DEVELOPMENT OF PREDICTIVE MODELS FOR SYNERGISTIC IMPACT OF AGE, PERIOD OF EXPOSURE AND NOISE LEVEL IN QUARRIES ON HEARING THRESHOLD OF WORKERS

BY

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CERTIFICATION

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DEDICATION

This work is dedicated to GOD and the entire members of Dosumu - Opeifa family.

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ABSTRACT

Despite the importance of quarry operations to the construction industry in developing countries, the excessive occupational noise involved in quarry operations is a threat to the health of workers. Studies have shown that the age and years of work exposure (YE) are two of the major factors that contribute to auditory health problems among the quarry workers. Information on the effect of noise and related susceptibility factors on hearing damage among Nigerian quarry workers are sparse. This study was conducted to develop suitable models in order to investigate the synergistic influence of age, YE and Noise Level (NL) in quarries on the Hearing Threshold (HT) of workers.

Questionnaires were administered to 204 quarry workers, who were randomly selected in the year 2018 from four different quarry sites in southwestern Nigeria, to obtain the age and YE. A follow up study was conducted on 185 of them in 2019. The NL at the quarry sites during the working hours were measured using a digital sound level meter, while an audiogram measured the HT at eight different frequencies (0.25, 0.50, 1.00, 2.00, 3.00, 4.00, 6.00 and 8.00kHz). Using ANOVA, eight regression models were developed and validated to predict both the effects of age, YE and NL on HT, and the safe HT. These were used to test for both the similarity of the NL conditions in the sites and the predictive significance of the regression model terms. The predictive accuracies of the developed models were evaluated using the predicted R^2, while paired sample t-test and correlation statistics were used to ascertain the impact of the workers' continual exposure to noise within the study period. Analyses were done using t-test at $\alpha_{0.05}$.

The percentage distribution of their age range in years were 9.7% (15-30), 50.8% (31-45), 38.4% (46-60), and 1.1% (60+). The mean age and YE were 42±9.01 and 18±7.03 years, respectively. The NL were in the range of 87.30-116.98dB as against the permissible exposure level of 85.00dB. The NL conditions on the sites were not significantly different (101.61±0.38, 99.28±0.51, 100.51±1.01, 99.28±0.10). The Mean HT of the workers was 45.60±1.24dB and 75.0% of them had HT higher than the safe HT of ≤30.00dB. The age predicted the workers' HT at all frequencies considered. The YE significantly predicted the HT at 1.00, 2.00, and 4.00 kHz, while NL significantly predicted the HT at 0.25 and 0.50 kHz. The models' predicted R^2 range was 0.71 – 0.82. The safe HT was predicted with age ≤52 years and YE ≤32 years. The validation results were in agreement with the data obtained during the experiment. The correlation and paired sample ranges were 0.17-0.79 and 6.50-26.7, respectively, which showed that the workers' HT continuously depreciated within the study period.

The developed models established that the synergistic factors of age, years of exposure and noise level influenced the hearing threshold of quarry workers. Thus, the models can be used for making decision in achieving workers' safe operations in quarry industry.

Keywords: Quarry industry, Occupational noise, Noise level, Hearing threshold.

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LIST OF ABBREVIATIONS

ACRONYMS	MEANING
Adeq	Adequate Precision
Adj	Adjusted Values
AG	Age of workers
ANFIS	Adaptive Neuro-Fuzzy Inference System
ANN	Artificial Neural Networks
ANSI	American National Standard Institute.
CV	Coefficient of Variation
FIS	Fuzzy Inference System
FL	Fuzzy logic
HDD	Historical Data Design
HL	Hearing Level
HPD	Hearing Protective Devices.
HT	Hearing Threshold
MFS	Membership function
MSE	Mean Square Error
NIHL	Noise Induced Hearing Loss
NL	Noise Level
NN	Neural Network
NRR	Noise Reduction Rating
Nummfs	Membership functions number
Ob	Observed Value(s),
PEL	Permissible Exposure Level
PRE	Predicted Value(s)
Pred	Predicted Values
PTA	Pure Tone Audiogram
PTS	Permanent Threshold Shift
R^2	Coefficient of Determination
RMSE	Root Mean Square Error
RSM	Response Surface Method
TTS	Transient Threshold Shift
TWA	Time Weighted Average
YE	Years of Exposure

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Noise is defined as an unwanted, excessive sound which can be harmful to the health and wellbeing of the subjects exposed to it (Al-Maghrabi *et al.* 2013; Fink, 2019). It is considered hazard and thus a safety problem because of its potential to negatively affect the safety and health of those exposed to it. Several occupational environments including construction, manufacturing, mining, music, agriculture and sports have been identified as being susceptible to noise hazards (Acoustical Surfaces, 2013; Pulsar Instruments, 2015). Nanda (2012) stated that noise types such as intermittent noise, impact or impulsive noise, repetitive impact noise, continuous wide band noise, continuous narrow band noise are continual occurrences in these types of occupational environments.

Research has shown that the chronic exposure to these noise forms could directly lead to irreparable physical health effects such as hearing damage (Le *et al.* 2017; Holman *et al.* 2019), rising cases of dementia (Lin *et al.* 2011), and increased rate of hospitalisation (Correia *et al.* 2013; He *et al.* 2019). In addition, other safety problems that have been indirectly linked with unwanted noise include physiological, psychological and psychosocial (Mick *et al.* 2014; Kamil and Lin, 2015; Cunningham and Tucci, 2017; Shukla *et al.* 2020) and economic consequences (Allen and Eddins, 2010; Bainbridge and Wallhagen, 2014). Thus to be able to significantly reduce or mitigate these noise related safety problems, there is need for the application of proper noise control measures.

The quarry industry is one that is also characterized by the predominance of noise pollution. It typically involves the use of high noise generating mechanical equipment for the extraction of materials from the surface of the earth to produce materials such as sand, stones, laterite clay and granite (Johnson, 2023). Globally it is considered an important industry since it helps in the production of support materials for other industries such as manufacturing and construction. In Nigeria, the quarry industry is a large one with multiple quarrying activity sites present in thirty five states of the country in addition to the federal capital territory. In 2018 alone, the total product output from quarry activities was reported to be more than fifty-four million tonnes (National Bureau of Statistics, 2019). It is considered as one of the most viable production sectors in Nigeria and its socioeconomic impact has been considered quite significant as it serves as a source of employment to more than half a million people (Oladimeji *et al.* 2019; Salawu and Sadiq, 2020). Adeniyi (2021) reported that as at 2014, the industry accounted for 10.6 percent of the country's GDP and 0.2 percent of the total workers employed.

One major occupational safety concern affecting quarry workers is that of Noise Induced Hearing Loss (NIHL) caused from chronic exposure to noise during work activities. It is considered to be the most common form of hearing impairment after presbycusis (Tripathy and Rao, 2017). According to the World Health Organisation (WHO, 2023), hearing loss can be defined as a situation where an individual is unable to hear sounds below 20 decibels (dBA). According to the American National Standards Institute [ANSI] (Anastasiadou and Al Khalili, 2022), NIHL among people exist in different classifications ranging from slight-mild hearing loss (16-40 dBA) to moderate-severe hearing loss (41-90 dBA). The threshold for the noise level beyond which can cause profound impairment and deafness somewhat varies among different regulatory bodies but lies between 80 and 90 dBA (Stevens *et al.* 2011; Humes, 2019; Anastasiadou and Al Khalili, 2022). The NIHL typically begins as secondary hearing losses; a scenario where an individual is unable to hear sounds at high frequencies within the range of 4-8 kHz and if unchecked may deteriorate to hear primary hearing losses where the individual cannot hear sounds at low frequencies (0.5-3 kHz) (Workman-Davies, 1989; Tripathy and Rao, 2017).

In this regard, several research outcomes have reported that a significant proportion of workforce involved in quarry processes are affected by the noise produced by heavy mechanical equipment for activities such as rock blasting, crushing, and power generation. (Ukpong, 2012; Gyamfi *et al.* 2016; Akinluyi *et al.* 2019; Kulabako, 2019). For example, research such as investigating the extent of noise level attenuation provided by personal protective equipment (Workman-Davies, 1989), assessment of and prediction model development for prediction of noise levels produced by mining equipment (Vardhan *et al.* 2004; Vardhan *et al.* 2006; Phillips *et al.* 2007; Nanda, 2012) and studies to ascertain knowledge, attitude, and practices of workers with respect to noise induced hearing losses (NIHL) (Ismail *et al.* 2013) have all been done.

Further research has also been done to have a broader understanding of this problem with a view to effectively managing its impact on workers. The outcomes from these research indicate that hearing losses from quarry activities generally occur as a function of three major factors namely; the age of a worker, the years of worker’s exposure to the noisy conditions and the noise levels at which the worker is exposed (Amedofu, 2002; Kerketta *et al.* 2012a; Nanda, 2012; Ismail *et al.* 2013; Mener *et al.* 2013; Gyamfi *et al.* 2016).

However, the extent in which age, exposure duration and noise level play singularly and interactively in the occurrence of NIHL among quarry workers has been given sparse attention. Nonetheless, a few study exist such as Kerketta *et al.* (2012b) who investigated the effect of the factors on secondary NIHL. Also, Onder *et al.* (2012) investigated the effects of these three factors on the NIHL on quarry workers. However, they were not specific with regards to the hearing frequencies at which the investigation was conducted. Furthermore, Tripathy and Rao (2017) undertook a more comprehensive study of effect of the three factors on the NIHL of mine workers at low and high frequencies.

1.2 Statement of the Problem

Previous literature revealed that some workstations with machine produces high noise level beyond Permissible Exposure Limit (PEL) which subject those workers involved to potential hearing threshold shift (Mulugate, 1992; Boateng and Amedofu, 2004; Ismail *et al.* 2013). In the same vein, quarry workers in Nigeria are exposed to high levels of noise due to the types of equipment used in their daily operation. It is thus a possibility that there will be a certain point or range of a worker’s age and exposure length combined with existing noise level, which can lead to irreparable damage to worker’s hearing system. As such, there is need to assess the synergistic impact of these factors on the NIHL in quarry workers in Nigeria.

However, information appears sparse regarding the existence of models or procedures to estimate the degree of synergistic interaction of the three factors that provides information on the safe hearing threshold of workers as well as determine their effects on hearing threshold over time in Nigerian quarries. This study is aimed at addressing this problem.

1.3 Aim and Objectives of the Study

The aim of this study is to develop models for predicting workers safe hearing threshold based on the synergistic impact of age, years of exposure and noise level.

The objectives of this study are to:

1. Measure the noise magnitude of the machinery used in quarry operation.
2. Develop predictive models for hearing threshold of quarry workers.
3. Determine the combination of values of age, years of exposure and noise level that can result to the safe hearing threshold of workers.
4. Determine the effects of age, years of exposure and noise level on hearing threshold over time.

1.4 Justification for the Research

A worker with occupational noise induced hearing loss may have problem of effective communication. This can be considered to be a reduction in job performance and cognition (Mohammadi *et al.* 2009). Selection of physiologically fit workers to a particular task enhances productivity with little or no losses. Since every worker has variations in age, years of exposure and noise levels, there may be different physiological differences among them. It will be of high benefit for the worker to engage at the appropriate workstation which cannot contradict their health and well-being status during and after work. More so, an employer wants to ensure an adequate manpower with little or no absenteeism, unnecessary compensations etc.

Data generated from this research work can be used to modify the quarry workstation to ease worker and working environment interactions. Such data, if utilised, will curb the effect of hearing problems which is the main indication of workers exposure to the unacceptable noise level. This could consequently help in framing comprehensive plans towards a safer, more effective and more efficient man-machine system.

This research is also imperative as the present workers and employers in noisy occupational environment in Nigeria may not notice the starting time of the hearing problem because it always starts as a hidden damage. Human response to noise has become a critical problem in these activities since overexposure may cause discomfort, thus, negatively influencing workers social performances, lower productivity or may even pose health risks. The outcome of this study will provide information for decision makers for the purpose of managing quarry workers responses to NIHL better.

1.5 Scope and Limitation of the Study

Only continuous noise from the machinery in the quarry was considered. The workers' race, ethnicity and life style like smoking, alcohol consumption were not considered in this study. It was observed that none of the quarry workers embrace the usage of any hearing protective device (HPD).

1.6 Outline of Succeeding Chapters

The review of relevant literature is presented in chapter two, Chapter three contains the Method of study. Chapter four comprises Results and Discussion, Summary, Conclusion and Recommendations are presented in Chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1 The problem of Noise

Due to increasing level of industrialisation, industrial noise is a growing problem. It is very important to be able to quantify and control this noise and as a consequence, its effects on man and its environment. In an environment where noise poses a problem to the general well-being of the people, a safety precaution is needed in order to reduce the effect. Safety devices such as earmuffs and ear plugs can also be used properly even though these do not actually suppress the noise effect on the operator (Bisong *et al.* 2004). An understanding of people's subjective response to noise allows environmentalists' and engineers to reduce noise in more effective ways. For example, noise should be reduced in the ear sensitive frequency range. Noise reduction should be by a magnitude which is subjectively significant.

The most notable effect of occupational noise is permanent loss of hearing due to higher hearing threshold, which can occur on a daily basis over many years in the workplace. Such hearing impairment generally regarded as noise induced hearing loss (NIHL) always occurs gradually and if not noticed, may cause permanent damage.

2.2 Hearing Loss

This is a phenomenon that occurs when the hearing threshold of a person is above the normal hearing threshold of a healthy person.

2.2.1 Noise Induced Hearing Loss

Hearing level (HL) is defined as the difference between audibility of a normal person having normal hearing and patient's threshold audibility at a given frequency

(Burtka and Chick, 1997; Ochmann and Piscoya, 2021).

Mathematical expression of Hearing loss is shown in equation (2.1).

$$HL = 10\log\left(\frac{I}{I_o}\right)\ \text{(dB)} \tag{2.1}$$

Where,

I = patient's ear threshold sound intensity.

I_o = normal ear threshold intensity.

The most serious pathological effects of noise on workers is the development of excessive hearing threshold leading to hearing loss or complete deafness. Continuous exposure to noise above 90 dBA may lead to the permanent hearing loss which the victims may be unaware of (Asfahl, 2004).

When workers with unprotected ears are exposed to loud noise continuously which are potentially injurious to hearing, the inner ear adapt to the noise firstly by exhibiting a transient threshold shift (TTS) or a permanent threshold shift (PTS) (England and Larsen, 2014). TTS hearing loss occurs within hours to a few days. Therefore, workers should be away from noise for between 24-48 hours before an audiometric testing to avoid the effect of TTS in the test (England and Larsen, 2014). PTS hearing loss is a permanent damage that occurs as a result of irreparable injury to the hearing organ. Hearing frequencies between 3000 Hz and 6000 Hz has maximal injury at 4000 Hz and usually leads to noise - induced deafness (England and Larsen, 2014).

2.2.2 Classification of Hearing Loss

Hearing loss is categorised by World Health Organisation (WHO, 1991) according to the various grade of impairment with corresponding audiometric values and performance as shown in Table 2.1

2.2.3 Presbycussis

It is the progressive age related sensorinueral hearing loss which occasionally occurs around age 40 years (Burtka and Chick, 1997), though early exposure to high noise level may lead to hearing loss more rapidly than aging (Basner *et al*. 2014).

Table 2.1: World Health Organisation classification of hearing impairment

	Grade of Impairment	Corresponding Audiometric ISO Value	Performance
1.	No impairment.	25dB or less	No hearing problems, whispers can be heard.
2.	Slight impairment	26-40dB	Normal voice call can be heard at 1m distance.
3.	Moderate impairment	41-60 dB	Repeated words can be heard when raised voice at 1m
4.	Severe impairment	61 – 80 dB	Some words can be heard.
5	Profound impairment including deafness	81 dB or greater	Shouted voice cannot be heard and understood.

Source: WHO (1991)

2.3 Effects of Noise on Human Health

Exposure to higher intensity of noise creates psychological and physiological effect on human being such as anger, stress, acceleration in heartbeat, sleeping disorders, annoyance and increased blood pressure (Cunningham and Tucci, 2017).

2.3.1 Annoyance

W.H.O (2002) identified noise induced annoyance as an adverse health problem. Noise annoyance could be caused by noise-related disturbances of individuals and it is usually linked to negative emotional reactions such as anger, disappointment and displeasure which can cumulatively lead to physiological symptoms. The symptoms are as a result of signals transmitted from the auditory system to the nervous system which enhances several reactions in human bodies (Ouis, 2002). In contrast, people who were working in the noisy occupational environment were found to be less annoyed in this scenario. Furthermore, exposure-response models for combination of noise source are lacking. Also on an individual level, there may be large variations in the annoyance response, depending on exposure modifying annoyance response, depending on exposure modifying factors as well as on personal and situational factors.

2.4 Controlling Noise Exposure

Engineering controls reduces noise exposure by altering or removing the source; administrative control reduces noise exposure by regulating the shift of the workers in lieu of the exposure. PPE helps by protecting the hearing system of the workers by wearing it when the hazard have not been reduced to an acceptable level, therefore audiologist should be able to select the personal hearing protectors and their effective functionalities over exposure to loud noise.

There are standard type of hearing protection established by OSHA for the various workstations which depends on the degree of noise exposure intensity. Earplugs and earmuffs together must be worn when a worker is in high noise level working environment. Hearing protector attenuate noise exposure of the workers in noisy environment. Table 2.2 summarises the minimum levels of protection required by Canadian Standard Association (CSA).

Table 2.2: Selection of Hearing Protection Devices according to CSA

Maximum Equivalent Noise Level (dBA L_{ex})	**CSA Class of Hearing Protection**
≤ 90	C, B or A
≤ 95	B or A
≤ 100	A
≤ 105	A
≤ 110	A earplug + A or B earmuff
> 110	A earplug + A or B earmuff and limited exposure time to keep sound reaching the worker's ear drum below 85dBA L_{ex}

Source: Government of Alberta (2009)

2.5 Studies on Age related Noise Effects

Boman *et al.* (2005) analysed noise effects in memory performance in different age groups in order to see whether there are interactions of age with noise in their effects of memory. It was revealed that there were no interaction between noise and age groups indicating that the obtained noise effects were not related to the capacity to perform the task.

2.6 Predictive Models for Design Purpose

Different predictive models have been proposed and used many years ago for exploring relationship between two or more variables for design purposes and control. Some number of factors need to be considered in prediction technique selection which is likely to bring about trade-offs; and depends on capability of the models and organizational requirements. Maximisation of the prediction accuracy is the major intent as well as other considerations (Tronto *et al.* 2007).

2.7 Multiple Linear Regressions

Many engineering and science research problems involve finding the relationship between two or more variables. Often regression analysis is always suitable for these types of problems. Many regression analysis models are those where there are more than one independent variable; such are called a multiple linear regression models (Montgomery and Runger, 2007). Typical multiple regressor model can be formulated as in equation (2.2)

$$Y = \beta_0 + \beta_1 X_i + \beta_2 X_i + \cdots + \beta_j X_k + C \tag{2.2}$$

Where:

Y is the dependent variable or response, k is the number of independent or regressor variables, X_1 is the independent or regressor variable, $i = 1, 2, \dots k$ and β_1 is the regression co-efficient, $j = 0, 1, 2, \dots k$ and C is a term that includes the effect of unmodelled sources of variability that affect the dependent variable. Therefore, the multiple linear regressor helps to summarise the various relationships involved among the independent variables with the response.

2.8 Neural Network Technique

In the last few years, there has been increased interest on the application of Artificial Neural Networks (ANN) to several research problems in science and engineering. They are useful in design solutions, control, classification and estimation of problems and models prediction (Barati-Harooni *et al.* 2016). However, the usage of neural network is disadvantageous due to its inability to represent monotonic relations (Bonissone, 2002).

2.9 Adaptive Neuro - Fuzzy Inference System (ANFIS)

The Adaptive Neuro-Fuzzy Inference System (ANFIS), which is based on the first-order Sugeno fuzzy model that uses either a back propagation algorithm alone or a hybrid learning algorithm, consists of both Artificial Neural Network (ANN) and Fuzzy logic (FL). It includes linguistic expressions of membership function (MFs) and if (observation) then (actuation) rules (Tatar *et al.* 2016). ANFIS is a tool that integrates the best features of fuzzy systems and Neural Network (NN).

ANFIS network depends heavily on the choice of process variables involved, the available data set and the domain used for training purposes. Basically, a fuzzy inference system is composed of five functions block (Jang, 1993): (i) a rule based on containing a number of fuzzy if-then rules success (ii) a database which defines the membership function of the fuzzy sets used in the fuzzy rules. (iii) a decision making unit which perform the inference operation on the rules. (iv) a fuzzification inference which transforms the crisp inputs into degrees of match with linguistic values. (v) a defuzzification inference which transforms the fuzzy results of the inference into a crisp output. Assume that the fuzzy inference system has two inputs x and y and one output f for a first-order sugeno fuzzy model, a common rule set with two fuzzy if-then rule operates (Jang, 1993; Dua and Taniskidou, 2017; Nguyen *et al*. 2019).

FIS structure is a network-type structure similar to that of a neural network, which maps inputs through input membership functions and associated parameters to outputs. The parameters associated with the membership functions are modified through learning process. The adjustment of the parameter is generated by the vector gradient. The adjusted parameters are subsequently applied to all optimisation routine to reduce measurement error. Usually, if y_t is the current value of period t and F_t is the forecast for the same period, then as shown in equation (2.3), the error is defined as:

$$E_t = y_t - F_t \tag{2.3}$$

A mean square error (MSE) as shown in equation (2.4), is defined as:

$$MSE = \left(1/_n\right) \sum_{t=1}^{n} (y_t - F_t)^2 \tag{2.4}$$

Where n is the number of time periods.

ANFIS uses a combination of minimum squares error and back propagation for the estimation of activation function parameters. In other words, ANFIS utilises the advantages of FL and ANN to adjust its parameters and find optimum solutions. Both FL and ANN have their advantages, the marriage of learning capabilities of Neural Network and knowledge representation ability of fuzzy logic has given birth to Fuzzy Neural Networks. As a result, the drawback of neural network blackbox inability to explain decision (lack of transparency), and weakness of learning in fuzzy logic have been conquered (Salleh *et al.* 2017; Talpur *et al.* 2020).

Therefore it is a good idea to combine their ability and make a strong tool which improves their weakness and leads to a minimum error. This popular fuzzy set theory based tool has been successfully applied to many military and civilian areas including decision analysis, forecasting, pattern recognition, system controls (Automated Fuzzy Control Tuning) and models (to explain past data and predict future behaviour), inventory management, logistic systems and operations management (Gheisari *et al.* 2017; Salleh *et al.* 2017; Petković *et al.* 2019; Talpur *et al.* 2020) . The non-linearity and structured knowledge representation of ANFIS are its primary advantages over classical linear approaches (Karaboga and Kaya, 2016).

2.10 Introduction to the exhaustive search and ANFIS modelling

Exhaustive search is a general problem-solving technique that consists of systematically enumerating all possible candidates for the solution and checking whether each candidate satisfies the problem's statement (Kisi *et al.* 2018). Exhaustive search is always used to perform a thorough search of input data that best relates with output data to produce the least training and checking error. Exhaustive search is a combinatorial function which selects the required number of inputs combination to be tried during the search.

Adaptive Neuro Fuzzy Inference System (ANFIS) is a hybrid intelligent system which has the ability of Fuzzy Logic (FL) to reason with Neural Network (NN) to learn (Ilse *et al.* 2020). The goal of ANFIS is to find a model which will simulate correctly the inputs with the outputs. The fuzzy inference system (FIS) is a knowledge representation where each fuzzy rule describes a local behaviour of the system (Amirian, 2019). ANFIS is the network structure that implements FIS and employs hybrid-learning. The basic structure of FIS is a model that maps input characteristics to input membership functions, and the output membership function to a single-value output or a decision associated with the output (Aslan *et al.* 2019).

Using a given input/output data sets, the toolbox function "anfis" in MATLAB constructs a fuzzy inference system (FIS) whose membership function (MF) parameters are tuned (adjusted) using either a back propagation algorithm alone or in combination with a least squares type of method (Karaboga and Kaya, 2019).

2.11 Some Application of Adaptive Neuro - Fuzzy Inference System

The detailed architecture and learning procedure of ANFIS can be found at large in the literature (Jang, 1993; Petkovic *et al.* 2019; Gheisari *et al.* 2019; Talpur *et al.* 2020).

Fuzzy control algorithms and especially ANFIS have been widely applied to predict process parameters or effluent parameters for aerobic biological treatment processes (Murnleitner *et al.* 2002), for forecasting wastewater flow-rates (Fernandez *et al.* 2009), for water management in anaerobic treatment units in sugar factories (Perendeci *et al.* 2007), predicting carbon and nitrogen removal in the aerobic biological treatment for sugar production industry (Civelekoglu *et al.* 2007), predicting suspended solids in the effluent from hospital Waste Water Treatment Plant (Pai *et al.* 2009) and modeling for stock price prediction (Gharakhani *et al.* 2011).

Mingzhi *et al.* (2009) clearly stated that successful practical applications of models developed using ANFIS are generally based on two or three parameter inputs and single output, more so, Talpur *et al.* (2020) stated that ANFIS is always effective when the inputs member is not more than five.

An ANFIS can be viewed as a special three-layer feed forward neural network. The first layer represents input variables, the hidden layer represents fuzzy rules and the third layer is an output. Figure 2.1 represents a typical ANFIS architecture that is based on:

Layer 1: Every node in this layer is an adaptive node with a node function that may be a generalized bell membership function, a Gaussian membership function or any membership function.

Layer 2: Every node in this layer is a fixed node labelled, representing the firing strength of each rule and is calculated by the fuzzy and connective of product of the incoming signals.

Layer 3: Every node in this layer is a fixed node labelled N, representing the normalized firing strength of each rule. The i^{th} node (1, 2) calculates the ratio of the ith rule's firing strength to the sum of the two rules' firing strengths.

Layer 4: Every node in this layer is an adaptive node with a node function indicating the contribution of ith rule toward the overall output.

