elapsed Time	00:00:00.052

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Silicon ((ppm))	5	72.22420	12.083471	5.403893

One-Sample Test

	Test Value = 98.342					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Silicon ((ppm))	-4.833	4	.008	-26.117800	-41.12141	-11.11419

```
T-TEST
  /TESTVAL=0.3
  /MISSING=ANALYSIS
  /VARIABLES=Iron
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:09:03
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3 /MISSING=ANALYSIS /VARIABLES=Iron /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.012

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with NaSi04.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Iron (ppm)	5	4.83400	1.055010	.471815

One-Sample Test

	Test Value = 0.3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Iron (ppm)	9.610	4	.001	4.534000	3.22403	5.84397

c. Hypothesis 6 (CaOH)

```
T-TEST
 /TESTVAL=6.5
 /MISSING=ANALYSIS
 /VARIABLES=pH
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:36:10
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=6.5 /MISSING=ANALYSIS /VARIABLES=pH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.020

C:\Users\USER\Desktop\Mr_David\Gruting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
pH	5	6.00400	.285009	.127460

One-Sample Test

	Test Value = 6.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
pH	-3.891	4	.018	-.496000	-.84989	-.14211

```
EST
 /TESTVAL=70
 /MISSING=ANALYSIS
 /VARIABLES=Hardness
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:36:30
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=70 /MISSING=ANALYSIS /VARIABLES=Hardness /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.062
	Elapsed Time	00:00:00.040

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hardness mg/l	5	212.20000	184.106491	82.334926

One-Sample Test

	Test Value = 70					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hardness mg/l	1.727	4	.159	142.200000	-86.39840	370.79840

```
T-TEST
  /TESTVAL=250
  /MISSING=ANALYSIS
  /VARIABLES=Turbidity
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:36:45
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=250 /MISSING=ANALYSIS /VARIABLES=Turbidity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.011

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Turbidity NTU	5	64.20000	14.956604	6.688797

One-Sample Test

	Test Value = 250					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity NTU	-27.778	4	.000	-185.800000	-204.37108	-167.22892

T-TEST

/TESTVAL=500
/MISSING=ANALYSIS
/VARIABLES=Conductivity
/CRITERIA=CI(.9500).

T-Test

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

Notes

Output Created		23-Jul-2017 14:37:08
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=500 /MISSING=ANALYSIS /VARIABLES=Conductivity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.011

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Conductivity us/cm	5	427.20000	80.088701	35.816756

One-Sample Test

	Test Value = 500					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Conductivity us/cm	-2.033	4	.112	-72.800000	-172.24326	26.64326

T-TEST
/TESTVAL=5.0
/MISSING=ANALYSIS
/VARIABLES=Phosphate Sodium Potassium
/CRITERIA=CI(.9500).

T-Test

Notes

Output Created		23-Jul-2017 14:39:53
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=5.0 /MISSING=ANALYSIS /VARIABLES=Phosphate Sodium Potassium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.037

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Phosphate mg/l	5	2.05540	.387210	.173166
Sodium (ppm)	5	17.28320	5.435983	2.431045
Potassium (ppm)	5	28.58740	6.503153	2.908298

One-Sample Test

	Test Value = 5.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Phosphate mg/l	-17.005	4	.000	-2.944600	-3.42539	-2.46381
Sodium (ppm)	5.053	4	.007	12.283200	5.53354	19.03286
Potassium (ppm)	8.110	4	.001	23.587400	15.51267	31.66213

```
T-TEST
  /TESTVAL=10.0
  /MISSING=ANALYSIS
  /VARIABLES=Calcium Magnesium
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:41:06
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=10.0 /MISSING=ANALYSIS /VARIABLES=Calcium Magnesium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.032
	Elapsed Time	00:00:00.010

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Calcium (ppm)	5	157.64880	61.442876	27.478089
Magnesium (ppm)	5	16.77780	2.417919	1.081326

One-Sample Test

	Test Value = 10.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Calcium (ppm)	5.373	4	.006	147.648800	71.35739	223.94021
Magnesium (ppm)	6.268	4	.003	6.777800	3.77556	9.78004