Rule 1: $If\ x\ is\ x_j$ and y is $y_{1,}$ is $f_1 = p_1x + q_1y + r_1$ (2.5)

Rule 2: $If\ x\ is\ x_2$ and y is $y_{2,}$ then $f_2 = p_2x + q_2y + r_2$ (2.6)

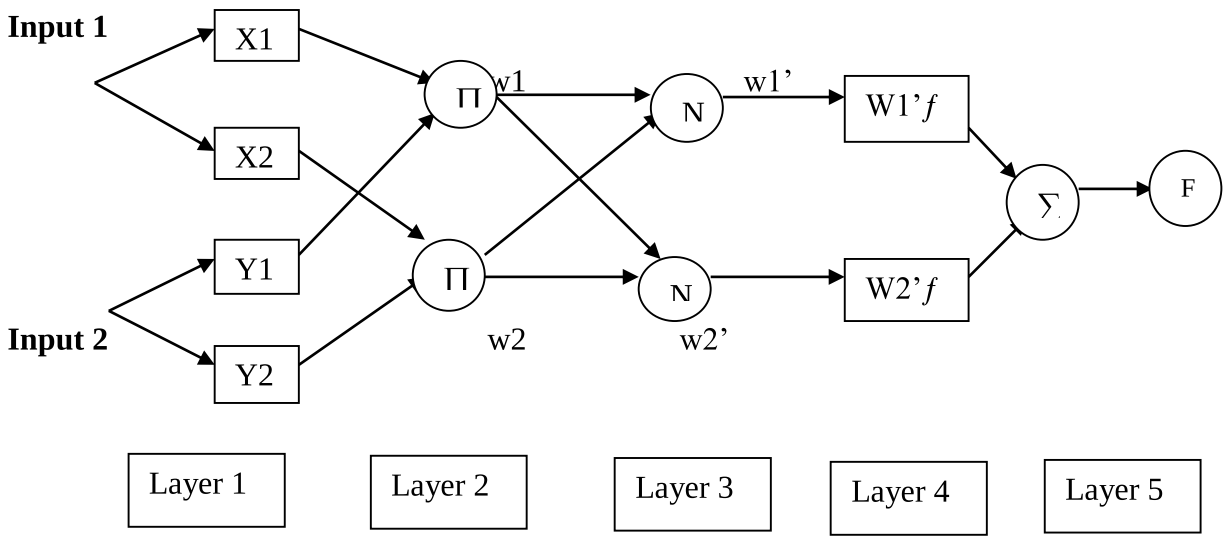

Figure 2.1: Structure of Adaptive Neuro-Fuzzy Inference System Network with Two Inputs and an Output

Source: Talpur *et al.* (2020)

2.12 Response Surface Method Experimental Design

An experiment is a series of tests, called runs, in which changes are prepared in the input variables in order to recognize the reasons for changes in the output response (Montgomery, 2012). The Response Surface Method (RSM) was first developed by Box and Wilson in the statistical field in the 1950s (Huiping *et al.* 2007).

RSM implemented in design expert environment is a collection of mathematical and statistical tools or techniques for designing experiments, optimisation of chemical reactions, agricultural processes, manufacturing processes, biological processes, factorial design, regression analysis, building models, evaluating effects of various factors and searching for the optimum conditions (Li *et al.* 2000; Do *et al.* 2001; Majumdar and Goyal, 2008; Kansedo *et al.* 2009; Ferilla *et al.* 2010).

RSM is a mathematical and statistical technique used to evaluate the relationship between one or more dependent variables (response) and a number of independent variables (factors) at a shorter time with less cost (Diniz and Martin, 1996; Vohra and Satyanarayana, 2002; Myers *et al.* 2009; Montgomery, 2012; Awolu *et al.* 2013). Its approach is useful in deriving approximation models from a number of physical experiments useful for optimum condition searching and improvement, mathematical modeling, interaction between factors, identification and examining engineering problems where certain number of variables have effect on response of concern, and producing multivariable equations (Shang and Tadikamalla, 1993; Myers *et al.* 2009; El-Tayeb *et al.* 2010; Tala-Ighil *et al.* 2011; Abbasi & Mahlooji, 2012; Wu *et al.* 2012).

2.13 Analysis of a First-Order Response Surface

The relationship between the response variable y and the independent variables are usually unknown. In general, the low order polynomial model is used to describe the response surface *f*. A polynomial model is usually a sufficient approximation in small regions of the response surface. Thus, depending on the approximation of unknown function *f*, either first-order or second-order model are employed. Furthermore, the approximated function *f* is a first-order model when the response is a linear function of independent variables. A first-order model with N experimental runs carried out on *k* design variables and a single response *y* can be expressed as in equation (2.5).

$$Y_i = \beta_0 + \beta_1 X_{i1} + \ \dots + \beta_k \beta_{ik} + \in \tag{2.5}$$

Where,

$$(i = 1, 2, 3, \dots N)$$

The response Y is a function of the design variables $X_{i1}, X_{i2}, \dots\ X_{ik}$ denoted as *f*, plus the experimental error $\in$. A first-order model is a multiple-regression model and the β_i,s are regression coefficients. A second-order model is useful in approximating a portion of the true response surface with parabolic curvature. The second-order model includes all the terms in the first-order model, plus all quadratic terms like $\beta_{11} X_{1i}^2$ and all cross product terms like $\beta_{13} X_{1i}$. It is usually expressed as shown in equation (2.6).

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i \ + \sum_{i<j}^{k} \beta_{ij} X_i X_j + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \in \tag{2.6}$$

The second-order model is flexible, because it can take a variety of functional forms and approximates the response surface locally. Therefore this model is usually a good estimation of the true response surface. In addition to the first and second order models, general polynomial models can also be used to regress the response surface. All kinds of polynomial response surface models can be rewritten as an equation in matrix form as shown in equation (2.7):

$$\boldsymbol{y} = X\boldsymbol{\beta} + \in \tag{2.7}$$

Where

$$\boldsymbol{y} = \begin{Bmatrix} Y_1 \\ Y_2 \\ \vdots \\ \vdots \\ \vdots \end{Bmatrix} \ = \begin{Bmatrix} 1\ x_{11} x_{12} \ \dots \ x_{1m} \\ 1\ x_{21} x_{22} \ \dots \ x_{2m} \\ . \quad . \quad . \ . \ . \ . \ . \\ . \quad . \quad . \ . \ . \ . \ . \\ . \quad . \quad . \ . \ . \ . \ . \end{Bmatrix} . \begin{Bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \vdots \\ \vdots \end{Bmatrix} + \begin{Bmatrix} \in_0 \\ \in_1 \\ \vdots \\ \vdots \\ \vdots \end{Bmatrix} \tag{2.8}$$

Equation (2.7) is a vector form of (2.8). For x_{ij} in equation (2.8), *x* represents the linear terms, square terms and linear by linear interactions items in equation (2.6), *i* represents the ith group data of regress, *j* represents the jth response term in equation (2.6)

In general all RSM problems use either one or a mixture of these models. In each model, the levels of each factor are independent of the levels of other factors. In order to get the most efficient result in the approximation of polynomial the proper experimental design must be used to collect data. Once the data are collected, the method of least square is used to estimate the parameters in the polynomials. The response surface analysis is performed by using the fitted surface. The response surface designs are types of designs for fitting response surface.

Therefore, the objective of studying RSM can be accomplished by

(i) Understanding the topography of the response surface (local maximum, local minimum, ridge lines), and

(ii) Finding the region where the optimal response occurs. The goal is to move rapidly and efficiently along a path to get to a maximum or a minimum response so that the response is optimised.

The analysis of a second-order model is usually done by computer software. The analysis of variance for fitting the data to the second-order and the contour plots will help characterise the response surface.

The RSM optimisation procedure is as follows (Oehlert, 2000):

(i) Plan and run a typical design near or at the current operational variables.

(ii) Fit a linear model (no interaction or quadratic terms) to the data.

(iii) Determine path of steepest ascent (PSA) which is a quick way to move to the optimum conditions.

(iv) Run tests on the PSA until response no longer improves.

(v) If curvature of surface is large go to step (vi), else go to step (i).

(vi) Neighbourhood of optimum – design, run and fit (using least squares) a 2^{nd} order model based on 2^{nd} order-pick optimal settings of independent variables.

There are several design types available in RSM: Box – Behnken, Central – composite, one – factor, optimal and historical data (Montgomery and Runger 2007).

2.14 Historical Data Design for the Response Surface

Historical data design (HDD) type can accommodate all available data into a blank design layout from an already conducted experiment (Jeirani *et al.* 2013). It is also suitable for conducting multi-factor experiments because it provides information on the influence of factor interactions (Asmara, 2013). Salam *et al.* (2018) employed HDD in RSM for the modeling and optimisation of sand minimum condition in pipeline multiphase flow by obtaining the past experimental data from reputable archive, which gave appropriate empirical model for relating the operational parameters, and good prediction of operating conditions affecting their response.

Ighalo *et al.* (2020) used HDD on Design Expert in modelling the effect of Sorbate Sorbent interphase on the adsorption of pesticides and herbicides. Their result yielded a good response model with dataset that were obtained from several retrospective reputable published papers in the previous five years, having using sixty six lines of data for analysis using RSM.

Good results were also recorded when HDD tool box in the Design Expert software was used for modeling of interactions between or among variables when design of experiment approach was not used to design before the start of experiment. Some of such reported works are Aremu *et al.* (2014), Salam *et al.* (2015), Salam *et al.* (2018), Salam *et al.* (2020), where HDD in the Design Expert software was used for model development and captured the interactions among variables.

2.15 Multiple Reponses: The Desirability Approach

The desirability function approach is one of the most widely used methods in industry for the optimisation of multiple response processes. It is based on the idea that the ‘quality’ of a product or process that has multiple quality characteristics, with one of them outside of some ‘desired’ limits, is completely unacceptable (Derringer and Suich, 1980; Bobadilla *et al.* 2017; Gómez *et al.* 2017; Lostado-Lorza *et al.* 2018). The method finds operating conditions x that provide the ‘most desirable’ response values.

For each response $Y_i(x)$, a desirability function assigns numbers between 0 and 1 to the possible values of Y_i with $d_i(Y_i) = 0$ representing a completely undesirable value of Y_i

and $d_i(Y_i) = 1$ representing a completely desirable or ideal response value. The individual desirability is then combined using the geometric mean, which gives the overall desirability *D.*

$$D = (1.1 \ldots . 2.2)k.k \ ^{1/k} \tag{2.9}$$

with k denoting the number of responses. Notice that if any response Y_i is completely undesirable $(d_i(Y_i) = 0)$, then the overall desirability is zero. In practice, fitted response values Y_i are used in place of d_i.

Depending on whether a particular response Y_i is to be maximised, minimised, or assigned a target value, different desirability function $d_i(Y_i)$ can be used. A useful class of desirability functions was proposed by Kuhn (2013). Let L_i, U_i and T_i be the lower, upper, and target values, respectively, that are desired for response $Y_{i,}$ with $\mathrm{L_i} \leq \mathrm{T_i} \leq \mathrm{U_i}$

If a response is of 'target is best' kind, then its individual desirability function is

$$d_i\left(\hat{Y}_i\right) = \begin{cases} 0 & \text{If } \hat{Y}_i(x) < L_i \\ \left(\dfrac{\hat{Y}_i(x) - L_i}{T_i - L_i}\right)^s & \text{If } L_i \leq \hat{Y}_i(x) \leq T_i \\ \left(\dfrac{\hat{Y}_i(x) - U_i}{T_i - U_i}\right)^t & \text{If } T_i \ \hat{Y}_i(x) \leq U_i \\ 0 & \text{If } \hat{Y}_i(x) > U_i \end{cases} \tag{2.10}$$

with the exponents *s* and *t* determining how importance it is to hit the target value. For $s = t = 1$, the desirability function increases linearly towards $T_i$for $\mathrm{s} < 1, t < 1$. the function is convex, and for $\mathrm{s} > 1, t > 1$, the function is concave.

If a response is to be maximized instead, the individual desirability is defined as

$$d_i\left(\hat{Y}_i\right) = \begin{cases} 0 & \text{If } \hat{Y}_i(x) < L_i \\ \left(\dfrac{\hat{Y}_i(x) - L_i}{T_i - L_i}\right)^s & \text{If } L_i \leq \hat{Y}_i(x) \leq T_i \\ 1.0 & \text{If } \hat{Y}_i(x) > U_i \end{cases} \tag{2.11}$$

with T_i in this case interpreted as a large enough value for the response.
Finally, if response is to be minimized, we could use

If a response is to be maximized instead, the individual desirability is defined as

$$d_i\left(\hat{Y}_i\right) = \begin{cases} 1.0 & \text{If } \hat{Y}_i(x) < T_i \\ \left(\dfrac{\hat{Y}_i(x) - U_i}{T_i - U_i}\right)^s & \text{If } T_i \le \hat{Y}_i(x) \le U_i \\ 0 & \text{If } \hat{Y}_i(x) > U_i \end{cases} \tag{2.12}$$

with T_i denoting a small enough value for the response.

The desirability approach consists of the following steps:

1. Conduct experiments and fit response models for all *k* responses;
2. Define individual desirability functions for each response; and
3. Maximize the overall desirability D with respect to the controllable factors.

2.16 Previous Noise Related Research done Using Artificial Intelligence methods

Adaptive fuzzy model was developed for noise prediction using genetic algorithm based on the adoption of the Takagi and Sugeno, (1985); optimisation phase approach (Caponetto *et al.* 1997). It was concluded that genetic algorithm based fuzzy model gave results with unacceptable computational value.

Fuzzy model for noise annoyance prediction was formulated by Verkeyn *et al.* (2001). Their fuzzy rule based model was for the prediction of traffic noise annoyance. Several inferences were compared with the prediction capacity. At end of the designed mode, a genetic algorithm was applied.

Neural networks were used for the classification of urban environmental noise by Stoeckle *et al.* (2001). The main objective of their research was to create new ways of monitoring of the complex urban environmental noise. Fast Fourier transform method was used to produce spectral data of sounds from different sources for the classification using neural networks. Zaheeruddin *et al.* (2003) conducted a research on the effects of noise pollution on human work efficiency. Noise level, exposure time and types of tasks were set as variables, the effects of age of the workers were not considered. The results of their model showed that exposure time, noise level and nature of task can predict the work efficiency.

Kolarik *et al.* (2004) studied the human performance assessment in the noisy environment by developing knowledge-based assessment approach in dealing with uncertainty and subjectivity involved. The fuzzy knowledge was also used to offer reliability assessment at the dynamic circumstances.

Zaheeruddin *et al.* (2006) applied a fuzzy model to predict annoyance caused by noise. The fuzzy model represented the inputs and outputs relationship in the form of simple IF-THEN rules. The model predicted noise level, duration of occurrence and the socioeconomic status of a person as a predictor of the annoyance. The fuzzy logic toolbox of MATLAB was used to implement the model also using Takagi and Sugeno (1998) techniques.

Aluclu *et al.* (2008) conducted comprehensive field studies on noise measurement with consideration for the element of control measures. Noise reduction quantity in decibels was incorporated as two subsystems in the model. Acoustical features of the materials used in the working place were considered as the first subsystem of the fuzzy model. The second subsystem involves the atmospheric parameter interactions.

The models were trained in many stages, with many patterns testing as well, which were determined by considered formal standard measurement using pattern and specialist experiences. The model result was compared with those produced by various statistical tools (correlation, max-min, average, and skewers coefficient) and error mode (error, relative error and root mean square). The error modes were low with significantly high correlation coefficient while other statistics were much closer to the data.

Zaheeruddin and Jain (2008) investigated the effects of noise pollution in speech interference by developing an expert system by fuzzy application. Speech interference was measured in terms of speech intelligibility as a function of noise level, distance between speaker and listener, and the listener's age. The main source of model development is the reports of World Health Organisation (WHO) and field surveys conducted by various researches which was implemented on Fuzzy logic Toolbox of MATLAB using both Mandani and Sugeno Techniques. The results are found to be in good agreement with the findings of W.H.O. and U.S. Environmental Protection Agency (EPA). The study reveals that for good communication at normal distances (short and medium) encountered in ambient environment, the noise level should not exceed 65dBA for young and middle aged, and 55dBA for old persons. MATLAB was used to develop the models by also using both Takagi and Sugeno (1998) techniques. Their results showed that in normal distance communication in ambient environment, the noise level should not exceeded 65 dBA for young and middle ages, and 55 dBA for old persons. Their model also established the usefulness of the fuzzy techniques in studying the environmental problems.

Noise pollution effect on human work efficiency was predicted as a function of age, noise level and years of exposure of the machine operators in a construction company. A fuzzy model was used to compute, analyse and establish the models. The inputs and outputs relationship system was represented in the form of IF-THEN rules (Mallick *et al.* 2009). The interactions of the inputs parameters were not considered and no major predictor was pronounced.

Ojolo and Ismail (2011), modeled the effects of noise on machine operators. Major hearing losses were traced to noise generated by machinery. The results showed that hearing loss increases with increase in frequency of exposure and age. Additional influencing factors such as the loudness level and sound intensity were also reported. A fourth order Newton difference scheme was used in modeling, the result was simulated using MATLAB program with the operator's age as the major factor.

Torija *et al.* (2012) predicted sound pressure level of urban environments by using back-propagation neural networks. The neural network indicated a good precision in prediction which has been proved to be more effective than the usage of Multi Linear Regression (MLR).

Bouloiz *et al.* (2013) established the combination of fuzzy logic and dynamic system of a human factor influenced work environment. The environment studied contained a set of variables that influence human behaviour in the context of industrial safety. The uncertain nature and qualification of the variables value were obtained with the fuzzy logic serving as a tool and used for modeling the behaviour of human factor.

Maccà *et al.* (2015) used multivariate analysis to investigate the effects of age, occupational sound and noise exposure in high frequency hearing threshold, they showed that age was the primary predictor; and noise and exposure as the secondary predictors in the high frequency range. The result only highlighted one factor at a time and concluded that age was the only determinant, without checking for other possible combination of other factors.

Akanbi and Oriolowo (2016) explored the impact of occupational noise safety of quarry workers, their work showed that workers were exposed to a high level of noise at their workstation. It was concluded that the age of the workers was the major contributory factor in hearing threshold prediction. Their work was also based on a single factor analysis with non-consideration for interacting effects.

Akanbi *et al.* (2021) studied the contributions of age of the workers, years of exposure and noise level on the hearing threshold as well as their interactive effects, using statistical design in selecting factors. The reported results indicated that the degree of prediction and contribution of the three independent variables was the highest with noise level and least with the age.

A summary of the previous work regarding the effect of noise on hearing threshold is summarised in Appendix A.

2.17 Research Gap

Though many research work including the aforementioned have been conducted in the area of the factors affecting hearing threshold (age, years of exposure and noise level), this study is yet to find literature that establish the degree of combinations of the age, years of exposure and noise level that simultaneously lead to the specific values of hearing threshold of workers at their workstations. However, this present study predicted the combined range of values of age, years of exposure and noise level exposure for a worker that correspond to the safe hearing threshold in the quarry. This will allow the possibility of predicting a fit worker's hearing threshold at a particular frequency as well as establishing the impact of the interactive factor.

CHAPTER THREE

METHODOLOGY

3.1 Criteria for the Measurement of Sound

Noise measurement in this study was carried out in accordance with the Canadian Standard Association (CSA) noise measurement standard Z107.56– 06 procedures (Occupational Health and Safety, 2014). All tools and equipment used in this study were evaluated using standard procedures, pretested and revised to ensure their validity and reliability.

Four approaches were adopted for data collection:

(i) Subject selection at the selected quarries and self – reported questionnaire / interview (Appendix B: Consent and voluntary participation form; and Appendix C: Questionnaire on hearing threshold for the quarry workers).

(ii) Measurement of the noise emitted at the quarry which workers were exposed to when machine are in operation (Appendix D: 2018 Experiment; and Appendix E: 2019 Experiment).

(iii) Audiometric measurement of each subject by a consultant in the laboratory to determine hearing threshold of each participant in the study (Appendix D: 2018 Experiment; and Appendix E: 2019 Experiment).

(iv) The process was replicated in a year duration interval to be able to make decision on time - bound impact of noise on the subjects (Appendix E: 2019 Experiment).

The following equipment were used for the data collection during the two years experiment:

Digital Sound level meter (TESTO 815, Test Equipment Depot, United State of America) with sound calibrator (TESTO

816, Test Equipment Depot, United State of America) and sound proofing testing booth (TRIVENI TAM-10 5100B, Golden Ears Audiology, Delhi).

3.1.1 Subject selection

In the months between June and July 2018, based on random sampling, two hundred and four were selected from 271 workers in the four quarry sites from production section;the remaining 67 subjects were not available during the sampling time. Thirty five (35) other subjects were also selected from the non-production section as control (Appendix E). This represented 75.30% of the population of the quarry workers in the production section and was considered reasonably adequate, since this percentage more than satisfies the recommended range (Suskie, 1996; Nardi, 2003; Neuman, 2007) (Appendix F).

Follow up research arrangement was conducted from September – October, 2019 with one hundred and eighty five (185) subjects of the production section out of the 204 who participated in the study in the year 2018; the remaining 19 subjects were not available during this sampling period. 30 out of the 35 from non-production section that participated in the year 2018 were also available for sampling again (Appendix E). This arrangement was carried out in other to verify whether there is change or not in the hearing threshold of the same workers that participated in the experiment in two consecutive years of this study.

Workers from different sections in each quarry were selected. No preselecting process was undertaken and all subjects had the purpose and the experimental procedure explained to them. The permission of the quarries management was obtained before the study commenced. Participants were notified several days before the study began, followed by questionnaire which was administered before data collection began. The workers in this study had completely rested for more than 48 hours after their day shift in order to prevent transient hearing loss.

3.1.2 Assessing noise levels

This study considered the operators that are exposed directly to the following noise emitted equipment: Primary Crushers, Secondary Crushers, Dumpers, Payloader, Wagon drilling machine, Lathe, Drilling Machine and Excavator. Their operations were used in categorizing the workers into ten groups: Primary Crusher, Secondary Crusher, Compressor, Dumper, Wagon Drilling, Pay loader, Lathe, Drilling Machine and Excavator operators and Administrative staffs. With the location of noise sources, the noise levels which workers are exposed to were assessed with ethical approval. Individual workers' noise exposure level over eight hours at an hour intervals were measured.

Digital Sound Level Meter (TESTO 815, Test Equipment Depot, United State of America) was used to measure the sound level with sound calibrator (TESTO 816, Test Equipment Depot, United State of America) (Plate 3.1a and 3.1b respectively) was used to calibrate the sound level meter to the appropriate level, in conformity to the American National Standard Institute, ANSI, and Standard SI. 4 – 2006 (IAPA, 2008) for the purpose of assessing noise levels.

3.1.2.1 Procedure followed in measuring noise exposure with sound level meter

In measuring the noise exposure in the quarries, the following procedure was adhered to:

(i) The correct use of the microphone was ensured in obtaining accurate measurements by pointing it directly at the sound source;

(ii) Measurements were taken at 1.5m above the ground and 3m from the noise source with microphone mounted on a conventional tripod of substantial construction.

(iii) Reflecting and obstacles objects were avoided.

(iv) Measurements were made when the average wind speed measured with Cup Anemometer (GS026, Texas, United State of America) was less than 5m/s;

(v) A microphone windshield was used for all outdoor measurements.

(vi) Air temperature was between 18.1^{o}C and 32.5^{o}C

(vii) There was no background noise level differences greater than 10 dBA

3.1.2.2 Noise exposure assessment

Regarding the noise exposure assessment, the digital Sound Level Meter (TESTO 815, Test Equipment Depot, United State of America) (Plate 3.1a), with sound calibrator (TESTO 816, Test Equipment Depot, United State of America) (plate 3.1b) was used to calibrate the sound level meter to the appropriate level, in conformity to the American National Standard Institute, ANSI, and Standard SI. 4 – 2006 (IAPA, 2008) for the purpose of noise exposure measurement. The fast response setting of the digital Sound Level Meter was used in this work since it measures how noise fluctuates over time rather than noise exposure (OHS, 2014). It consists of a microphone that converts sound pressure variations into electrical signals. Any form of vibration, excessive heat and shock that may occur on field were prevented by the calibrator attached to the microphone. The reading was then compared with the calibrator's value. The sound level meter was adjusted when required to bring it into calibration. For each particular application, the measurement technique was carefully chosen and controlled to obtain accurate and consistent results.

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Plate 3.1a: Sound level meter (TESTO 815, Test Equipment Depot, United State of America)

Plate 3.2b: Sound callibrator (TESTO 816, Test Equipment Depot, United State of America)

3.1.2.3 Measurement of pure tone audiogram / hearing status (Audiometric test)

This test was conducted in an audiogram sound proofing testing booth (TRIVENI TAM - 10 5100B, Golden Ears Audiology, Delhi) (Hoffman *et al.*, 2017), on each subject at the hospital in Ibadan by a specialist. Audiometric air conduction tests were performed by presetting a pure tone at frequencies of 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz, since this range of frequency encompasses the speech frequencies, are the most important range of communication and the aim of using these frequencies were not for medical management (ASHA, 1990; ANSI, 2004; ASHA, 2004; Healthy hearing.com, 2020) at 5 dBA interval to the ear of the participant through an earphone. The lowest tone that participants responded to, known as hearing threshold (dB), was recorded at that frequency. Hearing was considered normal if the threshold level was less than or equal to 25 dBA at the selected frequency. The stimuli intensity was increased beyond 25 dBA at any frequency until a response was obtained. Intervals of 5 seconds duration were maintained between the tones. The average preset tone duration was 3 seconds. The average time used to perform the audiometric test on a subject was 5 minutes.

3.2 Test of Variance between the 2018 and 2019 Dataset

The data collected from the subjects at all quarries consisted of 204 in the year 2018 and 185 data points in year 2019. These were subjected to a test of variance in order to ascertain if there was similarity (or not) between the 2018 and 2019 dataset in terms of the age, years of exposure, noise level and hearing threshold (Appendix G).

3.3 Exhaustive Search and ANFIS modelling on the Data

Exhaustive search was performed to determine the most significant parameters (among age, years of exposure and noise level) as shown in Figure 3.1

The syntax structure of exhaustive search is:

[input_index, elapsed_time] = exhsrch(in_n, trn_data, chk_data, input_name, mf_n, epoch_n)

Where input_index: index of the inputs selected by exhaustive search, Elapsed_time: time in input selection, in_n: number of inputs to be selected from the input candidates (restricted to be 1…3); trn_data: original training data; chk_data: original checking data; input_name: input name for all input candidates; mf_n: number of membership function for each input; epoch_n: number of training epochs for ANFIS (default to 1).

The ANFIS model Graphical User Interface (GUI) is being partitioned into four parts and this accounts for the steps involved in using this model. These parts are: Load data points, generate FIS, train FIS and test FIS (Kisi *et al.* 2018).

(A) Load Data Points

Here, the data is partitioned into two equal halves called the training data and checking data using MATLAB toolbox. The training data consists offset of odd number values between 1 and the total data points while the checking data consists of set of even number values from 2 to the total data points. These data sets were then loaded into the ANFIS GUI by specifying the data type (training or checking), selecting the data from a file or the MATLAB workshop and then clicking load data.

(B) Generate FIS:

The initial FIS model used in ANFIS training is being generated by choosing either a grid partition (which generates a single-output Sugeno type FIS by using grid partitioning on the data) or Sub-clustering (which generates an initial model for ANFIS training by first applying subtractive clustering on the data). In this work grid partition technique was adopted in order to produce all possible rules to interpret the problem for better accuracy (Talpur *et al.* 2020). Grid partition technique is most often adopted in order to produce all possible rules to interpret the problem for better accuracy (Talpur *et al.* 2020). Grid partition technique generates FIS structure from the data loaded into the GUI, with the number of input membership function, input MF type and output MF type.

(i) Data: - is the training data matrix, which must be entered with all but the first columns representing input data, and the last column representing the single output.

(ii) Number of input MF: is a vector whose coordinates specify the number of membership functions associated with each input. If one want the same number of membership functions to be associated with each input, then specify numMFs as a single number. The number of MF used in this work is 2 for all the inputs.

(iii) Input MF type: is a string array in which each row specifies the membership function type associated with each input. This can be a one-dimensional single string if the type of membership functions associated with each input is the same. These input MF type are trimf, trapmf, gbellmf, gaussmf, gauss2mf, pimf, dsigmf and psigmf.

(iv) Output MF type: is a string that specifies the membership function type associated with the output. There can only be one output, because this is a Sugeno-type system. The output membership function type must be either linear or constant. The output MF type used in this work is constant.

(C) Train FIS

In training the FIS model generated, the steps involved are: choosing of optimization method which is either hybrid or back propagation (The hybrid method was used in this work because is a combination of least-squares and back propagation gradient descent method), enter the number of training Epochs and the training Error Tolerance to set the stopping criteria for training. The training process stops whenever the maximum epoch number is reached or the training error goal is achieved and finally click Train Now to train the FIS. This action adjusts the membership function parameters and displays the error plots.

(D) Test FIS

After the FIS is trained, the model was validated using a Testing or Checking data that differs from the one used to train the FIS. This action plots the data against the FIS output.

3.4 Presentation and Analysis of the Models

The data collected from the respondents were subjected to the predictive ability of exhaustive search in ANFIS training using MATLAB statistical software to determine significant parameters and then made predictions. The input variables were age, exposure and noise level while the output variable was the hearing threshold at different frequency levels (250 Hz, 500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz and 8 kHz). Each response was analysed separately. The methodology involved in the ANFIS training is Grid

Partitioning 'genfis1'. Different input MF types were used for data training and model analysis. The data partitioning involved a set of odd data point for training, and even number dataset as checking data as shown below.

Training_data = Data (1:2: end,:)

Checking_data = Data (2:2: end,:)

3.4.1 ANFIS training models for hearing threshold at different frequency levels

Train 3 ANFIS models, each with 1 input selected from 3 candidates for each frequency.

Frequency 250Hz

ANFIS model 1: Age --> trn=20.8637, chk=4.9711

ANFIS model 2: Exposure --> trn=20.8669, chk=4.9517

ANFIS model 3: Noise levels --> trn=20.8236, chk=4.9775

Frequency 500Hz

ANFIS model 1: Age --> trn=3.4141, chk=4.3273

ANFIS model 2: Exposure --> trn=4.0431, chk=4.5444

ANFIS model 3: Noise levels --> trn=4.6568, chk=5.8254

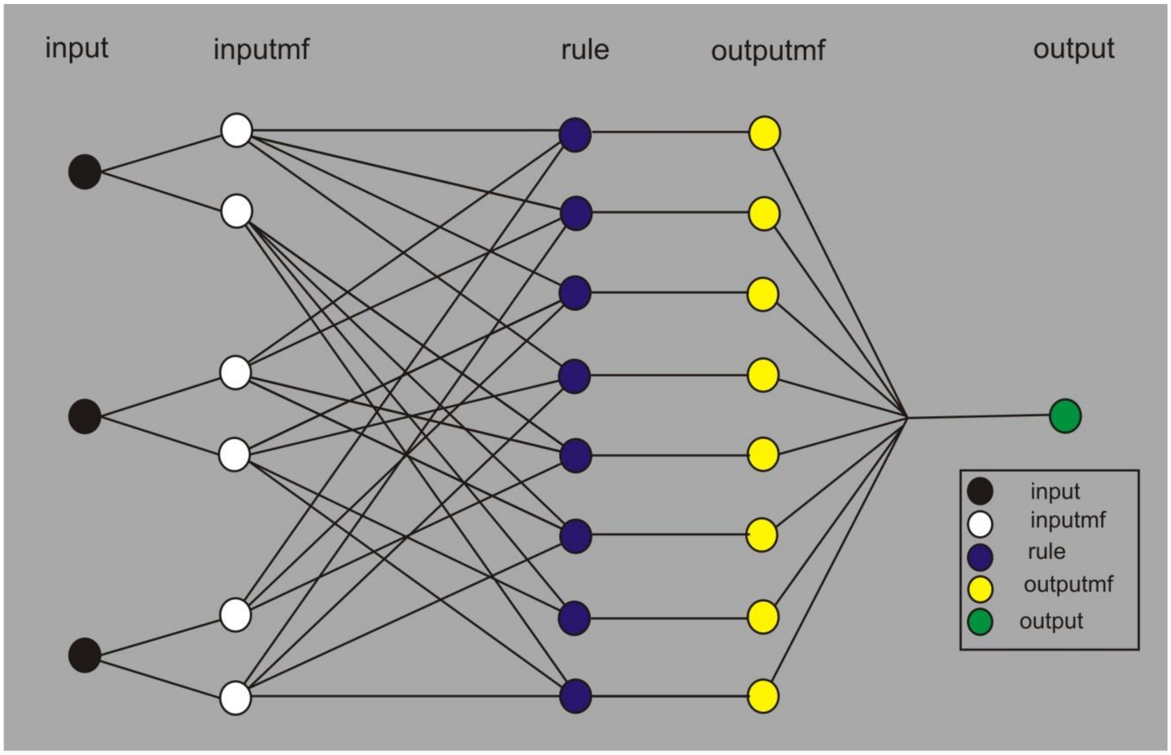

Figure 3.1: ANFIS architecture for input and output factors

Frequency 1 kHz

ANFIS model 1: Age --> trn=3.9118, chk=5.2127

ANFIS model 2: Exposure --> trn=4.3799, chk=5.2967

ANFIS model 3: Noise levels --> trn=6.2289, chk=7.0524

Frequency 2 kHz

ANFIS model 1: Age --> trn=4.5750, chk=5.9657

ANFIS model 2: Exposure --> trn=5.5594, chk=6.1661

ANFIS model 3: Noise levels --> trn=7.5085, chk=8.4801

Frequency 3 kHz

ANFIS model 1: Age --> trn=5.4766, chk=5.7943

ANFIS model 2: Exposure --> trn=6.3557, chk=6.1224

ANFIS model 3: Noise levels --> trn=8.9625, chk=9.5787

Frequency 4 kHz

ANFIS model 1: Age --> trn=8.0740, chk=8.2335

ANFIS model 2: Exposure --> trn=8.9899, chk=8.4371

ANFIS model 3: Noise levels --> trn=15.2515, chk=15.1411

Frequency 6 kHz

ANFIS model 1: Age --> trn=6.8546, chk=6.7931

ANFIS model 2: Exposure --> trn=7.4352, chk=7.3413

ANFIS model 3: Noise levels --> trn=11.2867, chk=11.2389

Frequency 8 kHz

ANFIS model 1: Age --> trn=7.0140, chk=7.5989

ANFIS model 2: Exposure --> trn=7.9421, chk=7.8937

ANFIS model 3: Noise levels --> trn=11.5548, chk=11.0229

3.4.2 Model development

In order to develop models that are suitable for generating difficult to estimate parameters from easy to estimate ones needed to predict the hearing threshold, it is necessary to select the combinations of age, years of exposure and noise level that are relevant to solve the model approximation task. The following section presents the procedures for the selection of regression model inputs, regression modeling and model's assumption.

3.4.3 Selections of regression model inputs

The number of inputs to a model increases its complexity. Therefore, in order to circumvent the problems associated with a complex model, it becomes pertinent to select the most influential inputs. According to Passino and Yurkovich (1998), it is quite difficult to figure out how the inputs should be selected such that the input dataset would be adequate to solve the model approximation task. However, exhaustive search method, seeks the best combination of the age, years of exposure and noise level that influences the hearing threshold the most. Exhaustive search method in MATLAB's Fuzzy Logic Toolbox (MATLAB Toolbox, 2009) builds an ANFIS model for each combination, trains it for one epoch, and reports the performance achieved.

In this study, the exhaustive search method was applied to select the best among the predictors (age, years of exposure and noise level) for each of the responses (hearing threshold). Exhaustive search reveals the best predictors (among age, years of exposure and noise level) that yield the least Root Mean Square Error (RMSE) as in equation (3.1); as well as evaluated using correlation coefficient (R) as in equation (3.2) (Abdulkadir *et al.* 2018). However, in selecting the best combination of age, years of exposure and noise level, two choices criteria were investigated. These are the minimum training RMSE and minimum checking RMSE, and the minimum difference between the training and checking RMSE. These measure were necessary, in a bid to avoid over fitting.

$$RMSE = \sqrt{\frac{1}{N}\sum(obs - pre)^2} \tag{3.1}$$

$$R = \frac{\sum(obs-obs')(pre-pre')}{\sqrt{\sum(obs-obs')^2\sum(pre-pre')^2}} \tag{3.2}$$

Where,

obs = observed values; pre= predicted values; obs'= average value of observed values; pre' = average value of predicted values.

3.4.3.1 Regression modelling

The obtained data was fitted to a second order polynomial regression model as presented in equation (3.3). This task was separately performed for each of the response variables (hearing threshold), using the selected predictors (age, years of exposure and noise level) as inputs.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i<1}^{k} \beta_{ij} X_i X_j + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \in \qquad (3.3)$$

For each response, the statistical significance of the regression model terms was evaluated by ANOVA partial SS (Type III). Also the models' predictive performances were checked by lack-of-fit test, R^2, *Adj* R^2, *Pred* R^2, *Adeq* Precision and *F*-test. The significance of the *F*-Value was adjudged at 95% level of confidence. The lack of fit is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the regression or variations in models cannot be accounted for by random error (Montgomery, 2012)

The occurrence of a low probability value indicates a significant lack of fit which indicates that the response predictor should be discarded. The R^2 is known as Coefficient of Determination, it shows how much of the dependent variable is accounted for by the independent factors (Montgomery, 2012). Coefficient of variation (CV) indicates the relative dispersion of the experimental points from the prediction of the model.

Statistical Package Design Expert version 6.0.8 was used to obtain response surfaces and contour plots. The numerical and graphical optimisations were also performed by the same software for the clarity on the interaction relationship of age, years of exposure on noise level. The regression models were used to predict the response (hearing threshold) based on the values of the predictors (age, years of exposure and noise level). The degree of correlation between the predicted hearing threshold and actual values was also examined in order to ensure the model accuracy.

3.4.3.2 Model assumption

The following assumption are laid down to construct the prediction models.

(i) The subjects were quarry workers.

(ii) All the dependent (response) variables: age, years of exposure and noise level.

3.4.4 Statistical analysis

This work follows three (3) important phases which could be used to make a meaningful study, the experimental or planning phase, the design phase and the analysis phase. A Historical Data Design (HDD) was used to set up and optimise the experimental data. Design-Expert version 6.0.8 was used for the modelling of the identified variables. Analysis of variance (ANOVA) was used for the analysis of the data obtained from this experiment for frequencies 250Hz – 8000Hz. The ANOVA is labelled "sum of squares" is Type III – partial. This approach to ANOVA done by default, causes total sums – of – squares (SS) for the terms to come up short of the overall model when analysing data from a non-orthogonal array as in historical data.

The SS terms does not add up to the model (SS) so that sequential (Type I) sum of squares is formed. Approach is not good because it favours the first term fit into the model. ANOVA by partial SS (Type III) calculates prob > F *p*-value. Recalculating ANOVA by sequential sum of squares (Type I) always elevates the level of significant only because main effect of factor is usually fit first; which is not correct (Statease.com). The interaction between (age, years of exposure and noise level); and the response of different regression models developed for hearing threshold was investigated. The quality of the fitted polynomial model was expressed by the coefficient of determination R^2, and its statistical significance was checked by the Fisher's F-test in the same in-built statistical program of the Design Expert version 6.0.8. Model terms were evaluated by the p - value (probability) with 95% confidence level.

3.4.4.1 Response surface method

Response Surface Methodology (RSM) is one of the method that can give optimal situation in which the combination of age, years of exposure and noise level influence the hearing threshold. Mathematical models were developed and statistical analysis of the parameters interactions (age, years of exposure and noise level) on responses surface (hearing threshold) by RSM in MATLAB Statistical Software (Design Expert 6.0.8). Fitting and analysing response surfaces were done by the experimental design. Response Surface plot helps to visualize the possible interaction effect on the hearing threshold.

3.5 Selection of Values of Age, Years of Exposure and Noise Level for the Safe Hearing Threshold

Design – Expert allows to set criteria for all variables, the software was used to set for the range of optimal combinations of age, years of exposure and noise level which can result to the safe hearing threshold values of 25-30 dB for the quarry workers**.** The ranges of safe hearing threshold were used as a "Goal" to construct desirability (d_i). Desirability range from 0 to 1 for the hearing threshold at a particular frequency. The program combines each of the factors (age, years of exposure and noise level) desirability into a single number and then searches for the greatest overall desirability. A value of 1 represents the ideal case. 0 indicates that the hearing threshold fall outside desirable limits.

In setting the range, lower limit and upper limit was set in order to allow desirability equation works properly. By default, the range of values (25-30 dB) was set at the observed safe hearing threshold range.

Additional parameter called "Weights" was selected for safe hearing threshold at each frequency. Weights give added emphasis to upper or lower bounds value of safe hearing threshold at each frequency. With a weight of 1, desirability varies from 0 to 1 in linear fashion.

Weights greater than 1 (maximum weight is 10) give more emphasis to goals. Weights less than 1 (minimum weight is 0.1) give less emphasis to goals. Lower and upper weights at their default values of 1 and 1 respectively were entered in this work in order to ensure no bias.

"Importance" was used as a tool for changing relative priorities to achieve safe hearing threshold values of 25 – 30 dB for the optimisation of the combination of age, years of exposure and noise level. Out of 5 levels of importance produced by Design – Expert, ranging from 1 plus (+) to 5 plus (+ + + + +), this work used a medium setting of + + +. By leaving all importance criteria at their defaults, no goals were favored over others.

Running the optimisation is by clicking the solution tab; the defaults of the Ramps view occurred which give good visual on the best settings of age, years of exposure and noise level and the desirability of the predicted safe hearing threshold.

3.5.1 Determination of the combination of values of age, years of exposure and noise level that can result to the safe hearing threshold of workers

This work also established the relationship between a particular present age of the worker to work or be working in the quarry, point of entry age of the worker into the quarry production job, optimal years of exposure to noisy production area in the quarry; and suitable workers' age in noisy production area in the quarry.

The relationship can be expressed as in equation (3.4) as follows:

$$(X - K) + Y \leq Z \tag{3.4}$$

Where,

X - Present age of the worker to be worked or working in the quarry,

K - Point of entry age of the workers into the quarry production job,

Y - Optimal years of exposure to noisy production area in the quarry,

Z - Suitable workers' age in noisy production area in the quarry.

3.6 Effects of age, years of exposure and noise level on hearing threshold over time

In order to know what comes up by the combination of the factors considered (age, years of exposure and noise level) over the time, the two years experimental data were subjected to the following test:

(i) Paired sample Pearson correlation coefficient of mean difference between hearing threshold in first and second year

(ii) Paired sample statistics of the first and second year of mean hearing threshold of the respondents at all frequencies

(iii) Paired sample t – test for differences in the hearing threshold in the first and second year.

3.7 Ergonomic Evaluation of Hearing Threshold Predictors

The following hypothesis are accepted or rejected from the analysis of experiment conducted:

H_o: Age of workers, years of exposure and noise level cannot significantly predict hearing threshold of workers.

H_I: Age of workers, years of exposure and noise level significantly predict hearing threshold of the workers.

Decision rule: Accept H_o if *p*-value > α (=0.05) or reject H_o if *p*-value < 0.05.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Chapter Overview

This chapter presents and discusses the results of the analysis conducted on the workers in four Nigerian quarries (Q1, Q2, Q3 and Q4) to determine the synergistic interaction of Age, period of exposure and noise on hearing loss conducted at eight different hearing frequencies (0.25, 5.00, 1.00, 2.00, 3.00 4.00, 6.00 and 8.00 kHz). Essentially, the results presented and discussed include the,

(i) general noise emission of the equipment used in quarry operation and general hearing threshold of workers

(ii) ANFIS exhaustive search results for the factors that affect workers' hearing threshold at the various frequencies considered

(iii) Hearing threshold predictive accuracies of the ANFIS models

(iv) Hearing threshold predictive model equations of the quarry workers at various frequencies.

(v) ANOVA outputs for determining significant hearing threshold factor interactions

(vi) Effects of interacting factors on the hearing threshold of workers

The demographic distribution of the subjects showed that the age range of the workers was 15 to above 60 years. The modal age range was 31-45 years (51.50% in 2018 and 50.80% in 2019), while the age range with the least frequency was 60+ years (2.50% in 2018 and 50.80% in 2019). The sex distribution revealed that most of the quarry workers were mostly male (96.10% in 2018 and 96.70% in 2019). The academic qualifications of the respondents showed that the highest education attained by most of them was school certificate level. Tables 4.1 and 4.2 provide the demographic distribution details for the tests conducted in 2018 and 2019 respectively.

Table 4.1: Distribution of Demographic Characteristics of Respondents in the Year 2018

Demographic Factors		Frequency	Percentage
Gender	Male	196	96.1
	Female	8	3.9
Age	15 – 30 years	19	9.3
	31 – 45 years	105	51.5
	46 – 60 years	75	36.8
	60+ years	05	2.5
	Mean = 41.59		
Marital status	Single	11	5.4
	Married	191	93.6
	Divorced	2	1.0
Highest Academic Qualification	School certificate	89	43.6
	Technical college	28	13.7
	NCE/OND	58	28.4
	B.Sc/HND	29	14.2
Total		204	100

Table 4.2: Distribution of Demographic Characteristics of Respondents in the Year 2019

Demographic Factors		Frequency	Percentage
Gender	Male	179	96.7
	Female	6	3.3
Age	15 – 30 years	18	9.7
	31 – 45 years	94	50.8
	46 – 60 years	71	38.4
	60+ years	02	1.1
	Mean = 42.14		
Marital status	Single	11	5.6
	Married	172	93.3
	Divorced	2	1.0
Highest Academic Qualification	School certificate	78	42.2
	Technical college	26	14.1
	NCE/OND	54	29.2
	B.Sc/HND	27	14.6
Total		185	100

4.1 Hearing Threshold of the Respondents within the Four Quarries

As a precursor to utilizing the data collected in 2018 and 2019 from the respondents, a one way ANOVA test was conducted in order to ascertain if the respondents at all the four quarries were subjected to the same working conditions. The test of equality showed that the F values of variances for the 2018 and 2019 dataset equality for age, years of exposure, noise level and hearing threshold at frequency 250 Hz, 500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz and 8 kHz were not significant at $\alpha_{0.05}$. This inferred that the datasets on hearing threshold in the year 2018 and 2019 came from the same population of quarry workers. Thus, the dataset obtained in the year 2018 or in the year 2019 experiment could be used collectively (Appendix G).

4.2 General Noise levels and Hearing Threshold within Quarries

4.2.1 Noise Measurement at Various Facilities under Study

The four understudied quarries consisted of different production units having more or less of the same types of machinery (Tables 4.3 and 4.4 display the noise levels obtained from the machine in the 4 quarries observed in the year 2018 and 2019). The noise measurement were in the range of 87.3 to 116.98 dBA in the production section, which implies that the noise levels produced exceeded the limiting threshold level of 85 dBA except in the administrative blocks where the noise level was less than the threshold of 85 dBA. It was observed that each of all four quarries produced an excessive amount of noise with the potential of being injurious to the hearing capabilities of workers.

Table 4.3: Average noise levels (dBA) measured at workstations in the four quarries in 2018

Type of Machine	Q1	Q2	Q3	Q4
Primary Crusher	115	112.3	114.3	114.5
Secondary Crusher	116.9	112.3	114.9	112.2
Compressor	113.5	108.3	113	101.7
Dumper	96	94.5	92.8	96.5
Wagon Driller	94.4	91.1	92.3	98.1
Pay Loader	93.1	91.5	92.8	93.3
Drilling Machine	93.0	97.2	97.0	90.2
Lathe	88.3	87.3	88.0	88.2
Excavator	97.3	93.2	97.0	95.4
Administrative	39	28.4	53.3	59.7
Mean	100.83	98.63	100.23	98.90
Standard Deviation	±0.36	±0.41	±1.01	±0.10

Table 4.4: Average Noise Levels (dBA) Measured at Workstations in the Four Quarries in 2019

Type of Machine	**Q1**	**Q2**	**Q3**	**Q4**
Primary Crusher	116	113	115	115.5
Secondary Crusher	116.9	114	114	112
Compressor	114	109	113	103
Dumper	98	95	93	97
Wagon Driller	95	91	93	98.0
Pay Loader	94.1	92	93.8	93
Drilling Machine	94.5	98	97.5	91
Lathe	88	87.5	87.3	88
Excavator	98	94	98.0	96
Administrative	39	28.8	50	60
Mean	101.61	99.28	100.51	99.28
Standard Deviation	±0.38	±0.51	±1.01	±0.10

4.2.2 Hearing Threshold of respondents within the Quarries

The hearing threshold among the workers in the quarries was 45.60±1.24 dBA from which 138 respondents (75%) had hearing thresholds higher than 25 dBA. Comparatively, the mean hearing threshold among workers at Q3 (47.92 dBA) > Q4 quarry (47.51 dBA) > Q2quarry (46.75 dBA) > Q1 (40.48 dBA) (Appendix I).

The one-way ANOVA test, (Appendix I) shows the differences between the mean values of hearing threshold level of the respondents of the four quarries as not significant ($F = 1.068$, $p = 0.364$). This indicates that the hearing threshold values of the workers operating in the four quarries under study are more or less the same. Thus, the respondents at all the quarries were subjected to about the same working conditions and environmental noise levels.

4.3 ANFIS exhaustive search results for the factors that affect workers' hearing threshold at the various frequencies considered

(A) Response 1- Hearing Threshold at 250 Hz

From the exhaustive search performed (Figure 4.1) to select the most significant factor on the worker's hearing threshold at 250 Hz, the training errors was much higher than the checking error, thus confirming many outliers and inconsistency with the data with much over fitting. It may be concluded that to obtain the most significant factor contributing to the hearing threshold at this frequency is not feasible; the reason for this may be related to low magnitude of the frequency involved. The influence of 3 categories of factors considered in this work cannot be determined.

(B) Response 2 - Hearing Threshold at 500 Hz

From the exhaustive search shown in Figure 4.2, the worker's age gave the least training error of 3.4141, thus significant on the hearing Threshold. Therefore, age is the highest contributing factor to the hearing threshold at this frequency.

(C) Response 3 - Hearing Threshold at 1 kHz

The exhaustive search shown in figure 4.3, the worker's age gave the least training error of 3.9118, thus significant on the hearing threshold.