```
T-TEST
  /TESTVAL=0.05
  /MISSING=ANALYSIS
  /VARIABLES=Lead Silver Cobalt
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:42:01
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.05 /MISSING=ANALYSIS /VARIABLES=Lead Silver Cobalt /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.062
	Elapsed Time	00:00:00.044

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lead (ppm)	5	.56880	.408664	.182760
Silver (ppm)	5	.03180	.059575	.026643
Cobalt (ppm)	5	.02480	.051100	.022853

One-Sample Test

	Test Value = 0.05					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Lead (ppm)	2.839	4	.047	.518800	.01138	1.02622
Silver (ppm)	-.683	4	.532	-.018200	-.09217	.05577
Cobalt (ppm)	-1.103	4	.332	-.025200	-.08865	.03825

```
T-TEST
  /TESTVAL=0.3
  /MISSING=ANALYSIS
  /VARIABLES=Copper Manganese Cadmium Chromium Zinc
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:53:52
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3 /MISSING=ANALYSIS /VARIABLES=Copper Manganese Cadmium Chromium Zinc /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.011

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Copper (ppm)	5	.01620	.015834	.007081
Manganese	5	.39800	.252107	.112746
Cadmium (ppm)	5	.01720	.020825	.009313
Chromium (ppm)	5	.05300	.020322	.009088
Zinc (ppm)	5	.41420	.108421	.048488

One-Sample Test

	Test Value = 0.3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper (ppm)	-40.079	4	.000	-.283800	-.30346	-.26414
Manganese	.869	4	.434	.098000	-.21503	.41103
Cadmium (ppm)	-30.365	4	.000	-.282800	-.30866	-.25694
Chromium (ppm)	-27.177	4	.000	-.247000	-.27223	-.22177
Zinc (ppm)	2.355	4	.078	.114200	-.02042	.24882

```
T-TEST
  /TESTVAL=0.03
  /MISSING=ANALYSIS
  /VARIABLES=Mercury Cobalt
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:55:10
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.03 /MISSING=ANALYSIS /VARIABLES=Mercury Cobalt /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.010

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Mercury (ppm)	5	.26920	.366880	.164074
Cobalt (ppm)	5	.02480	.051100	.022853

One-Sample Test

	Test Value = 0.03					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Mercury (ppm)	1.458	4	.219	.239200	-.21634	.69474
Cobalt (ppm)	-.228	4	.831	-.005200	-.06865	.05825

```
T-TEST
  /TESTVAL=0.3
  /MISSING=ANALYSIS
  /VARIABLES=Zinc
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:55:36
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3 /MISSING=ANALYSIS /VARIABLES=Zinc /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.032
	Elapsed Time	00:00:00.019

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Zinc (ppm)	5	.41420	.108421	.048488

One-Sample Test

	Test Value = 0.3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Zinc (ppm)	2.355	4	.078	.114200	-.02042	.24882

```
T-TEST
  /TESTVAL=0.3
  /MISSING=ANALYSIS
  /VARIABLES=Iron
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:55:53
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3 /MISSING=ANALYSIS /VARIABLES=Iron /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.128

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Iron (ppm)	5	1.84140	.885969	.396217

One-Sample Test

	Test Value = 0.3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Iron (ppm)	3.890	4	.018	1.541400	.44132	2.64148

```
T-TEST
  /TESTVAL=0.00
  /MISSING=ANALYSIS
  /VARIABLES=Arsenic
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		23-Jul-2017 14:56:48
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.00 /MISSING=ANALYSIS /VARIABLES=Arsenic /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.010

C:\Users\USER\Desktop\Mr_David\Grouting with CaOH.sav

Warnings

The One-Sample Test table is not produced.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Arsenic (ppm)	5	.00000	.000000[a]	.000000

a. t cannot be computed because the standard deviation is 0.

d. Hypothesis 6 (CaCl)