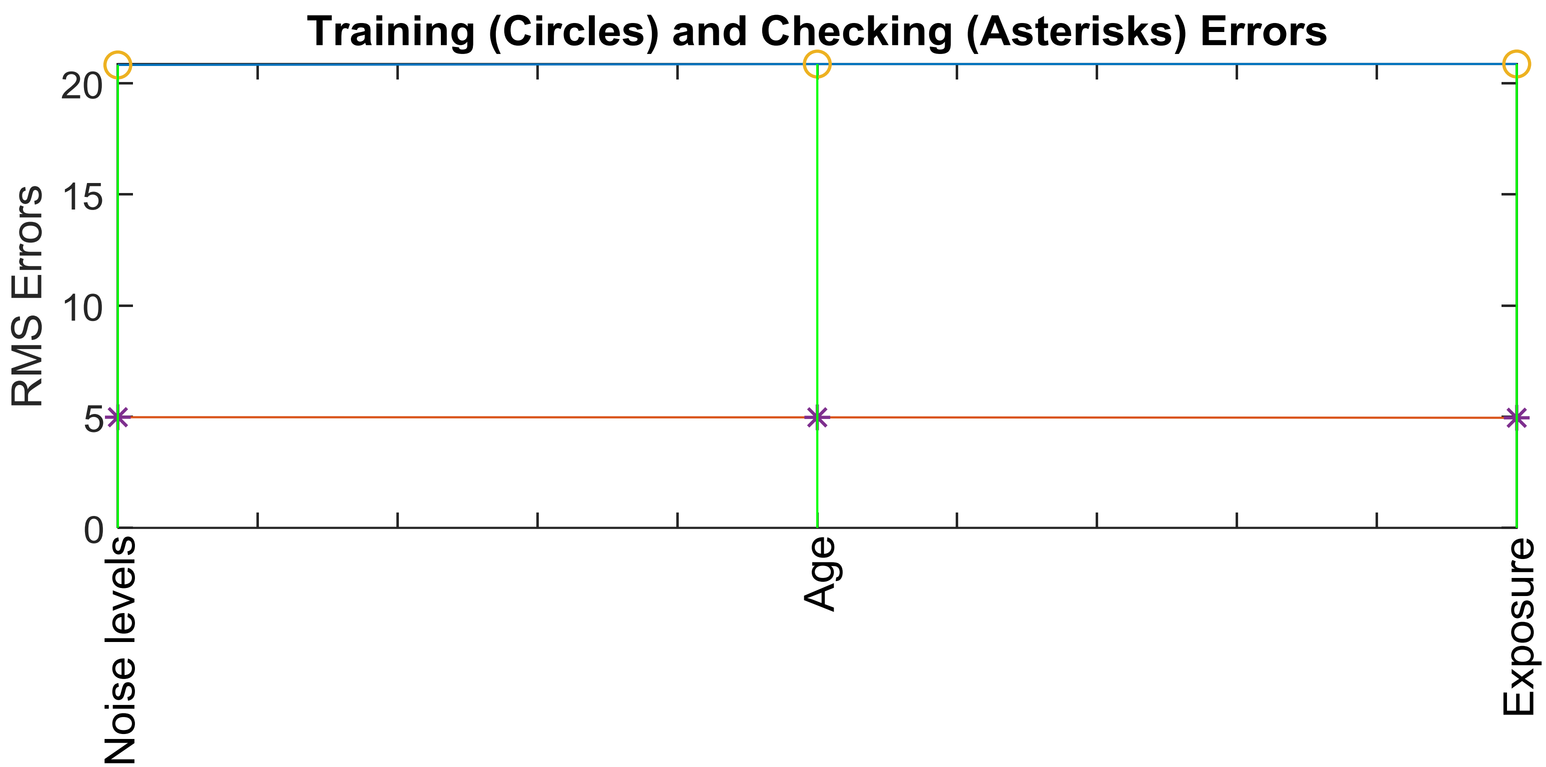

Figure 4.1: Exhaustive search for the operating parameters on hearing threshold at 250Hz

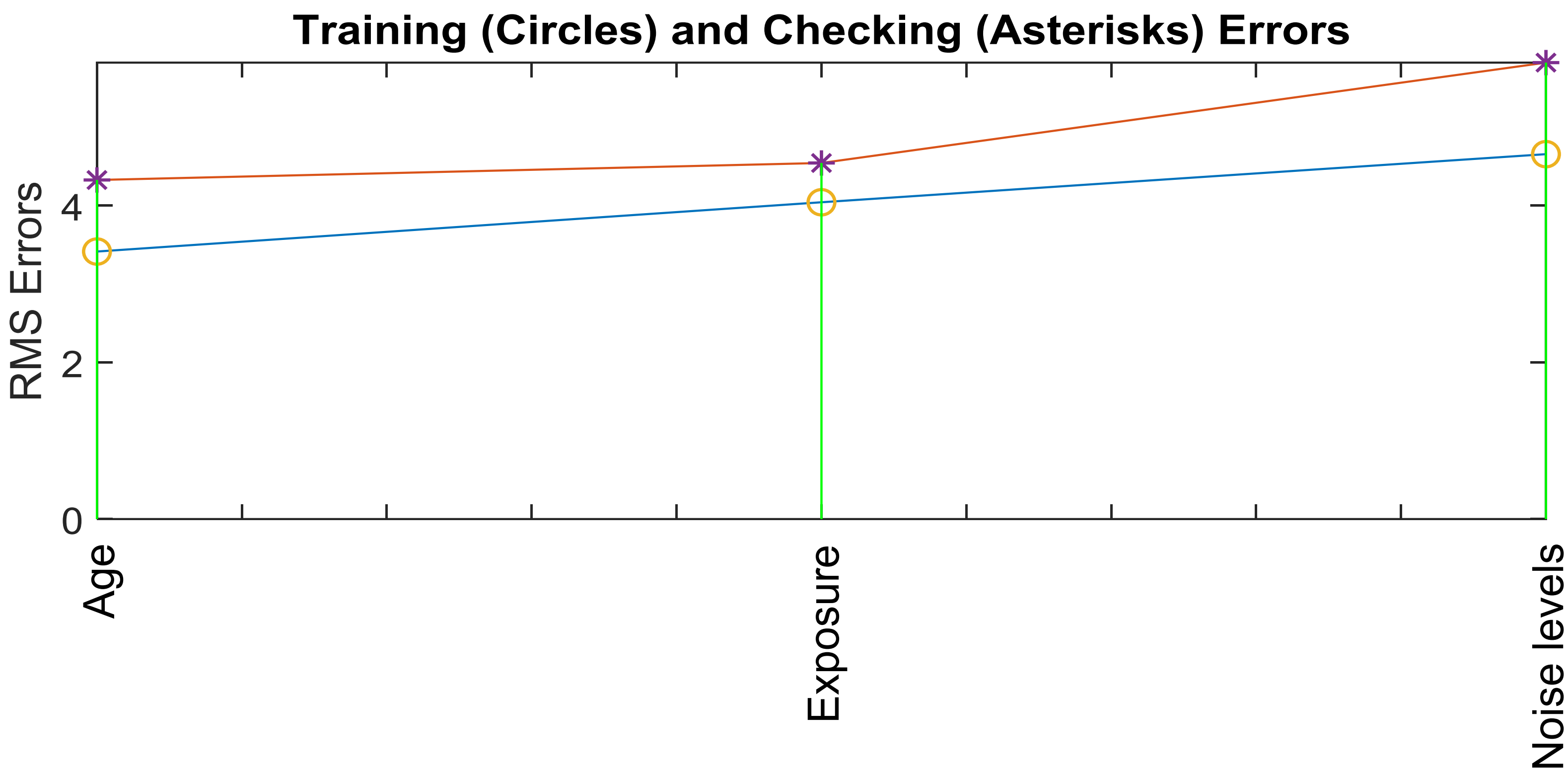

Figure 4.2: Exhaustive search for the operating parameters on hearing threshold at 500 Hz

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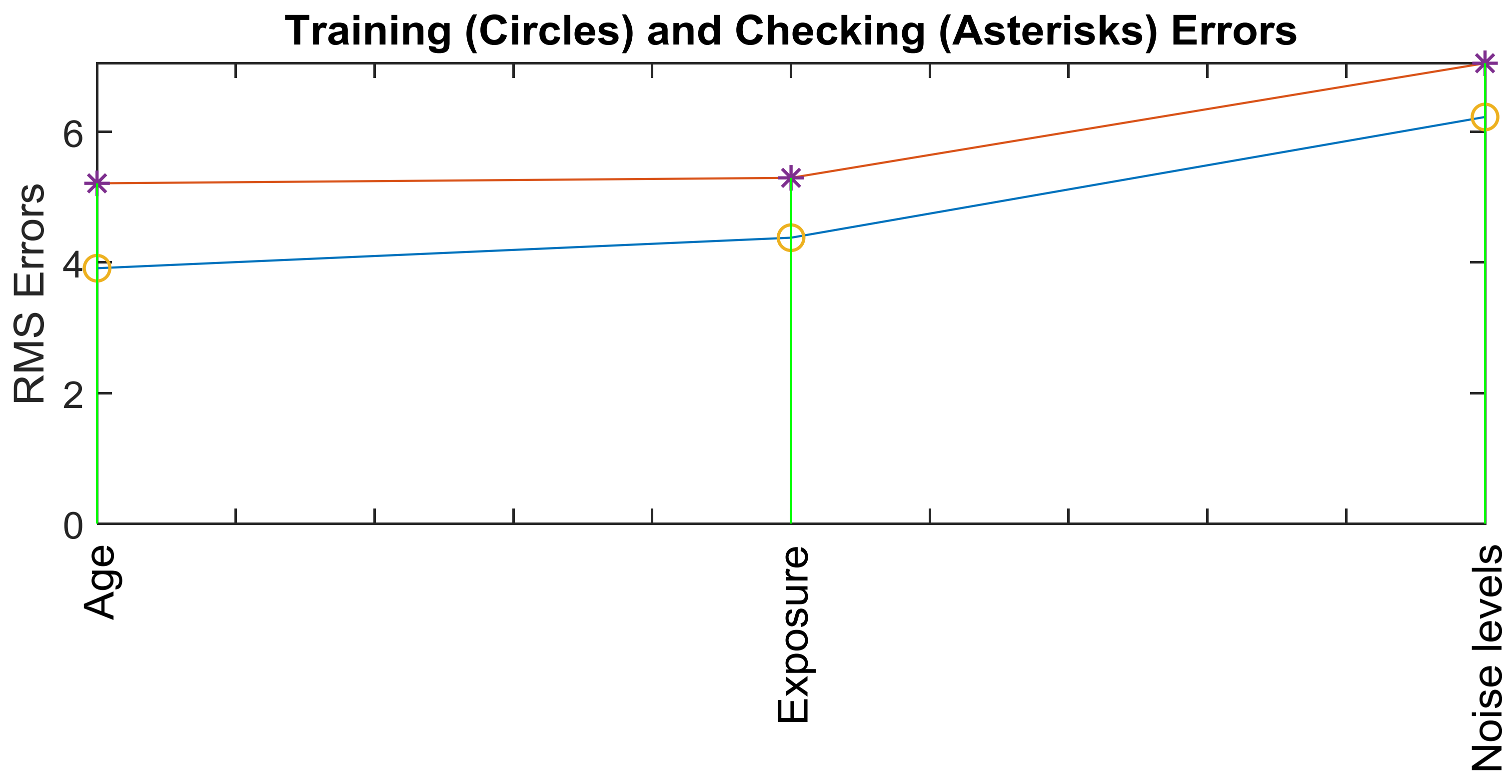


Figure 4.3: Exhaustive search for the operating parameters on hearing threshold at 1 kHz

(D) Response 4 - Hearing Threshold at 2 kHz

Exhaustive search in Figure 4.4 showed that the worker’s age gave the least training error of 4.5750, thus significant on the hearing threshold.

(E) Response 5 - Hearing Threshold at 3 kHz

From the exhaustive search shown in Figure 4.5, the worker’s age gave the least training error of 5.4766, thus significant on the hearing threshold.

(F) Response 6 - Hearing Threshold at 4 kHz

From the exhaustive search shown in Figure 4.6, the worker’s age gave the least training error of 8.0740, thus significant on the hearing threshold.

(G) Response 7 - Hearing Threshold at 6 kHz

From the exhaustive search shown in Figure 4.7, the worker’s age gave the least training error of 6.8546, thus significant on the hearing threshold.

(H) Response 8 - Hearing Threshold at 8 kHz

From the exhaustive search shown in Figure 4.8, the worker’s age gave the least training error of 7.0140, thus significant on the hearing threshold.

From the exhaustive search analysis of the three factors, it is clearly shown that quarry workers’ age is the most contributing factor among the 3 factors (age, years of exposure and noise level) that influence the quarry workers hearing threshold with the range of 250 Hz and 8 kHz.

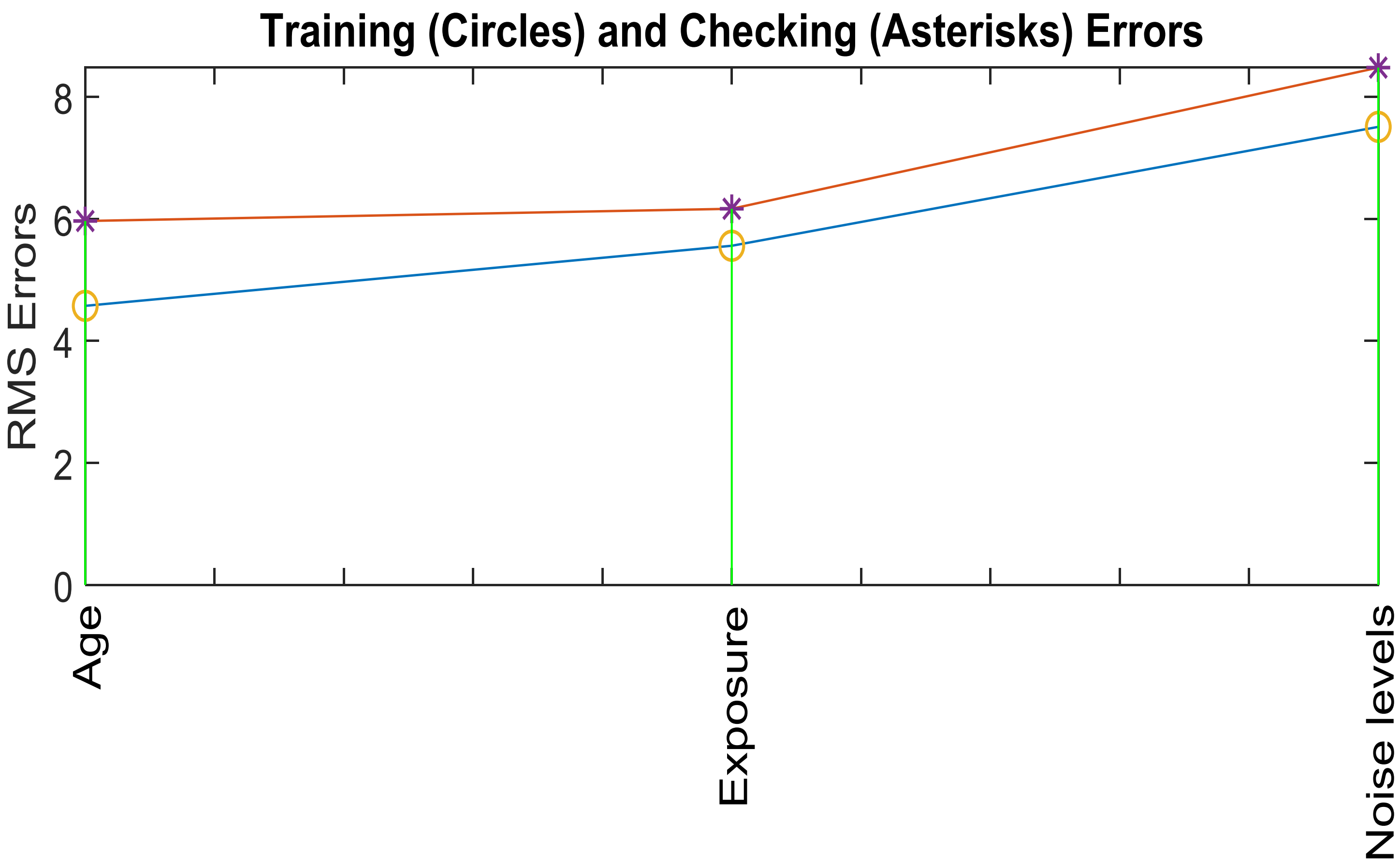


Figure 4.4: Exhaustive search for the operating parameters on hearing threshold at 2 kHz

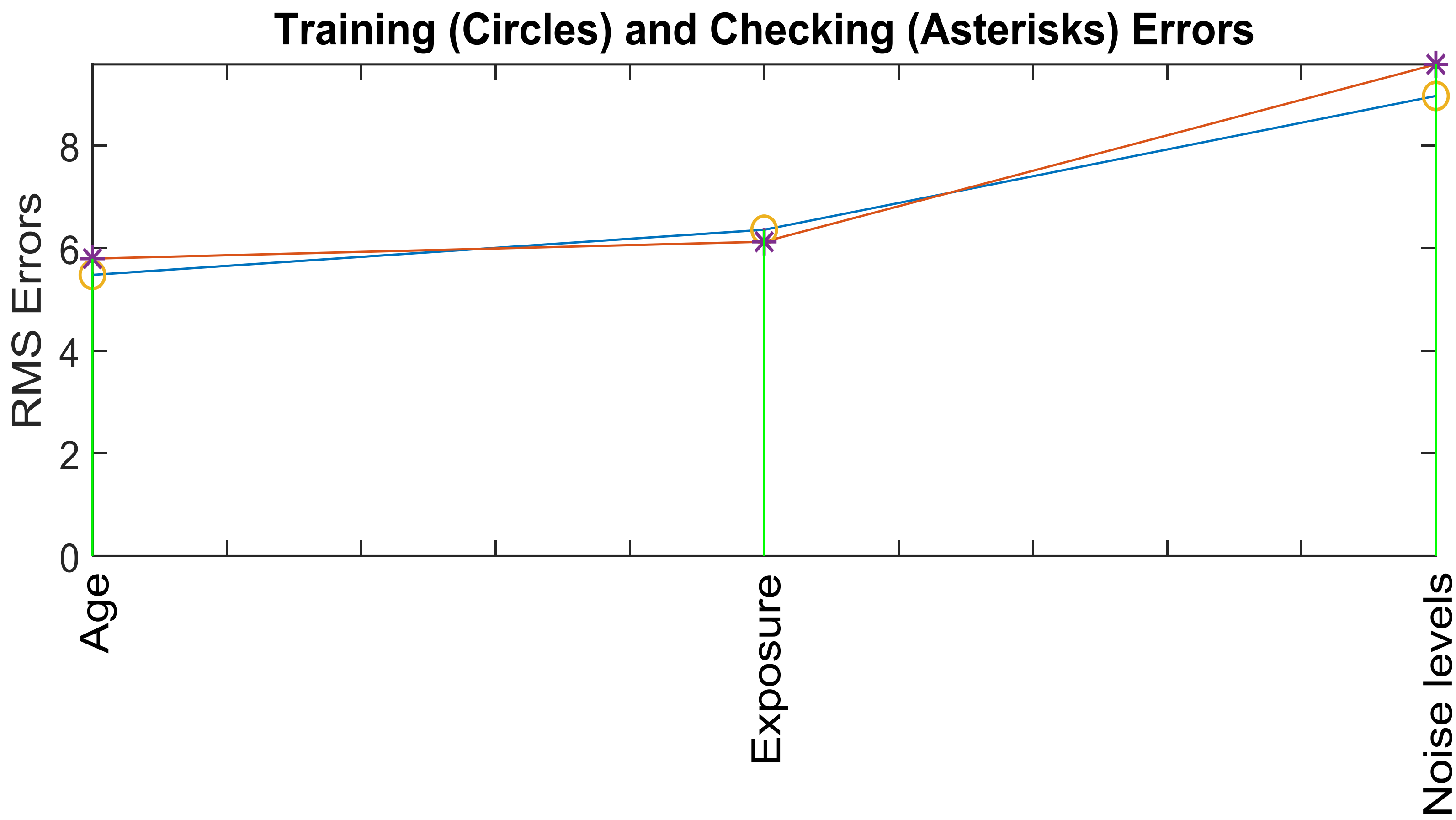


Figure 4.5: Exhaustive search for the operating parameters on hearing threshold at 3 kHz.

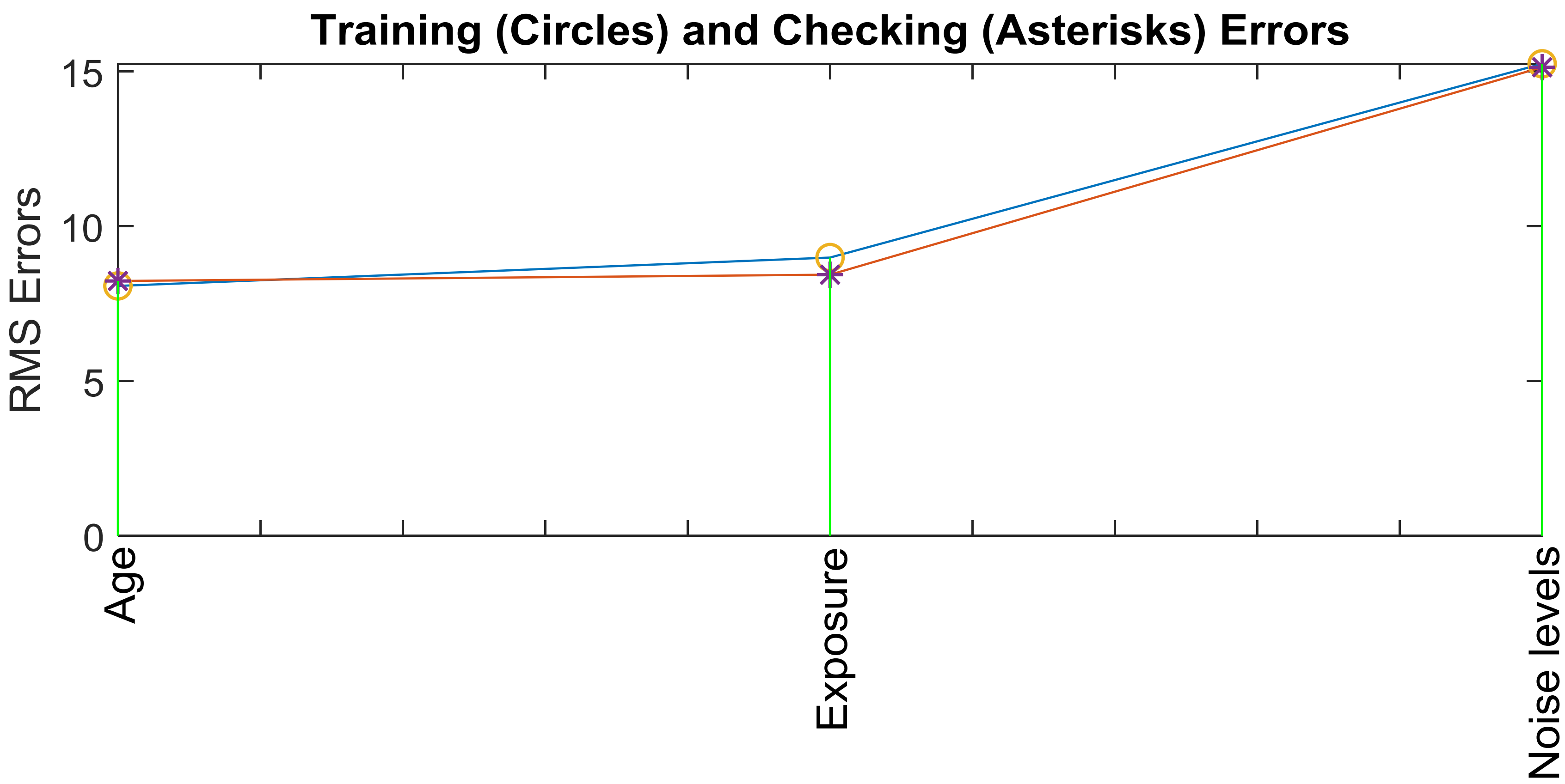


Figure 4.6: Exhaustive search for the operating parameters on hearing threshold at 4 kHz

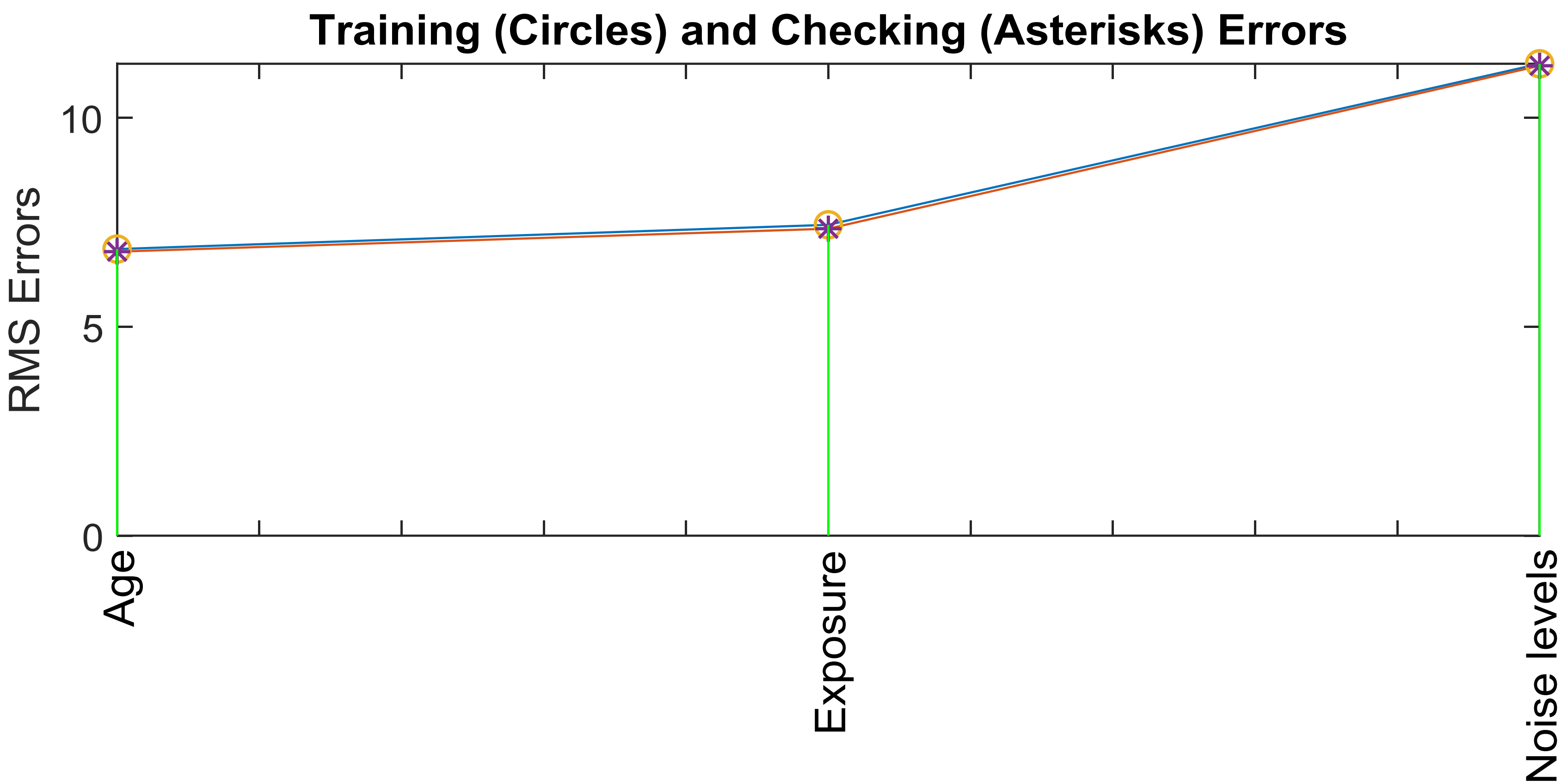


Figure 4.7: Exhaustive search for the operating parameters on hearing threshold at 6 kHz

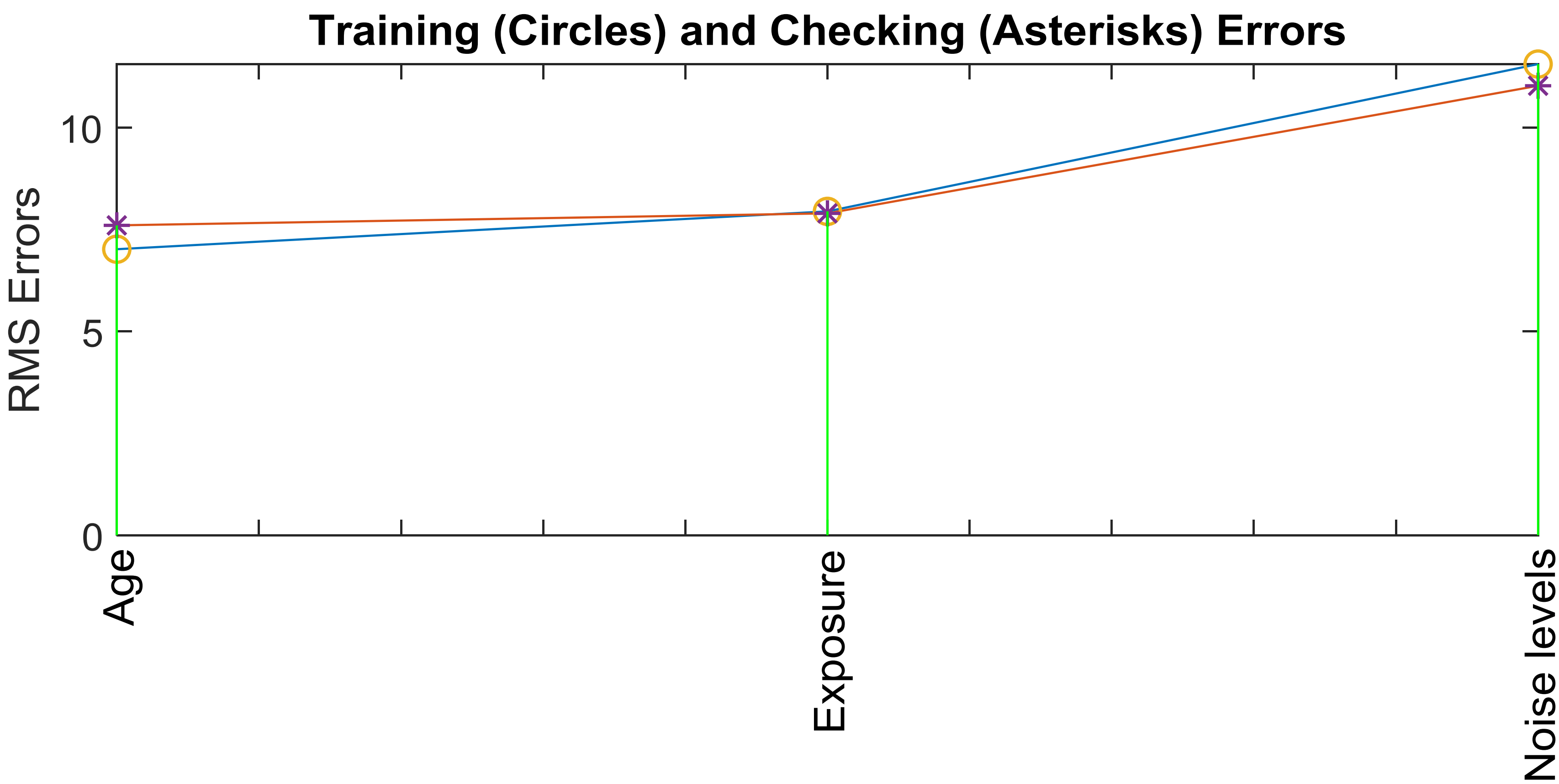


Figure 4.8: Exhaustive search for the operating parameters on hearing threshold at 8 kHz

4.4 ANFIS Models Hearing Threshold Accuracies at Various Frequencies

The exhaustive search model accuracies (in terms of RMSE and R-values) for the hearing threshold analysis conducted at the eight frequencies (500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz and 8 kHz) considered in this study are here presented.

(A) Hearing Threshold at 250 Hz

Since it is not feasible to obtain the most significant factor that contribute to the hearing threshold at the frequency 250 Hz, hence Root Mean Square Error (RMSE) and R – values cannot be determined.

(B) Hearing Threshold at 500 Hz

From Table 4.5, the model estimation was performed using five input MF type (trimf, trapmf, gbellmf, gaussmf, gauss2mf). The best prediction and evaluation of the model occurred at input MF type gbell membership function which produced a low training error of 4.5202 and the checking error value of 5.7514, with the least positive difference between the training and checking RMSE (1.2312), and the highest correlation coefficient of 0.7610.

The plot of original data against predicted data for model estimation of the hearing threshold shows good prediction of the model (Figure 4.9). Both experimental data and predictive data follows the same trend as residuals (Figure 4.10), while the regression plot of experimental output and predicted output in Figure 4.11 also gives a correlation coefficient of 0.76103 which also indicates good prediction for the hearing threshold at 500 Hz.

(C) Hearing Threshold at 1 kHz

The best prediction and evaluation of the model occurred at input MF type trimf membership function which gave low training error of 4.5872 and the checking error value of 6.7494, with the least positive difference between the training and checking RMSE 2.1622, with the highest correlation coefficient of 0.7991 (Table 4.6). The plot of original data against predicted data for model estimation of the hearing threshold shows good prediction of the model (Figure 4.12).

Table 4.5: RMSE and R- values for hearing threshold at 500 Hz

Input MF type	RMSE		Correlation coefficient (R-value)
	Training	**Checking**	
Trimf	4.6159	6.5547	0.7578
Trapmf	5.6696	7.3474	0.6961
Gbellmf	4.5202	5.7514	0.7610
Gaussmf	5.0171	6.6484	0.7443
gauss2mf	5.3549	7.0046	0.7216

MF number: 2, Epoch number = 100, Output MF type: Constant

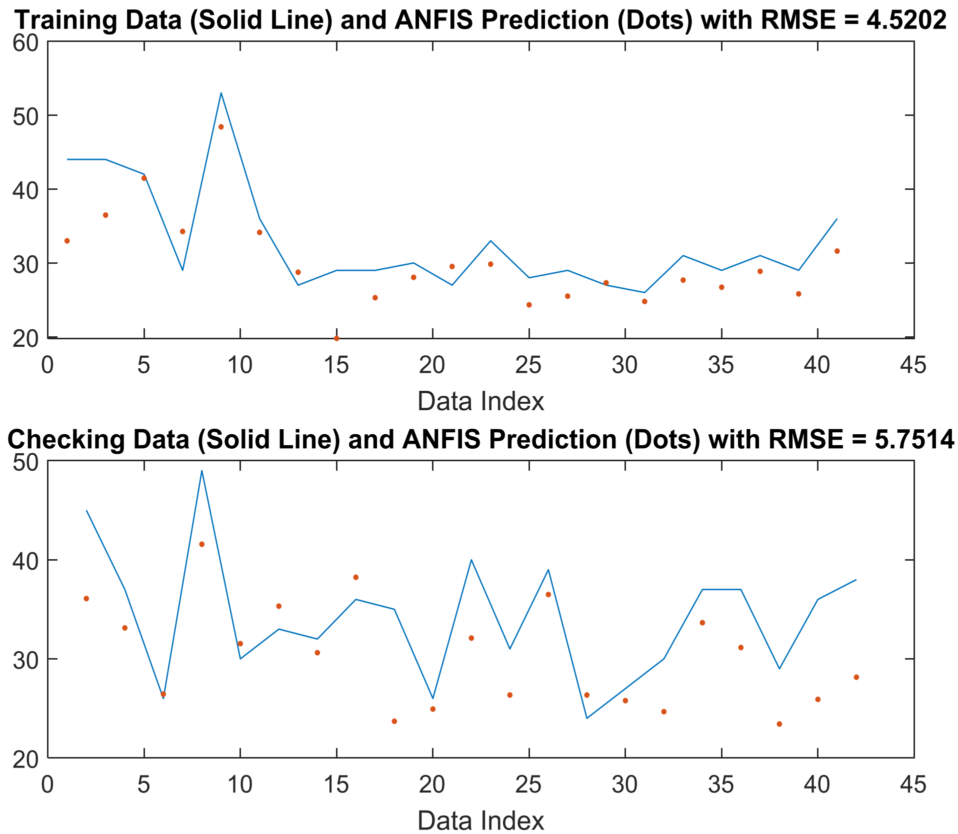


Figure 4.9: Plot of original data against predicted data for model estimation of the hearing threshold at 500 Hz

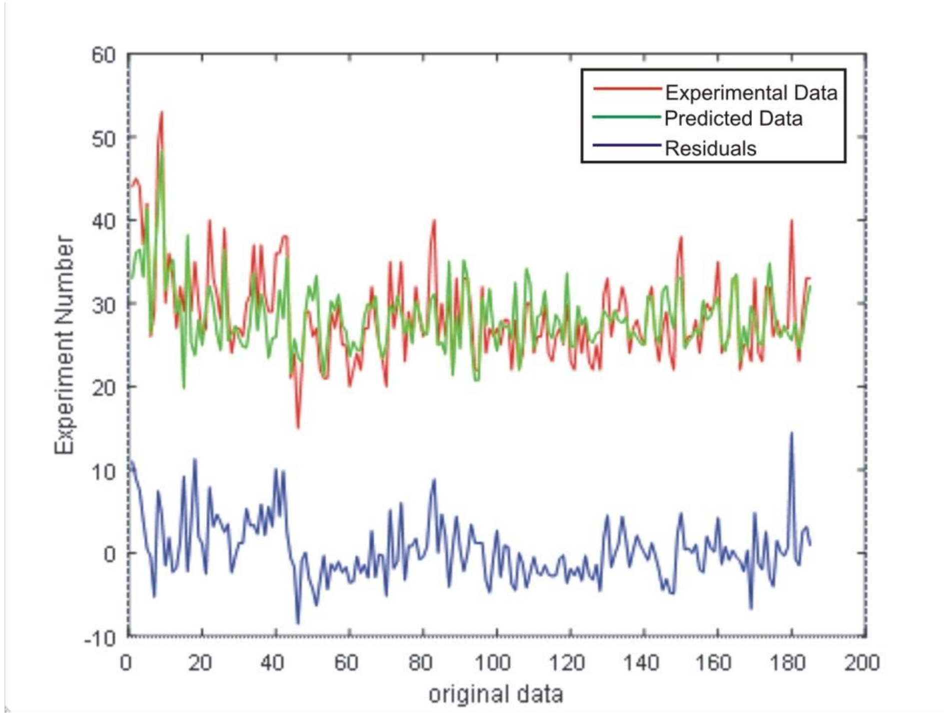


Figure 4.10: Plot of predicted output with residuals for the hearing threshold at 500Hz

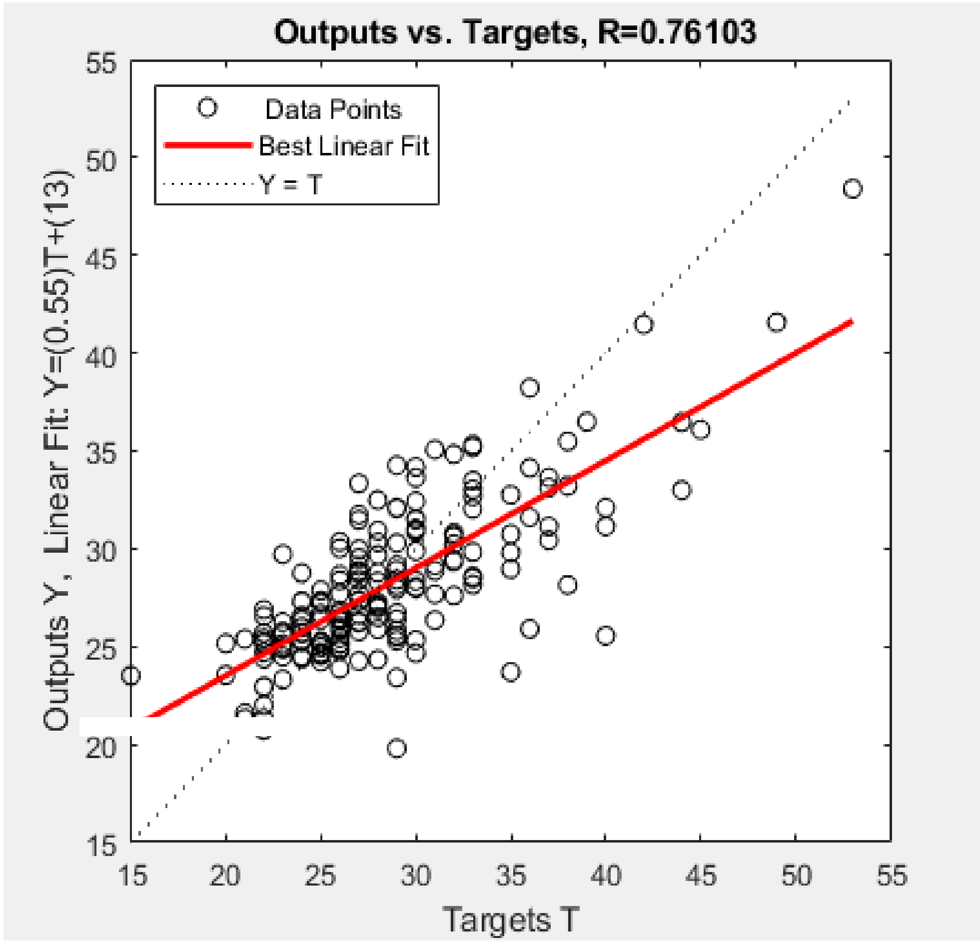


Figure 4.11: Regression plot of experimental and predicted output for the hearing threshold at 500 Hz

Table 4.6: RMSE and R-values for hearing threshold at 1 kHz

Input MF type	RMSE		Correlation coefficient (R-value)
	Training	Checking	
trimf	4.5872	6.7494	0.7991
trapmf	5.0812	7.6363	0.7606
gbellmf	4.3729	6.9998	0.7949
gaussmf	4.5322	6.8266	0.7952
gauss2mf	4.5933	7.2922	0.7780

MF number: 2, Epoch number = 100, Output MF type: Constant

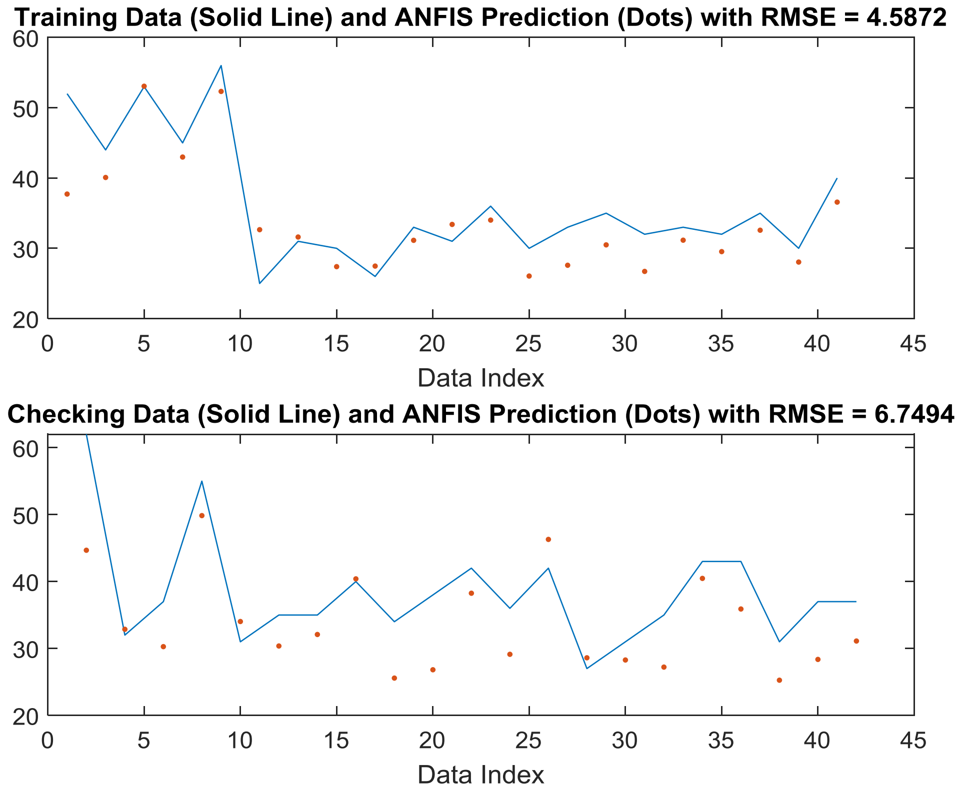


Figure 4.12: Plot of original data against predicted data for model estimation of the hearing threshold at 1 kHz

Both experimental data and predictive data follows the same trend as residuals (Figure 4.13), while the regression plot of experimental output and predicted output in Figure 4.14 also gives good correlation coefficient of 0.79909 which also indicates good prediction of the hearing threshold at this frequency.

(D) Hearing Threshold at 2 kHz

Input MF type gbell membership function gives the best prediction and evaluation of the model at frequency 2kHz with low training error of 4.6731 and the checking error value of 6.5173, resulted in a positive difference between the training error and checking RMSE of 1.8442 (Table 4.7). The plot of original data against predicted data for model estimation of the hearing threshold shows good prediction of the model (Figure 4.15). Both experimental data and predictive data follow the same trend as residuals (Figure 4.16). Correlation coefficient value of 0.82381 in the regression plot of experimental output and predicted output in Figure 4.17 also indicates good model prediction for the hearing threshold at this frequency.

(E) Hearing Threshold at 3 kHz

MF type gbell membership function gives low training error of 5.9462, checking error value of 5.0187, least positive difference between training and checking RMSE value of 0.9275 with the highest correlation coefficient of 0.8329 (Table 4.8). The plot of original data versus predicted data for the model estimation of the hearing threshold depicts good model prediction (Figure 4.18). Figure 4.19 shows the good prediction accuracy with the good relationship between the plot of experimental data, prediction data and residuals. Correlation coefficient value of 0.83293 in the regression plot of experimental output and predicted output in figure 4.20 also established good model prediction at this frequency.

(F) Hearing Threshold at 4 kHz

The best prediction and evaluation of the model occurred at input MF type gbell membership function which gave low training error of 8.9601 and the checking error value of 9.3694 , with the least positive difference between the training and checking RMSE (0.4093), and the highest correlation coefficient of 0.8678 (Table 4.9).

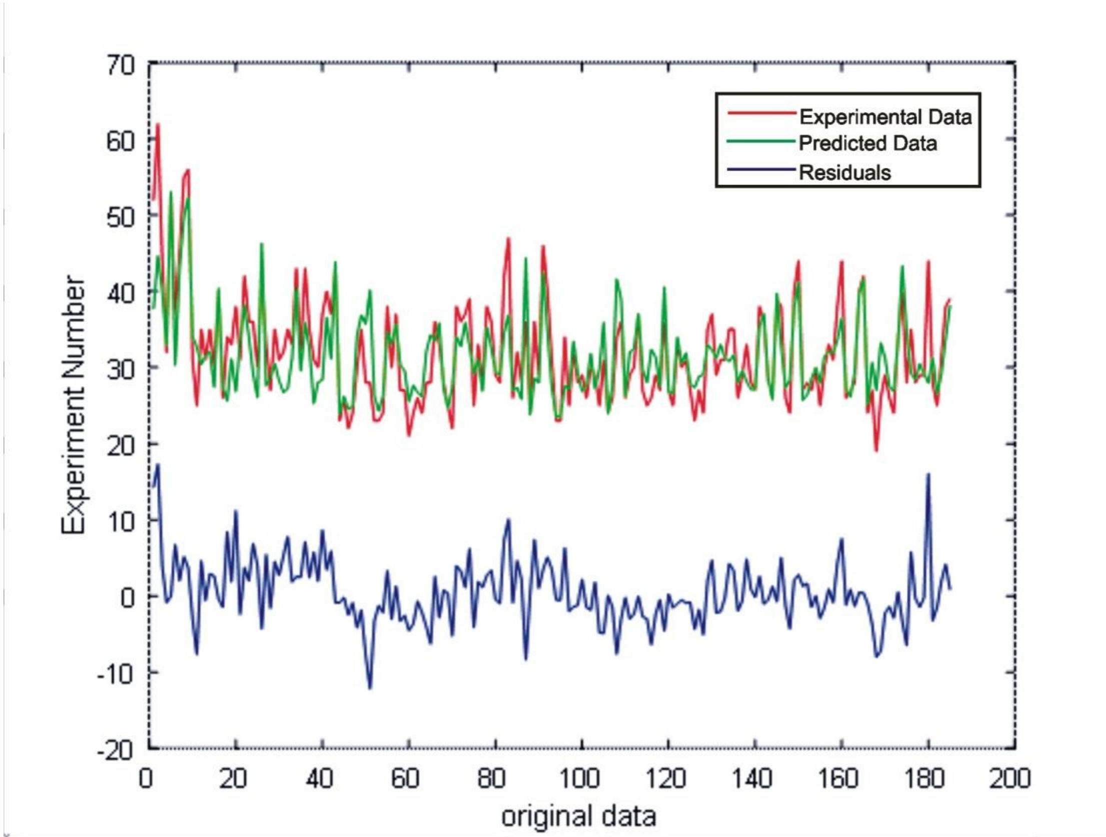


Figure 4.13: Plot of predicted output with residuals for the hearing threshold at 1 kHz

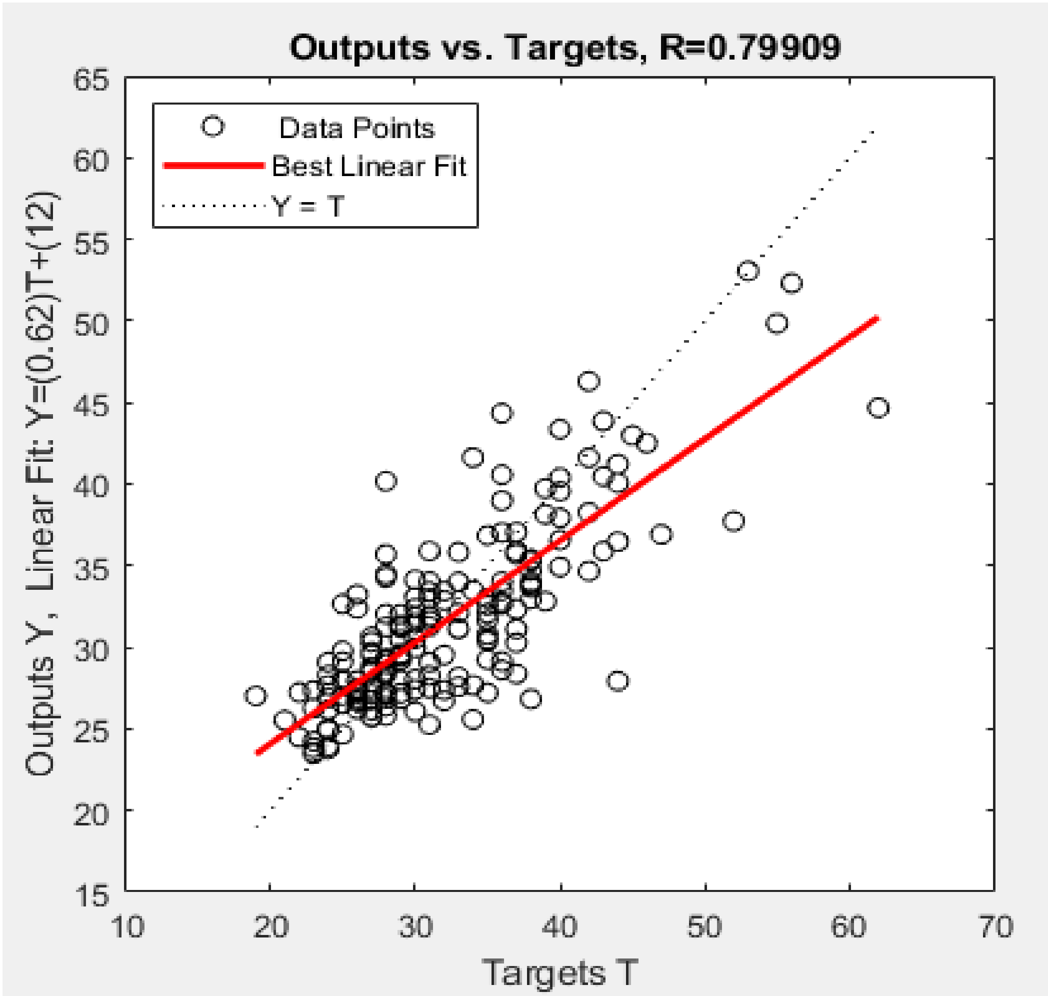


Figure 4.14: Regression plot of experimental and predicted output for the hearing threshold at 1 kHz

Table 4.7: RMSE and R-values for hearing threshold at 2 kHz

Input MF type	RMSE		Correlation coefficient (R-value)
	Training	Checking	
Trimf	5.1839	7.1771	0.8198
Trapmf	5.65	7.8937	0.7946
Gbellmf	4.6731	6.5173	0.8238
Gaussmf	5.0427	7.1369	0.8190
gauss2mf	5.1356	7.6100	0.8079