```
T-TEST
  /TESTVAL=6.5
  /MISSING=ANALYSIS
  /VARIABLES=pH
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 07:57:03
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=6.5 /MISSING=ANALYSIS /VARIABLES=pH /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.047
	Elapsed Time	00:00:00.249

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
pH	5	1.82840	.807529	.361138

One-Sample Test

	Test Value = 6.5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
pH	-12.936	4	.000	-4.671600	-5.67428	-3.66892

```
T-TEST
  /TESTVAL=70
  /MISSING=ANALYSIS
  /VARIABLES=Hardness
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 07:58:48
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=70 /MISSING=ANALYSIS /VARIABLES=Hardness /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.016

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Hardness mg/l	5	2.33360	.606164	.271085

One-Sample Test

	Test Value = 70					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hardness mg/l	-249.613	4	.000	-67.666400	-68.41905	-66.91375

```
T-TEST
  /TESTVAL=250
  /MISSING=ANALYSIS
  /VARIABLES=Turbidity
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 07:59:30
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=250 /MISSING=ANALYSIS /VARIABLES=Turbidity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.015

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Turbidity NTU	5	1.82840	.807529	.361138

One-Sample Test

	Test Value = 250					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity NTU	-687.194	4	.000	-248.171600	-249.17428	-247.16892

```
T-TEST
 /TESTVAL=500
 /MISSING=ANALYSIS
 /VARIABLES=Conductivity
 /CRITERIA=CI(.9500)
```

T-Test

Notes

Output Created		22-Jul-2017 08:00:15
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=500 /MISSING=ANALYSIS /VARIABLES=Conductivity /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.016

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Conductivity us/cm	5	2.33360	.606164	.271085

One-Sample Test

	Test Value = 500					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Conductivity us/cm	-1.836E3	4	.000	-497.666400	-498.41905	-496.91375

```
T-TEST
 /TESTVAL=5.0
 /MISSING=ANALYSIS
 /VARIABLES=Nitrate Phosphate Sodium Potassium
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 08:01:42
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=5.0 /MISSING=ANALYSIS /VARIABLES=Nitrate Phosphate Sodium Potassium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.015
	Elapsed Time	00:00:00.017

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Nitrate mg/l	5	1.82840	.807529	.361138
Phosphate mg/l	5	2.33360	.606164	.271085
Sodium (ppm)	5	20.81580	3.196908	1.429701
Potassium (ppm)	5	26.04740	9.847837	4.404086

One-Sample Test

	Test Value = 5.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Nitrate mg/l	-8.782	4	.001	-3.171600	-4.17428	-2.16892
Phosphate mg/l	-9.836	4	.001	-2.666400	-3.41905	-1.91375
Sodium (ppm)	11.062	4	.000	15.815800	11.84631	19.78529
Potassium (ppm)	4.779	4	.009	21.047400	8.81970	33.27510

```
T-TEST
 /TESTVAL=10.0
 /MISSING=ANALYSIS
 /VARIABLES=Calcium Magnesium
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 08:03:29
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=10.0 /MISSING=ANALYSIS /VARIABLES=Calcium Magnesium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.046

Notes

Output Created		22-Jul-2017 08:03:29
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=10.0 /MISSING=ANALYSIS /VARIABLES=Calcium Magnesium /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.046
	Elapsed Time	00:00:00.031

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Calcium (ppm)	5	207.69000	69.775902	31.204732
Magnesium (ppm)	5	318.99160	676.979168	302.754288