MF number: 2, Epoch number = 100, Output MF type: Constant

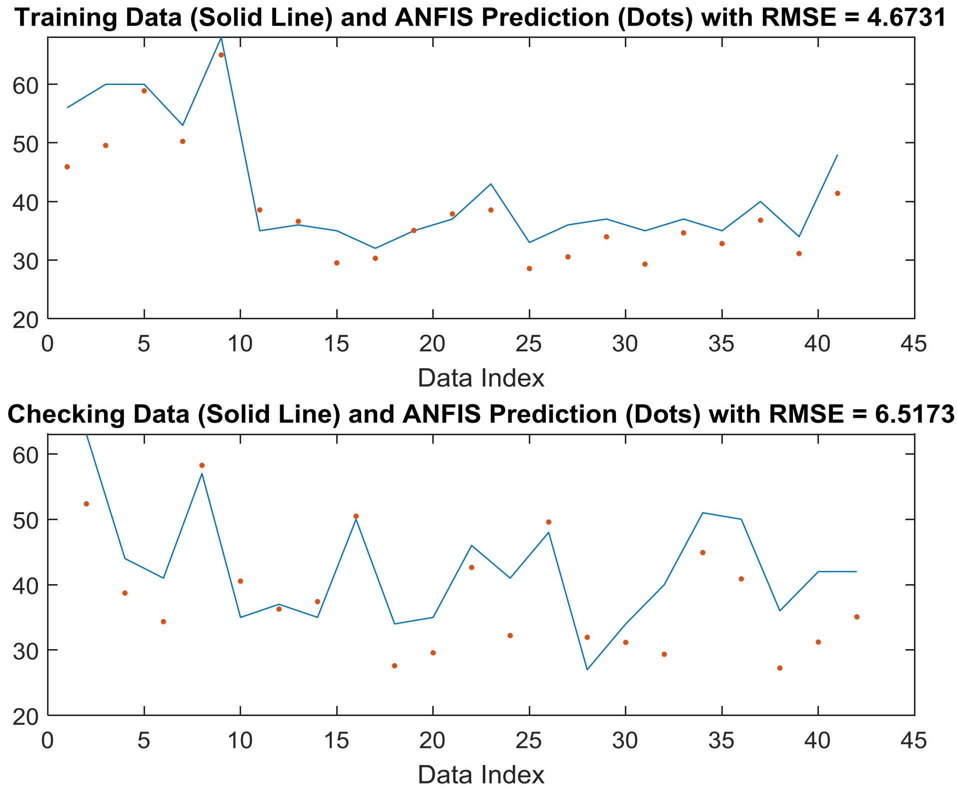


Figure 4.15: Plot of original data against predicted data for model estimation of the hearing threshold at 2 kHz

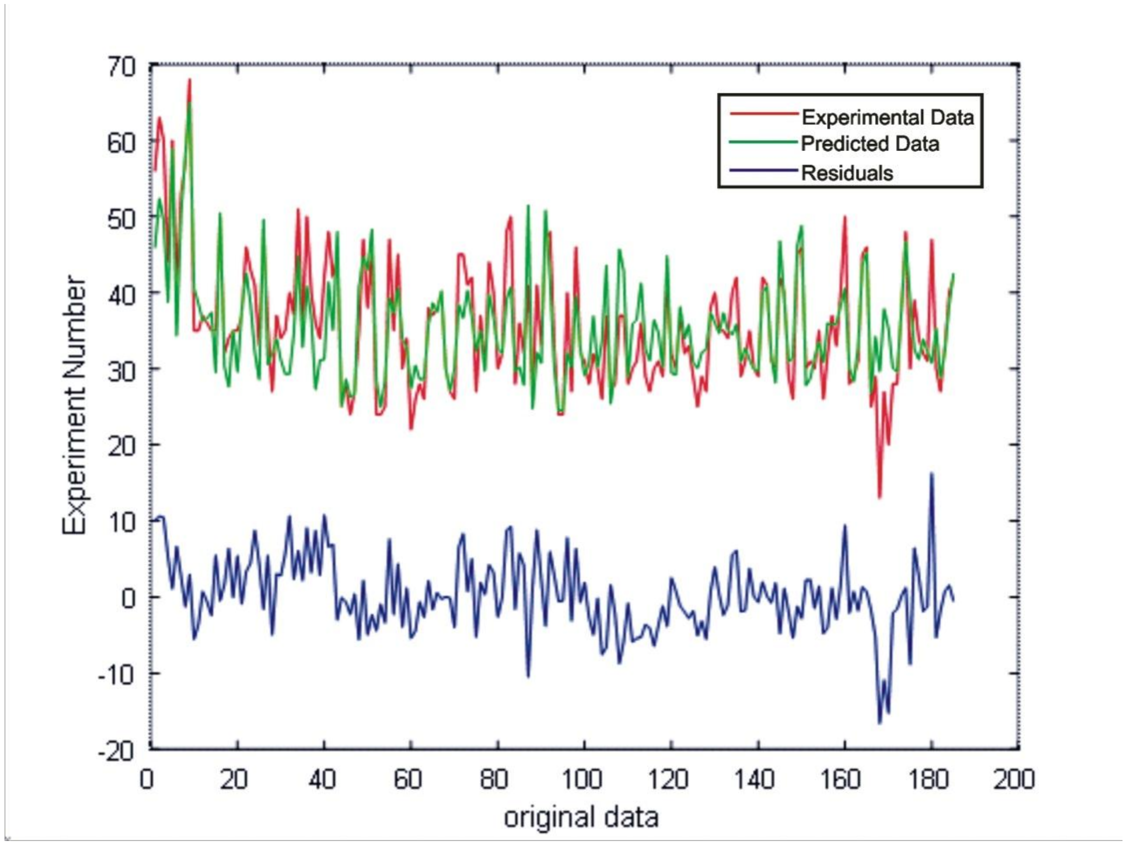


Figure 4.16: Plot of predicted output with residuals for the hearing threshold at 2 kHz

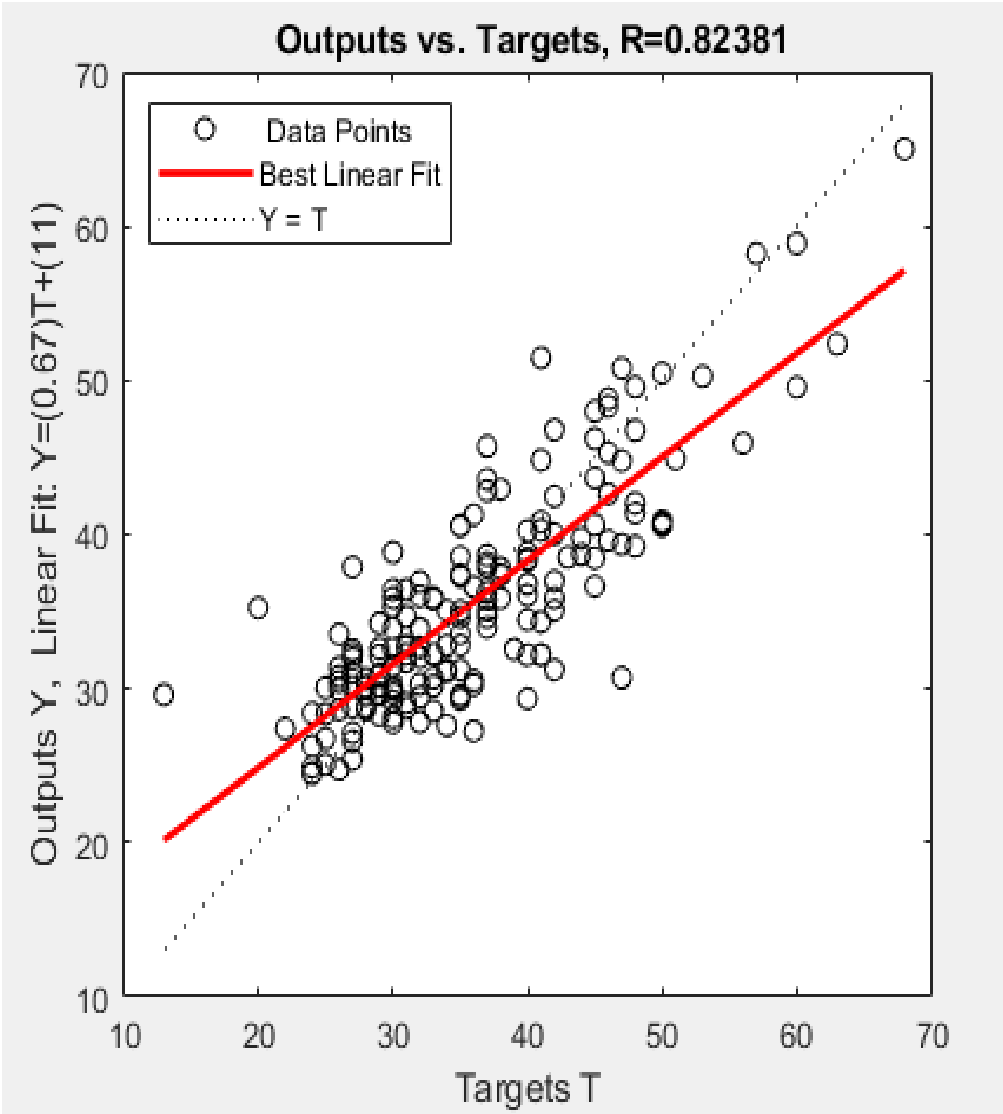


Figure 4.17: Regression plot of experimental and predicted output for the hearing threshold at 2 kHz

Table 4.8: RMSE and R-values for hearing threshold at 3 kHz

Input MF type	RMSE		Correlation coefficient (R-value)
	Training	Checking	
trimf	6.8562	5.3466	0.8170
trapmf	5.4153	6.9070	0.8209
gbellmf	5.9462	5.0187	0.8329
gaussmf	6.5821	5.2026	0.8264
gauss2mf	6.0383	7.1341	0.8269

MF number: 2, Epoch number = 100, Output MF type: Constant

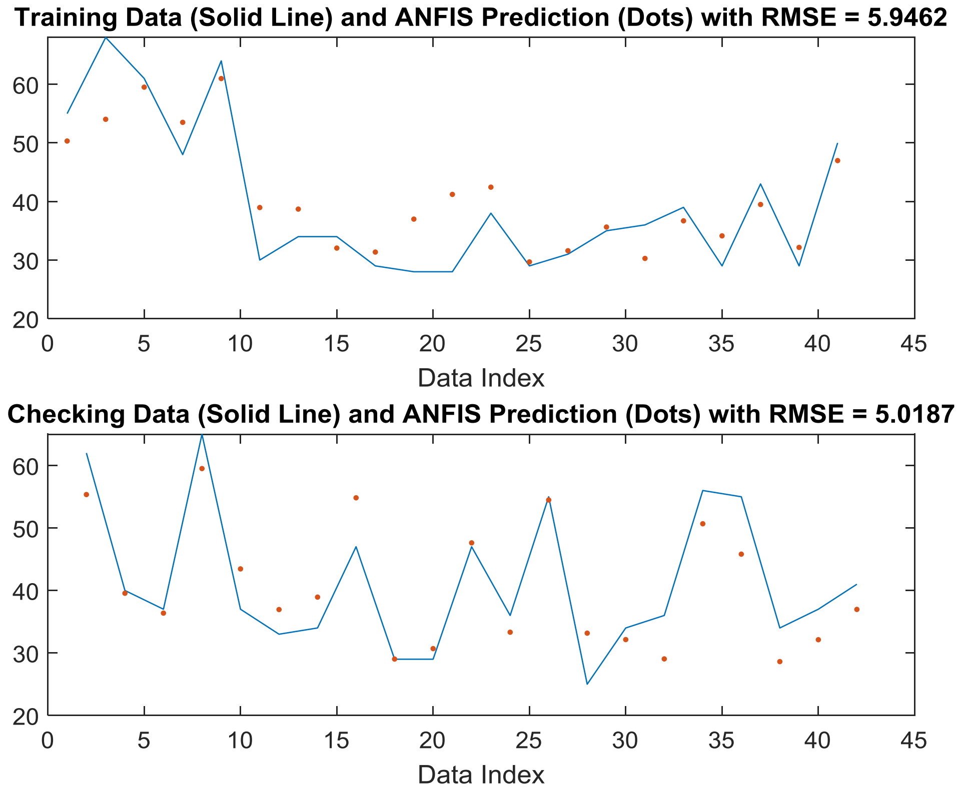


Figure 4.18: Plot of original data against predicted data for model estimation of the hearing threshold at 3 kHz

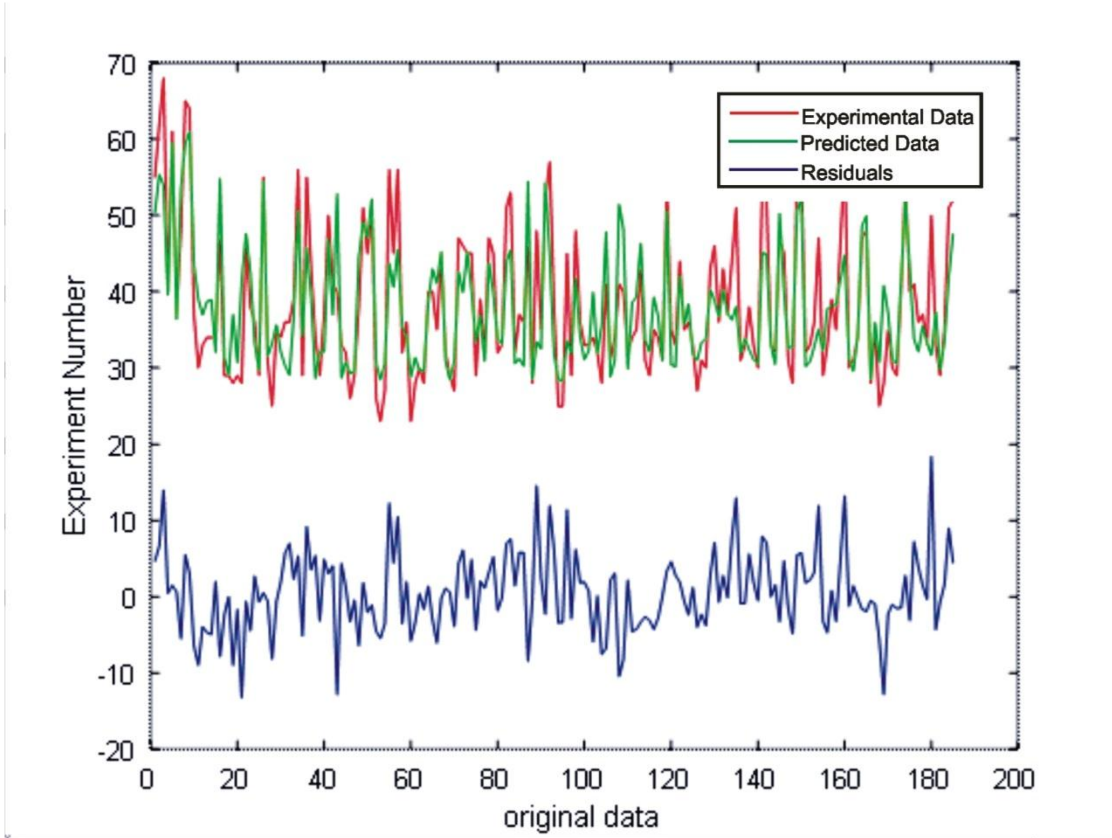


Figure 4.19: Plot of predicted output with residuals for the hearing threshold at 3 kHz

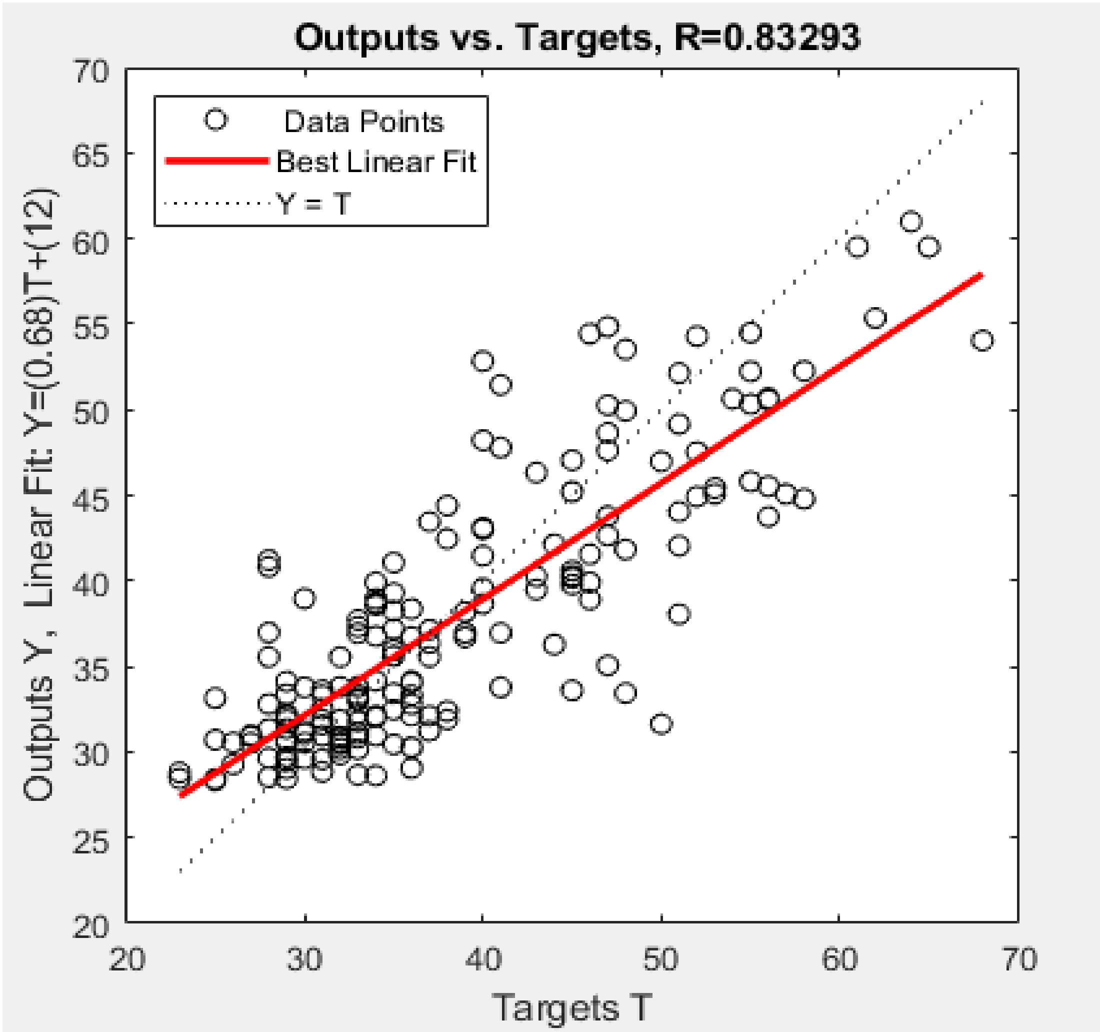


Figure 4.20: Regression plot of experimental and predicted output for the hearing threshold at 3 kHz

Table 4.9: RMSE and R-values for hearing threshold at 4 kHz

Input MF type	RMSE		Correlation coefficient (R-value)
	Training	Checking	
Trimf	9.5564	10.0758	0.8572
Trapmf	9.114	10.0037	0.8565
Gbellmf	8.9601	9.3694	0.8678
Gaussmf	9.5896	10.1394	0.8612
gauss2mf	9.006	10.2047	0.8633

MF number: 2, Epoch number = 100, Output MF type: Constant

The plot of original data versus predicted data for the model estimation of the hearing threshold depicts good model prediction (Figure 4.21). Both experimental data and predictive data follows the same trend (Figure 4.22), with residuals. The regression plot of experimental output and predicted output in Figure 4.23, also gives good correlation coefficient of 0.86784 which indicates good prediction of hearing threshold at this frequency.

(G)Hearing Threshold at 6 kHz

The best prediction and evaluation of the model occurred at input MF type gbell membership function which gave low training error of 8.2480 and the checking error value of 7.139, with the least positive difference between the training and checking RMSE (1.109), and the highest correlation coefficient of 0.8165 (Table 4.10). Original data versus predicted data plot for the model estimation of the hearing threshold depicts good model prediction (Figure 4.24). Both experimental data and predictive data follow the same trend (Figure 4.25) with the residuals plot. The Regression plot of experimental output and predicted output in Figure 4.26 also gives good correlation coefficient of 0.81648 which indicates good prediction of hearing threshold at the frequency 6 kHz.

(H) Hearing Threshold at 8 kHz

Five input MF type (trimf, trapmf, gbellmf, gaussmf, gauss2mf) was used for the model estimation. Input MF type gbell membership function gives low training error of 9.0428 and the checking error of 7.9062, having least positive difference between the training and checking RMSE value of 1.1366 and highest correlation coefficient of 0.7980 (Table 4.11). Hence input MF type gbell membership produced the best model prediction and evaluation at this frequency. The plot of original data against the predicted data for the model estimation depicts good prediction for the hearing threshold (Figure 4.27). Both experimental data and predictive data follow the same trend (Figure 4.28) with the residuals plot. The Regression plot of experimental output and predicted output in Figure 4.29 also gives good correlation coefficient of 0.79802 which indicates good prediction of hearing threshold at 8 kHz.

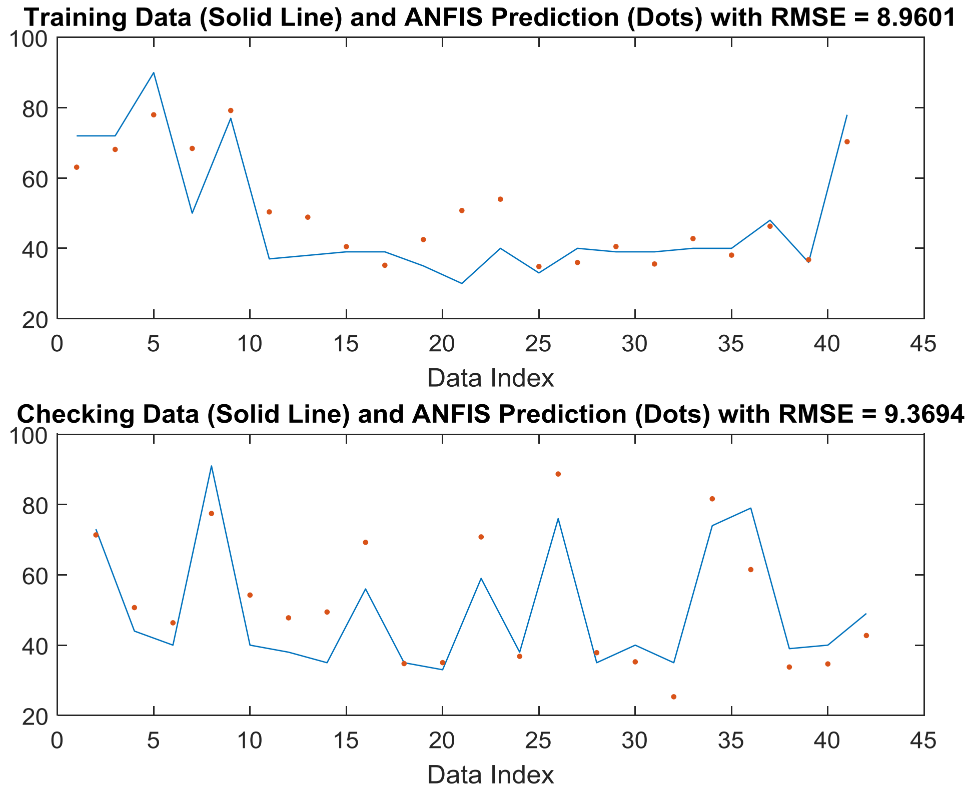


Figure 4.21: Plot of original data against predicted data for model estimation of the hearing threshold at 4 kHz

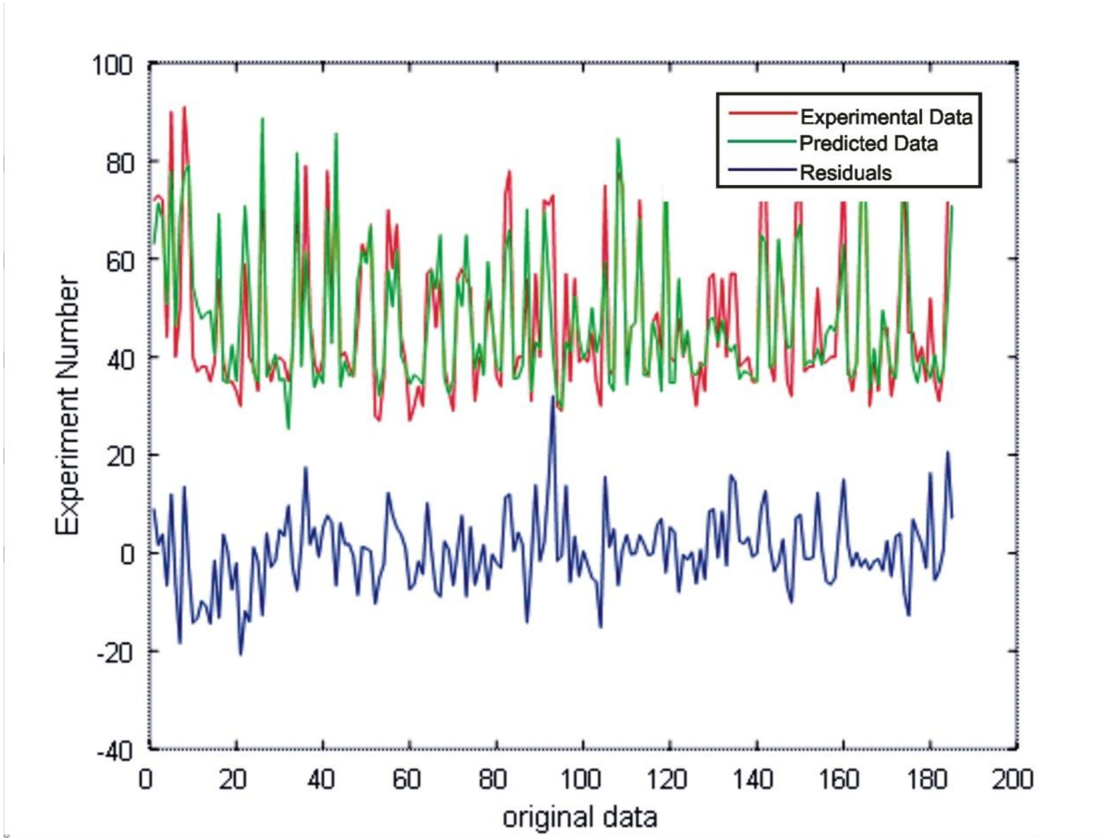


Figure 4.22: Plot of predicted output with residuals for the hearing threshold at 4 kHz

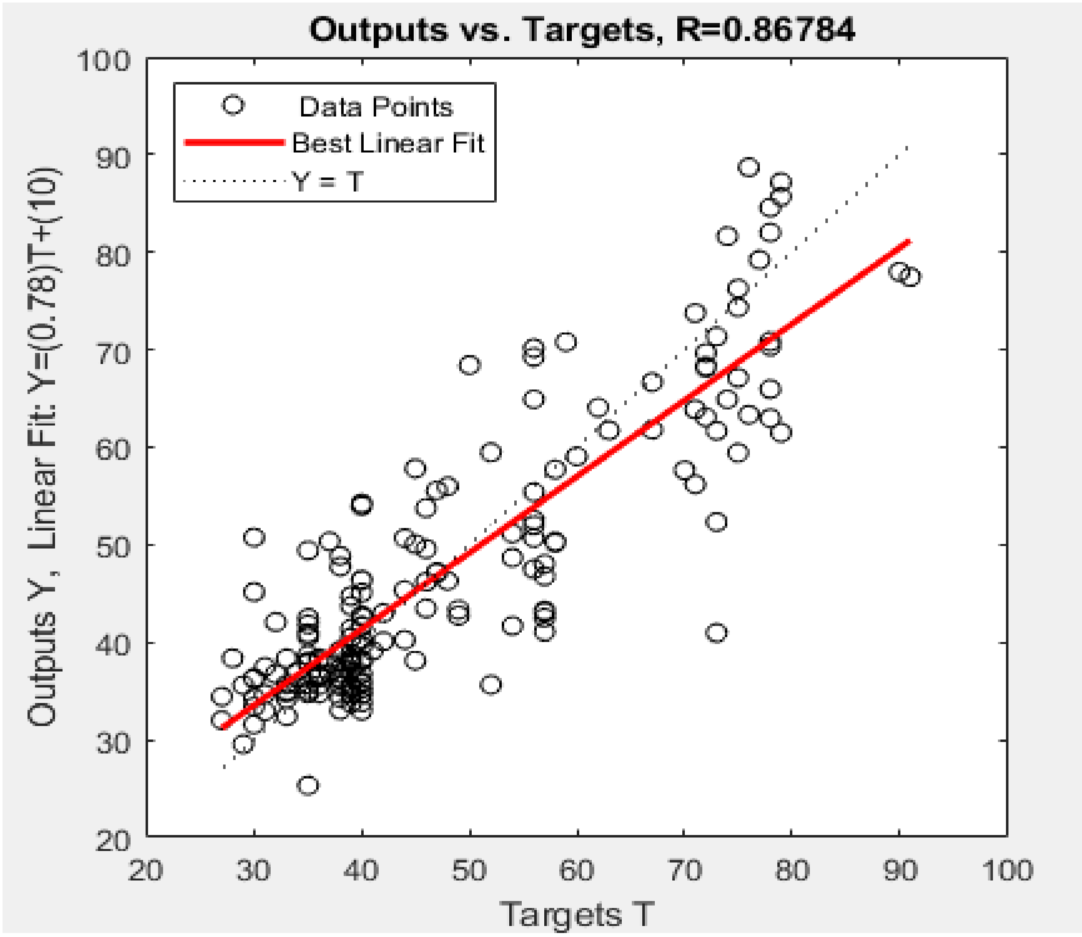


Figure 4.23: Regression plot of experimental and predicted output for the hearing threshold at 4 kHz

Table 4.10: RMSE and R-values for the hearing threshold at 6 kHz

Input MF type	RMSE		Correlation coefficient (R-value)
	Training	Checking	
Trimf	9.0412	7.5325	0.8036
Trapmf	8.9753	7.4627	0.8057
Gbellmf	8.2480	7.1390	0.8165
Gaussmf	8.7344	7.2566	0.8109
gauss2mf	8.8482	7.5775	0.8145

MF number: 2, Epoch number = 100, Output MF type: Constant

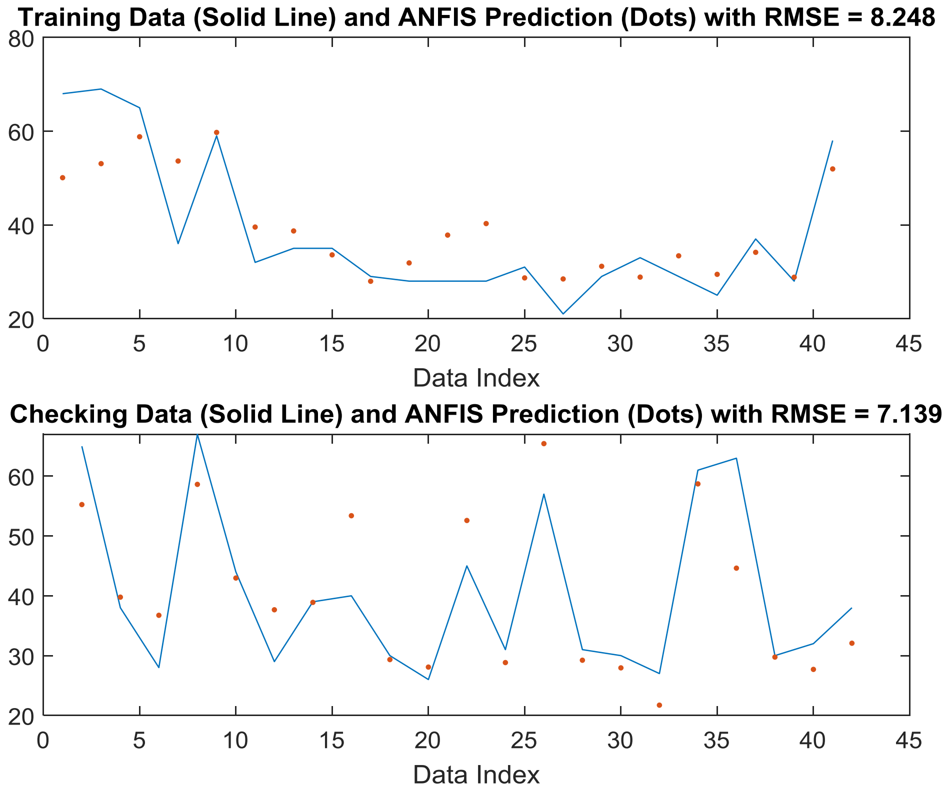


Figure 4.24: Plot of original data against predicted data for model estimation of the hearing threshold at 6 kHz

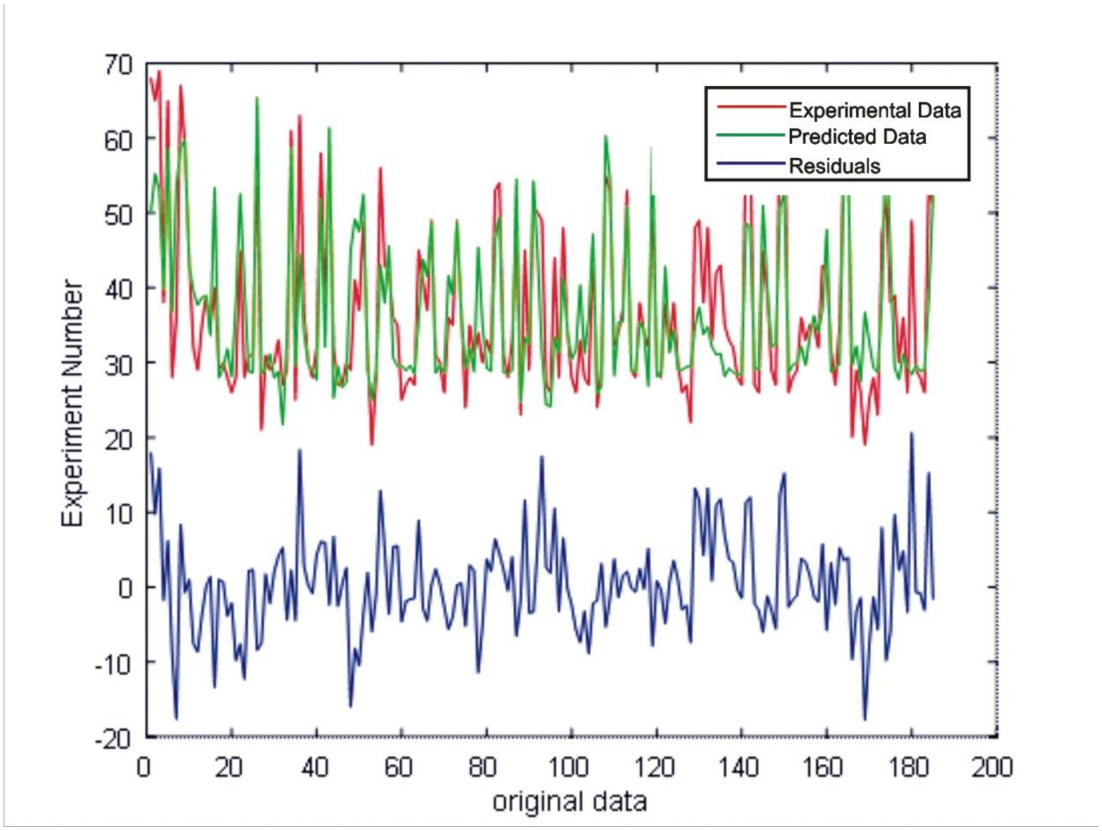


Figure 4.25: Plot of Predicted Output with Residuals for the Hearing Threshold at 6 kHz

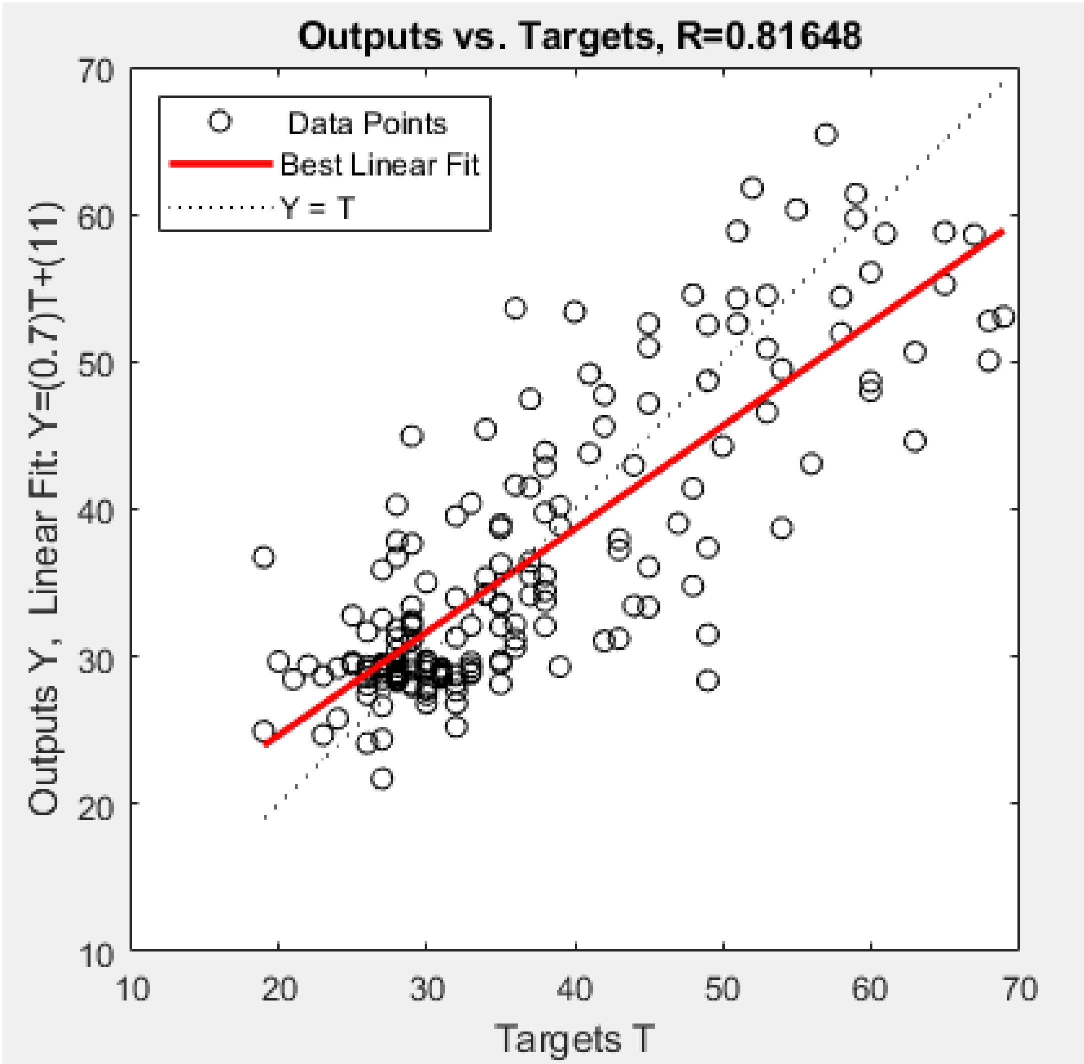


Figure 4.26: Regression plot of experimental and predicted output for the hearing threshold at 6 kHz

Table 4.11: RMSE and R-values for hearing threshold at 8 kHz

Input MF type	RMSE		Correlation coefficient (R-value)
	Training	Checking	
Trimf	9.5533	11.348	0.7719
Trapmf	7.5632	9.4475	0.7933
Gbellmf	9.0883	7.9720	0.7968
Gaussmf	8.7029	11.0262	0.7869
gauss2mf	9.0428	7.9062	0.7980

MF number: 2, Epoch number = 100, Output MF type: Constant

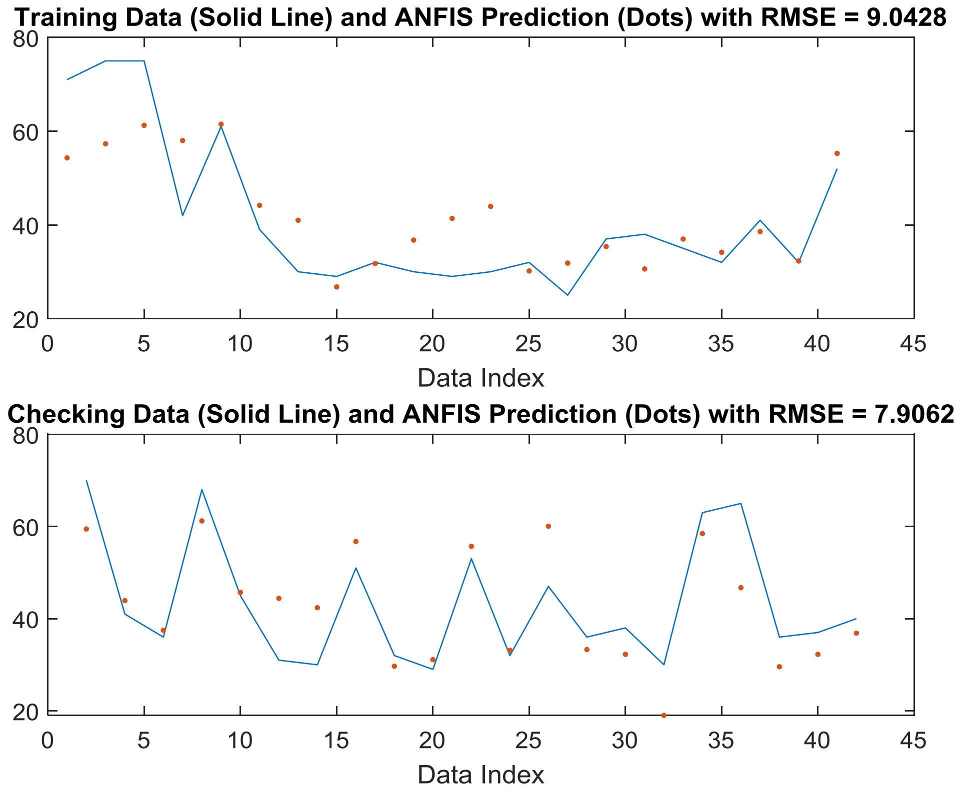


Figure 4.27: Plot of original data against predicted data for model estimation of the hearing threshold at 8 kHz

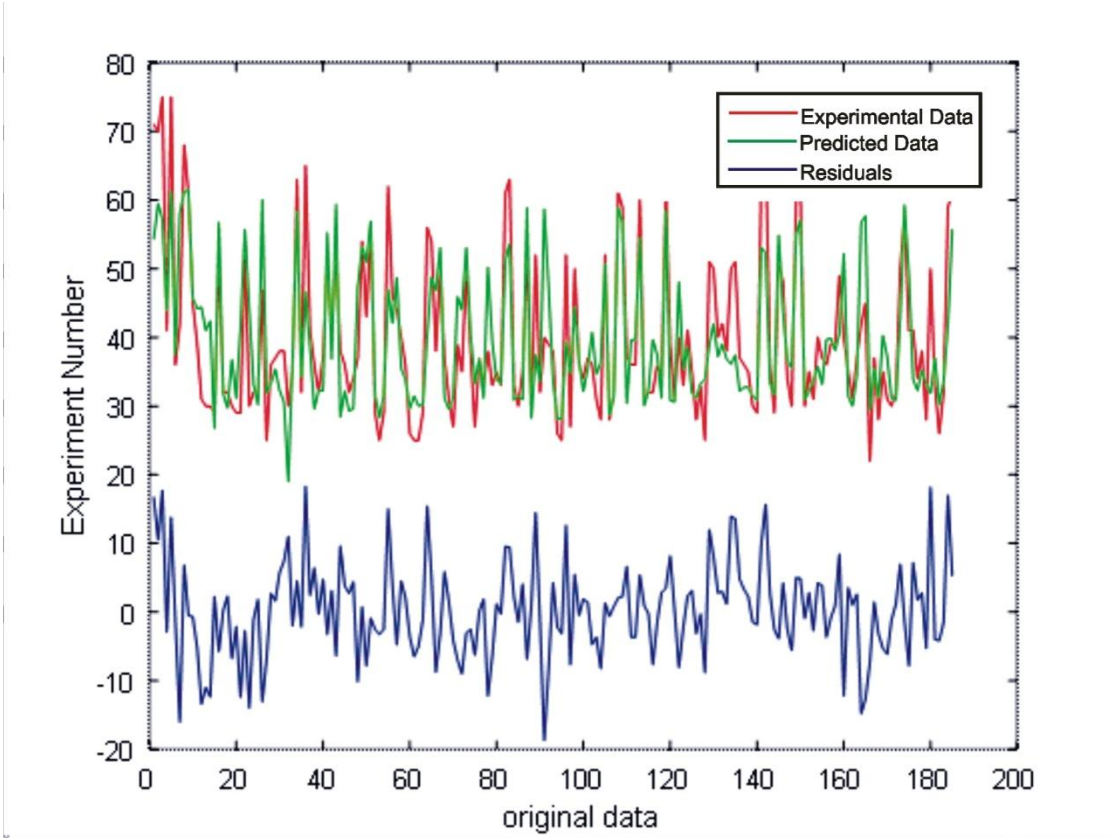


Figure 4.28: Plot of predicted output with residuals for the hearing threshold at 8 kHz

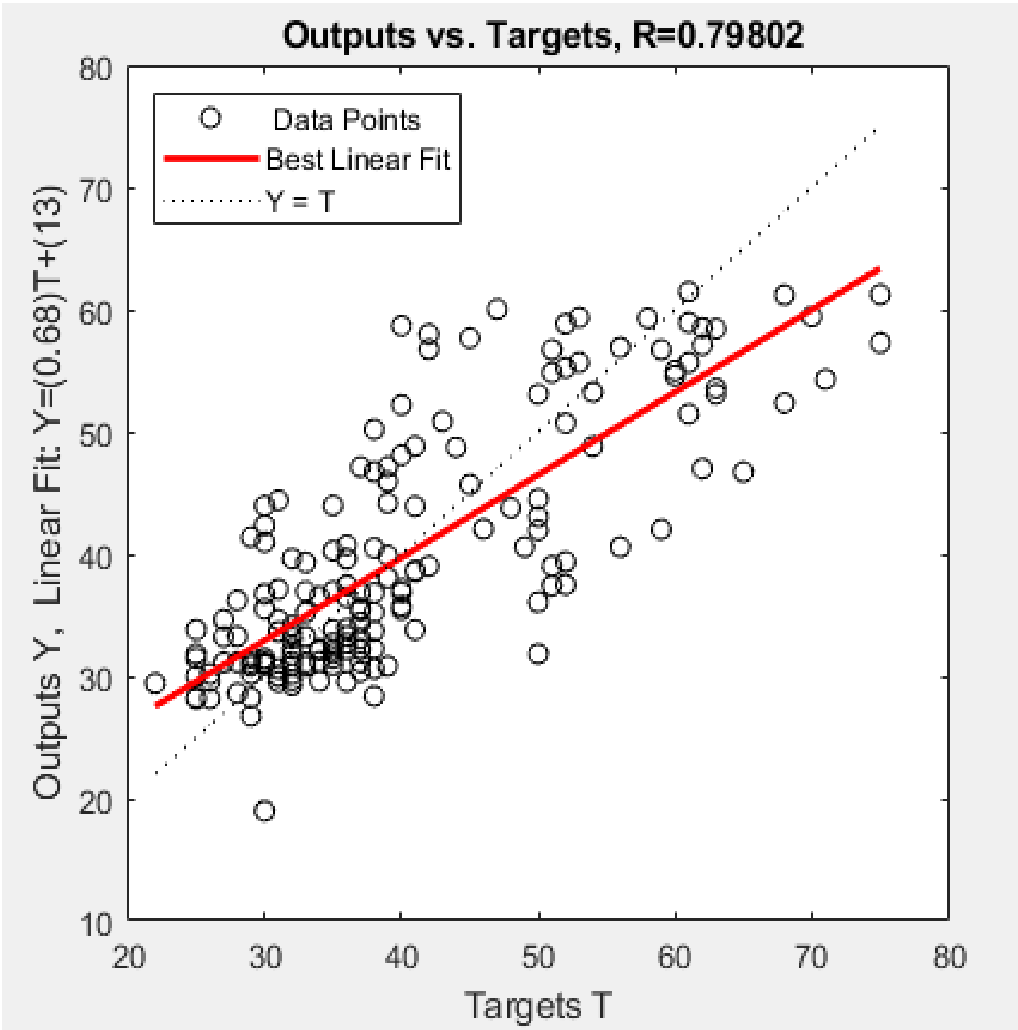


Figure 4.29: Regression plot of experimental and predicted output for the hearing threshold at 8 kHz

4.5 ANOVA for Quadratic Models Hearing Threshold outcomes at Various Frequencies

The analysis of variance (ANOVA) results for the quadratic regression models developed to evaluate the interaction of the studied factors on the hearing threshold of the quarry site workers at various frequencies is here presented.

4.5.1 Hearing Threshold at 250 Hz

In Table 4.12, the model F-value of 95.09 implies that one or more of the independent terms of the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. The p-value of less than 0.05 denotes the terms of model are significant. In this case A, C, A^2 are significant model terms. Values greater than 0.05 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), variable reduction may improve the model.

The Predicted R^2 of 0.8074 is in reasonable agreement with the Adjusted R^2 of 0.8215 of the model's validity. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 50.410 indicates an adequate signal. This model can be used to navigate the design space.

4.5.2 Hearing Threshold at 500 Hz

In Table 4.13, the Model F-value of 70.21 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. A p-value less than 0.05 indicate model terms are significant. In this case A, AC, A^2, C^2 are significant model terms. Values greater than 0.05 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), insignificant variables reduction may improve the model.

The Lack of Fit F-value of 0.23 implies there is a 76.30% chance that a Lack of Fit F-value could occur. This ensures the model fitness. The Predicted R^2 value of 0.7604 is in reasonable agreement with the Adjusted R^2 value of 0.7720; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable.

The ratio of 44.493 indicates an adequate signal. This model can be used to navigate the design space (Montgomery and Runger, 2007).

Table 4.12: ANOVA for quadratic model for the hearing threshold at 250 Hz

Source	Sum of Squares	df	Mean Square	F-value	p-value prob>F	
Model	1238.82	9	137.65	95.09	<0.0001	Significant
A-Age	113.89	1	113.89	78.68	<0.0001	Significant
B-Exposure	4.74	1	4.74	3.28	0.0720	
C-Noise level	13.17	1	13.17	9.10	0.0029	Significant
AB	0..9044	1	0.9044	0.6248	0.4304	
AC	0.2032	1	0.2032	0.1404	0.7084	
BC	0.7635	1	0.7635	0.5275	0.4686	
A^2	19.63	1	19.63	13.56	0.0003	Significant
B^2	5.34	1	5.34	3.69	0.0563	
C^2	0.5570	1	0.5570	0.3848	0.0537	Significant
Residual	253.32	175	1.45			
Lack of Fit	253.32	172	1.47			
Pure Error	0.0000	3	0.0000			
Cor Total	1492.13	184				

R^2: 0.8302, Adj. R^2: 0.8215, Pred. R^2: 0.8074, Adeq. Precision: 50.4099,

Std. Dev.: 1.20, Mean: 25.20, C.V. %: 4.77.