One-Sample Test

	Test Value = 10.0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Calcium (ppm)	6.335	4	.003	197.690000	111.05177	284.32823
Magnesium (ppm)	1.021	4	.365	308.991600	-531.58906	1149.57226

```
T-TEST
  /TESTVAL=0.05
  /MISSING=ANALYSIS
  /VARIABLES=Lead Silver Cobalt
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 08:05:59
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.05 /MISSING=ANALYSIS /VARIABLES=Lead Silver Cobalt /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.000

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Lead (ppm)	5	.69540	.248427	.111100
Silver (ppm)	5	.00000	.000000[a]	.000000
Cobalt (ppm)	5	.01220	.016739	.007486

a. t cannot be computed because the standard deviation is 0.

One-Sample Test

	Test Value = 0.05					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Lead (ppm)	5.809	4	.004	.645400	.33694	.95386
Cobalt (ppm)	-5.049	4	.007	-.037800	-.05858	-.01702

```
T-TEST
 /TESTVAL=0.3
 /MISSING=ANALYSIS
 /VARIABLES=Copper Manganese Cadmium Chromium Zinc
 /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 08:08:27
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.3 /MISSING=ANALYSIS /VARIABLES=Copper Manganese Cadmium Chromium Zinc /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.015

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Copper (ppm)	5	.03100	.022935	.010257
Manganese	5	.89540	.660043	.295180
Cadmium (ppm)	5	.00580	.005495	.002458
Chromium (ppm)	5	.06200	.022705	.010154
Zinc (ppm)	5	.62460	.101473	.045380

One-Sample Test

	Test Value = 0.3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper (ppm)	-26.227	4	.000	-.269000	-.29748	-.24052
Manganese	2.017	4	.114	.595400	-.22415	1.41495
Cadmium (ppm)	-119.708	4	.000	-.294200	-.30102	-.28738
Chromium (ppm)	-23.439	4	.000	-.238000	-.26619	-.20981
Zinc (ppm)	7.153	4	.002	.324600	.19860	.45060

```
T-TEST
  /TESTVAL=0.03
  /MISSING=ANALYSIS
  /VARIABLES=Mercury
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 08:09:41
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=0.03 /MISSING=ANALYSIS /VARIABLES=Mercury /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.031
	Elapsed Time	00:00:00.016

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Mercury (ppm)	5	.12660	.025274	.011303

One-Sample Test

	Test Value = 0.03					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Mercury (ppm)	8.546	4	.001	.096600	.06522	.12798

```
T-TEST
  /TESTVAL=120
  /MISSING=ANALYSIS
  /VARIABLES=Chloride
  /CRITERIA=CI(.9500).
```

T-Test

Notes

Output Created		22-Jul-2017 08:10:21
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	5
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST /TESTVAL=120 /MISSING=ANALYSIS /VARIABLES=Chloride /CRITERIA=CI(.9500).
Resources	Processor Time	00:00:00.000
	Elapsed Time	00:00:00.031

[DataSet1] C:\Users\USER\Desktop\Mr_David\Grouting with CaCl.sav

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Chloride mg/l	5	562.80000	743.802864	332.638753

One-Sample Test

	Test Value = 120					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Chloride mg/l	1.331	4	.254	442.800000	-480.75324	1366.35324

e. <u>Test For The Overalll Best Grouting Chemical</u>

```
UNIANOVA Data BY Chemicals Characteristics
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /POSTHOC=Chemicals Characteristics (LSD)
  /PRINT=HOMOGENEITY
  /CRITERIA=ALPHA(.05)
  /DESIGN=Chemicals Characteristics Chemicals* Characteristics.
```

Univariate Analysis of Variance

Notes

Output Created		24-Jul-2017 22:38:54
Comments		
Input	Data	C:\Users\USER\Desktop\Mr_David\MANOVA.sav
	Active Dataset	DataSet2
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	710
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax		UNIANOVA Data BY Chemicals Actions /METHOD=SSTYPE(3) /INTERCEPT=INCLUDE /POSTHOC=Chemicals Actions(LSD) /PRINT=HOMOGENEITY /CRITERIA=ALPHA(.05) /DESIGN=Chemicals Actions Chemicals*Actions.
Resources	Processor Time	00:00:00.046
	Elapsed Time	00:00:00.048