Table 4.13: ANOVA for quadratic model for the hearing threshold at 500 Hz

Source	Sum of Squares	df	Mean Square	F-value	p-value prob>F	
Model	3000.63	9	333.40	70.21	<0.0001	Significant
A-Age	256.02	1	256.02	53.91	<0.0001	Significant
B-Exposure	6.08	1	6.08	1.28	0.2592	
C-Noise level	0.8275	1	0.8275	0.1743	0.6769	
AB	15.52	1	15.52	3.27	0.0723	
AC	51.14	1	51.14	10.77	0.0012	Significant
BC	5.72	1	5.72	1.20	0.2740	
A^2	84.75	1	84.75	17.85	<0.0001	Significant
B^2	0.4409	1	0.4409	0.0929	0.7609	
C^2	26.85	1	26.85	5.65	0.0185	Significant
Residual	831.02	175	4.75			
Lack of Fit	829.02	172	4.82	0.23	0.7630	Not significant
Pure Error	2.00	3	0.6667			
Cor Total	3831.65	184				

R^2: 0.7831, Adj. R^2: 0.7720, Pred. R^2: 0.7604, Adeq. Precision: 44.4930,

Std. Dev.: 2.18, Mean: 28.36, C.V. %: 4.21.

4.5.3 Hearing Threshold at 1 kHz

Table 4.14 gives the Model F-value of 55.79 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. A p-value of less than 0.0500 indicate model terms are significant. In this case A, B, A^2 are significant model terms. Values greater than 0.05indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), insignificant variables reduction may improve the model.

The Lack of Fit F-value of 0.92 implies the Lack of Fit is not significant relative to the pure error. There is 84.52% chance that a Lack of Fit F-value could occur. Non-significant lack of fit is good, it indicates the model fitness. The Predicted R^2 value of 0.7109 is in reasonable agreement with the Adjusted R^2 value of 0.7282; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 35.892 indicates an adequate signal. This model can be used to navigate the design space.

4.5.4 Hearing Threshold at 2 kHz

Table 4.15 gives Model F-value of 66.83 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. A p-value of less than 0.0500 means that model terms are significant. In this case A, B, A^2, C^2 are significant model terms. Values greater than 0.05 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), insignificant variables reduction may improve the model.

The Lack of Fit F-value of 0.26 implies the Lack of Fit is not significant relative to the pure error. There is a 77.94% chance that a Lack of Fit F-value could occur. Non-significant lack of fit is good, as it supports the model fitness. The Predicted R^2 value of 0.7462 is in reasonable agreement with the Adjusted R^2 value of 0.7630; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 42.705 indicates an adequate signal. This model can be used to navigate the design space.

Table 4.14: ANOVA for quadratic model for the hearing threshold at 1 kHz

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value prob>F**	
Model	5227.70	9	580.86	55.79	<0.0001	Significant
A-Age	245.66	1	245.66	23.59	<0.0001	Significant
B-Exposure	103.22	1	103.22	9.91	0.0019	Significant
C-Noise Level	6.67	1	6.67	0.6404	0.4246	
AB	13.49	1	13.49	1.30	0.2566	
AC	16.91	1	16.91	1.62	0.2042	
BC	7.235E-06	1	7.235E-06	6.948E07	0.9993	
A^2	48.15	1	48.15	4.62	0.0329	Significant
B^2	14.31	1	14.31	1.37	0.2427	
C^2	39.97	1	39.97	3.84	0.0517	
Residual	1822.08	175	10.41			
Lack of Fit	1788.08	172	10.40	0.9173	0.8452	Not significant
Pure Error	34.00	3	11.33			
Cor Total	7049.78	184				

R^2: 0.7415, Adj. R^2: 0.7282, Pred. R^2:0.7109, Adeq. Precision: 35.8918,

Std. Dev.: 3.23, Mean: 31.72, C.V. %: 4.74.

Table 4.15: ANOVA for quadratic model for the hearing threshold at 2 kHz

Source	Sum of Squares	df	Mean Square	F-value	p-value prob>F	
Model	8399.39	9	933.27	66.83	<0.0001	Significant
A-Age	501.99	1	501.99	35.95	<0.0001	Significant
B-Exposure	97.54	1	97.54	6.99	0.0090	Significant
C-Noise Level	0.3885	1	0.3885	0.0278	0.8677	
AB	24.75	1	24.75	1.77	0.1848	
AC	41.28	1	41.28	2.96	0.0873	
BC	0.0375	1	0.0375	0.0027	0.9587	
A^2	163.03	1	163.03	11.68	0.0008	Significant
B^2	0.8334	1	0.8334	0.0597	0.8073	
C^2	103.77	1	103.77	7.43	0.0071	Significant
Residual	2443.66	175	13.96			
Lack of Fit	2430.66	172	14.13	0.26	0.7794	Not significant
Pure Error	13.00	3	4.33			
Cor Total	10843.05	184				

R^2: 0.7746, Adj. R^2: 0.7630, Pred. R^2: 0.7462, Adeq. Precision: 42.7045,

Std. Dev.: 3.74, Mean: 35.73, C.V. %: 3.25.

4.5.5 Hearing Threshold at 3 kHz

In Table 4.16, the Model F-value of 88.17 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. A p-value less than 0.0500 indicate model terms are significant. In this case A, B^2 are significant model terms. Values greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), insignificant variables reduction may improve the model.

The Lack of Fit F-value of 0.90 implies the Lack of Fit is not significant relative to the pure error. There is 78.34% chance that a Lack of Fit F-value could occur. Non-significant lack of fit is good which indicates the model fitness. The Predicted R^2 value of 0.7951 is in reasonable agreement with the Adjusted R^2 value of 0.8100; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 44.807 indicates an adequate signal. This model can be used to navigate the design space.

4.5.6 Hearing threshold at 4 kHz

Table 4.17 gives the Model F-value of 106.30, which implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. A p-value of less than 0.0500 implies that model terms are significant. In this case A, and AB are significant model terms. Values greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), insignificant variables reduction may improve the model.

The Lack of Fit F-value of 0.87 implies the Lack of Fit is not significant relative to the pure error. There is an 80.95% chance that a Lack of Fit F-value could occur. Non-significant lack of fit is good, which ensures the model fitness. The Predicted R^2 of 0.8206 is in reasonable agreement with the Adjusted R^2 of 0.8374; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 50.354 indicates an adequate signal. This model can be used to navigate the design space.

Table 4.16: ANOVA for quadratic model for the hearing threshold at 3 kHz

Source	Sum of Squares	df	Mean Square	F-value	p-value prob>F	
Model	12722.24	9	1413.58	88.17	<0.0001	Significant
A-Age	1480.27	1	1480.27	92.33	<0.0001	Significant
B-Exposure	2.31	1	2.31	0.1443	0.7045	
C-Noise Level	15.95	1	15.95	0.9946	0.3200	
AB	24.30	1	24.30	1.52	0.2199	
AC	2.68	1	2.68	0.1669	0.6834	
BC	21.00	1	21.00	1.31	0.2540	
A^2	62.31	1	62.31	3.89	0.0503	
B^2	124.62	1	124.62	7.77	0.0059	Significant
C^2	61.05	1	61.05	3.81	0.0526	
Residual	2805.68	175	16.03			
Lack of Fit	2793.18	172	16.24	0.90	0.7834	Not significant
Pure Error	12.50	3	4.17			
Cor Total	15527.92	184				

R^2: 0.8193, Adj. R^2: 0.8100, Pred. R^2:0.7951, Adeq. Precision: 44.8068,

Std. Dev.: 4.00, Mean: 38.81, C.V. %: 2.75

Table 4.17: ANOVA for quadratic model for the hearing threshold at 4 kHz

Source	Sum of Squares	df	Mean Square	F-value	p-value prob>F	
Model	36670.15	9	4074.46	106.30	<0.0001	Significant
A-Age	3231.75	1	3231.75	84.31	<0.0001	Significant
B-Exposure	119.71	1	119.71	3.12	0.0789	
C-Noise Level	26.42	1	26.42	0.6892	0.4076	
AB	234.63	1	234.63	6.12	0.0143	Significant
AC	1.59	1	1.59	0.0414	0.8390	
BC	6.39	1	6.39	0.1666	0.6836	
A^2	1.11	1	1.11	0.0289	0.8653	
B^2	112.41	1	112.41	2.93	0.0886	
C^2	0.0119	1	0.0119	0.0003	0.9860	
Residual	6707.88	175	38.33			
Lack of Fit	6667.38	172	38.76	0.87	0.8095	Not significant
Pure Error	40.50	3	13.50			
Cor Total	43378.03	184				

R^2: 0.8454, Adj. R^2: 0.8374, Pred. R^2:0.8206, Adeq. Precision: 50.3536,

Std. Dev.: 6.19, Mean: 47.77, C.V. %: 2.56.

4.5.7 Hearing threshold at 6 kHz

In Table 4.18, the Model F-value of 65.29 implies that the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. A p-value of less than 0.0500 denotes that model terms are significant. In this case A is a significant model term. Values greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), insignificant variables reduction may improve the model.

The Lack of Fit F-value of 6.16 implies there is a 17.85% chance that a Lack of Fit F-value this large could occur due to noise. Lack of fit is bad. The Predicted R^2value of 0.7291 is in reasonable agreement with the Adjusted R^2 value of 0.7587; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 38.820 indicates an adequate signal. This model can be used to navigate the design space.

4.5.8 Hearing threshold at 8 kHz

Table 4.19 shows the Model F-value of 73.01; this implies that the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. A p-value of less than 0.0500 showed that model terms are significant. In this case A is a significant model term. Values greater than 0.0500 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), insignificant variables reduction may improve the model.

The Lack of Fit F-value of 0.77 implies the Lack of Fit is not significant relative to the pure error. There is a 78.61% chance that a Lack of Fit F-value could occur. Non-significant lack of fit is good, it favours the model fitness. The Predicted R^2 value of 0.7667 is in reasonable agreement with the Adjusted R^2 value of 0.7789; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 40.291 indicates an adequate signal. This model can be used to navigate the design space.

Table 4.18: ANOVA for quadratic response model for the hearing threshold at 6 kHz

Source	Sum of Squares	df	Mean Square	F-value	p-value prob>F	
Model	15448.56	9	1716.51	65.29	<0.0001	Significant
A-Age	1249.15	1	1249.15	47.51	<0.0001	Significant
B-Exposure	79.62	1	79.62	3.03	0.0836	
C-Noise Level	56.54	1	56.54	2.15	0.1443	
AB	33.77	1	33.77	1.28	0.2586	
AC	11.20	1	11.20	0.4262	0.5147	
BC	5.27	1	5.27	0.2003	0.6551	
A^2	16.98	1	16.98	0.6460	0.4226	
B^2	14.36	1	14.36	0.5463	0.4608	
C^2	35.70	1	35.70	1.36	0.2455	
Residual	4600.86	175	26.29			
Lack of Fit	4587.86	172	26.67	6.16	0.1785	Not significant
Pure Error	13.00	3	4.33			
Cor Total	20049.42	184				

R^2: 0.7705, Adj. R^2: 0.7587, Pred. R^2: 0.7291, Adeq. Precision: 38.8199,

Std. Dev.: 5.13, Mean: 36.70, C.V. %: 3.18.

Table 4.19: ANOVA for quadratic model for the hearing threshold at 8 kHz

Source	Sum of Squares	df	Mean Square	F-value	p-value prob >F	
Model	16598.66	9	1844.30	73.01	<0.0001	Significant
A-Age	1815.20	1	1815.20	71.86	<0.0001	Significant
B-Exposure	6.23	1	6.23	0.2467	0.6200	
C-Noise Level	20.35	1	20.35	0.8054	0.3707	
AB	38.92	1	38.92	1.54	0.2162	
AC	54.15	1	54.15	2.14	0.1450	
BC	84.86	1	84.86	3.36	0.0685	
A^2	5.10	1	5.10	0.2019	0.6537	
B^2	5.32	1	5.32	0.2108	0.6467	
C^2	63.89	1	63.89	2.53	0.1136	
Residual	4420.70	175	25.26			
Lack of Fit	4322.20	172	25.13	0.7654	0.7861	Not significant
Pure Error	98.50	3	32.83			
Cor Total	21019.35	184				

R^2: 0.7897, Adj. R^2: 0.7789, Pred. R^2: 0.7667, Adeq. Precision: 40.2909,

Std. Dev.: 5.03, Mean: 40.27, C.V. %: 4.52.

4.6 Model Equation in Terms of Actual Factors at Frequency 250 Hz, 500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz and 8 kHz

The model equations derived from the ANOVA by partial SS (Type III) from the MATLAB in Design Expert version 6.0.8 are shown (Equations 4.1- 4.8). Initially the equation was set to the cubic form which MATLAB proved it to be infeasible, but only feasible in form of quadratic equation form. The equations exist in terms of actual factors from Design – Expert 6.0.8 software, which can be used to make predictions about the hearing threshold for a given frequency of each factor. Here, the levels (frequency) should be specified in the original units for each factor. It is worth noting that the equations cannot be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

(A) Hearing Threshold at 250 Hz

$$HT_{250Hz} = 44.14033 + 0.591251AG + 0.390885YE - 0.186337NL - 0.005017AG*YE - 0.000790AG*NL + 0.001839YE*NL - 0.012083AG^2 - 0.008045YE^2 - 0.001079NL^2 \quad (4.1)$$

(B) Hearing Threshold at 500 Hz

$$HT_{500Hz} = 337.4358 - 2.60847AG + 1.35031YE - 1.96007NL - 0.020783AG*YE \quad (4.2)$$

(C) Hearing Threshold at 1 kHz

$$HT_{1kHz} = 48.123758 - 1.58652AG + 0.554330YE - 2.18851NL - 0.019374AG*YE + 0.007206AG*NL + 5.65979E\text{-}06YE*NL + 0.018925AG^2 + 0.013165YE^2 + 0.009144NL \quad (4.3)$$

(D) Hearing Threshold at 2 kHz

$$HT_{2kHz} = 196.76191 - 3.03851AG + 1.51158YE - 3.47315NL - 0.026243AG*YE + 0.011258AG*NL - 0.000408YE*NL + 0.034824AG^2 \quad (4.4)$$

(E) Hearing Threshold at 3 kHz

HT_3kHz = 60.88191 – 1.16049AG – 0.508885YE – 2.34256NL + 0.026004AG*YE – 0.002867AG*NL + 0.009643YE*NL + 0.021528AG^2 - 0.038853YE^2 +0.011301NL^2

(4.5)

(F) Hearing Threshold at 4 kHz

HT_4kHz = 104.26160 – 0.346203AG – 1.08671YE + 0.119216NL – 0.080805AG*YE – 0.002207AG*NL – 0.005318YE*NL + 0.002869AG^2 - 0.036901YE^2 +0.000158NL^2

(4.6)

(G) Hearing threshold at 6 kHz

HT_6kHz = 35.080805 – 0.159487AG – 1.01857YE – 1.67968NL + 0.030655AG*YE – 0.005865AG*NL + 0.004828YE*NL + 0.011240AG2- 0.013190YE2+ 0.008642NL^2

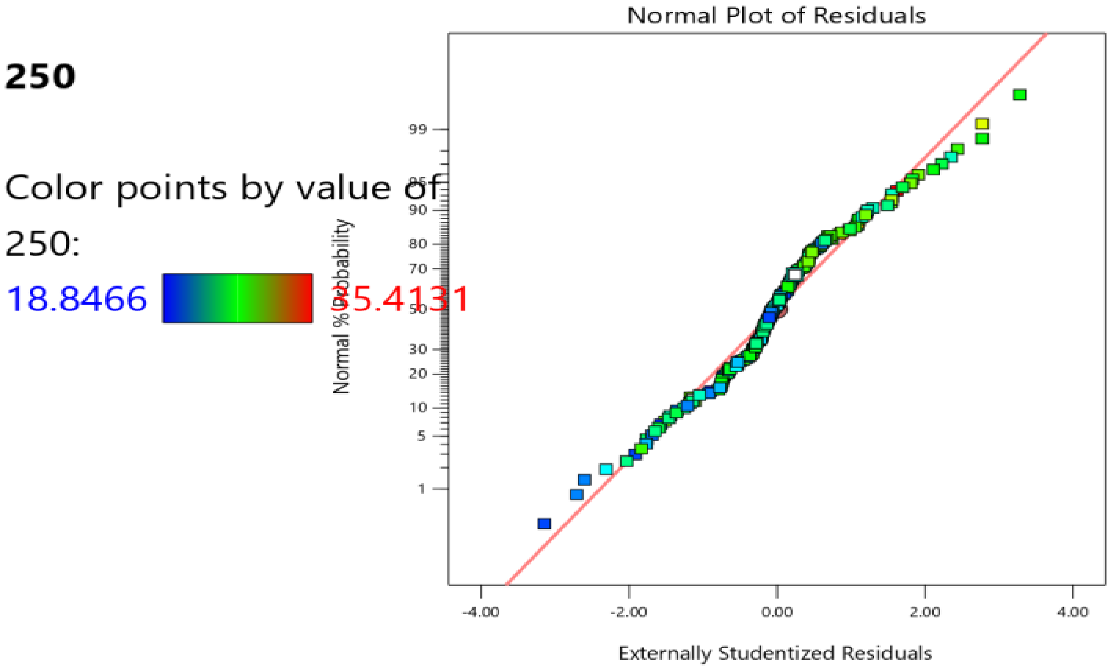
(4.7)

(H) Hearing threshold at 8 kHz

HT_8kHz = 87.26089 – 1.53852AG + 0.991447YE – 2.55636NL + 0.032911AG*YE + 0.019384YE*NL + 0.006159AG^2 – 0.008031YE^{2+} 0.011561NL^2 (4.8)

4.7 Normal Probability Plot of Residuals and Predicted Output for Hearing Threshold at Different Frequencies

In Figures 4.30 – 4.37, the normal probability plot of residuals and predicted output for range of frequency 250 Hz – 8 kHz indicated the adequacy of the developed model for the hearing threshold; having all data points aligned on straight line.



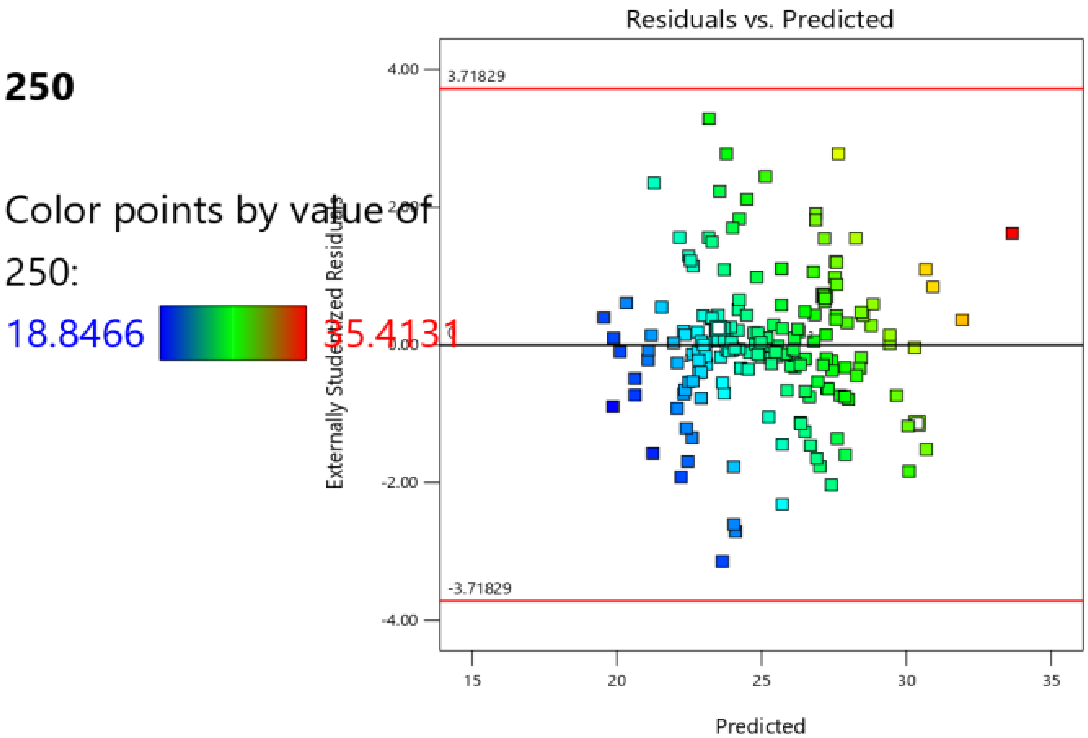
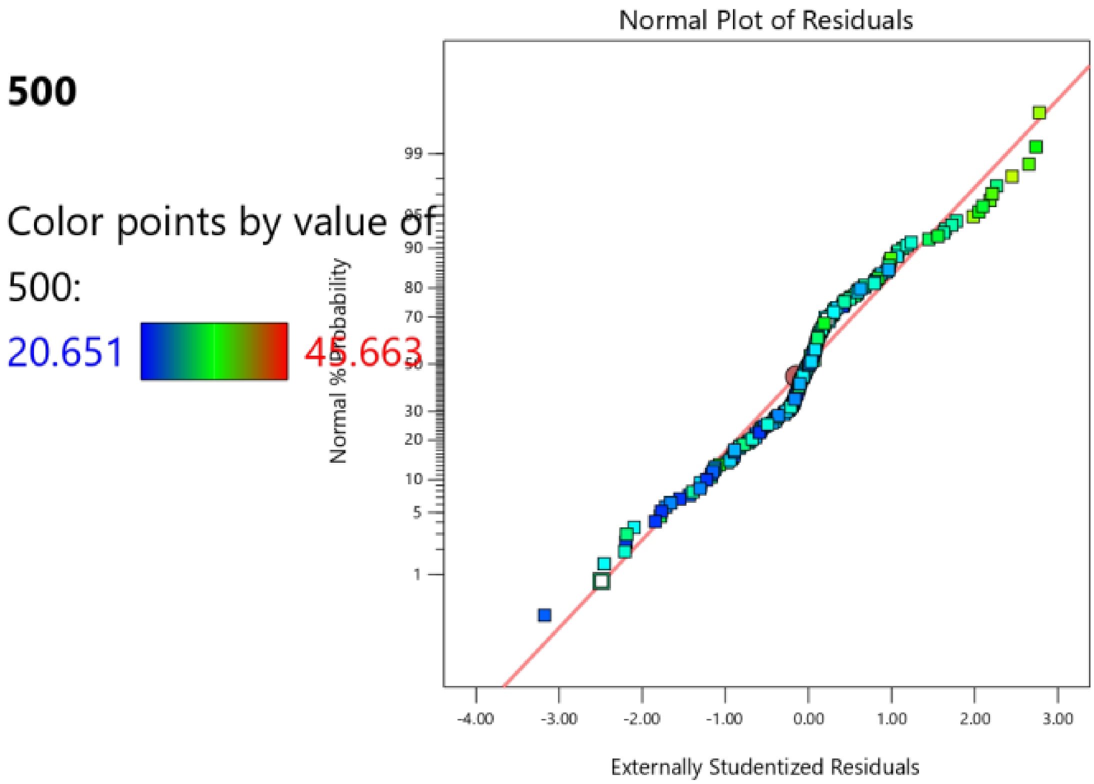


Figure 4.30: Normal probability plot of residuals and predicted output for hearing threshold at 250 Hz



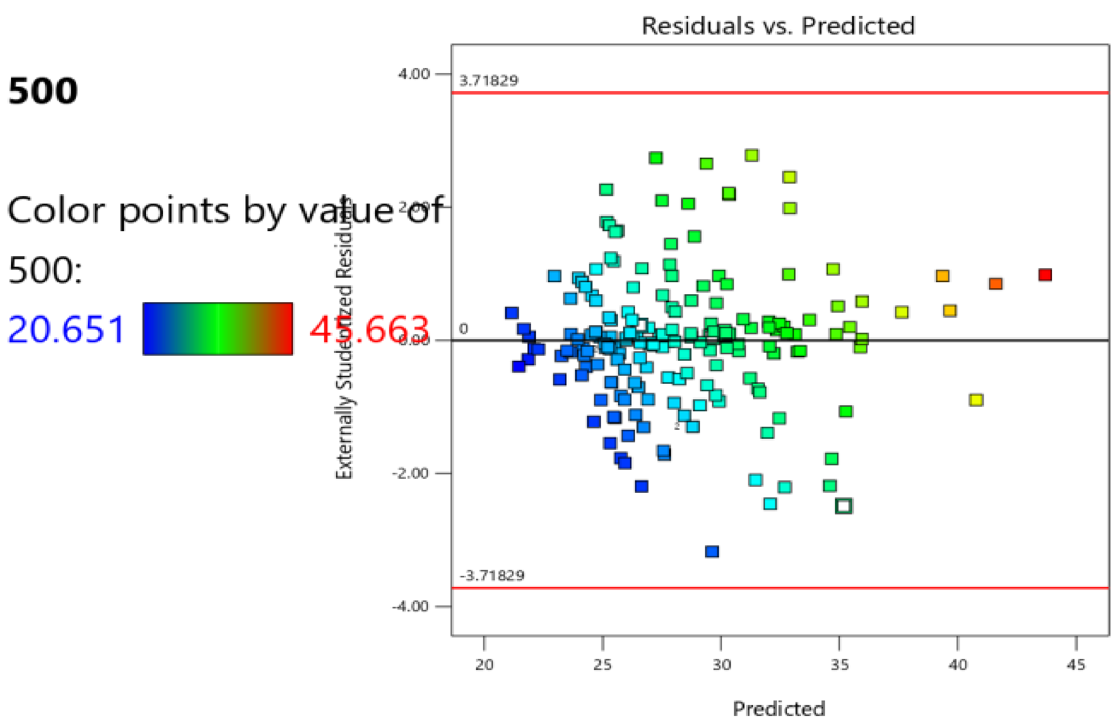


Figure 4.31: Normal probability plot of residuals and predicted output for the hearing threshold at 500 Hz

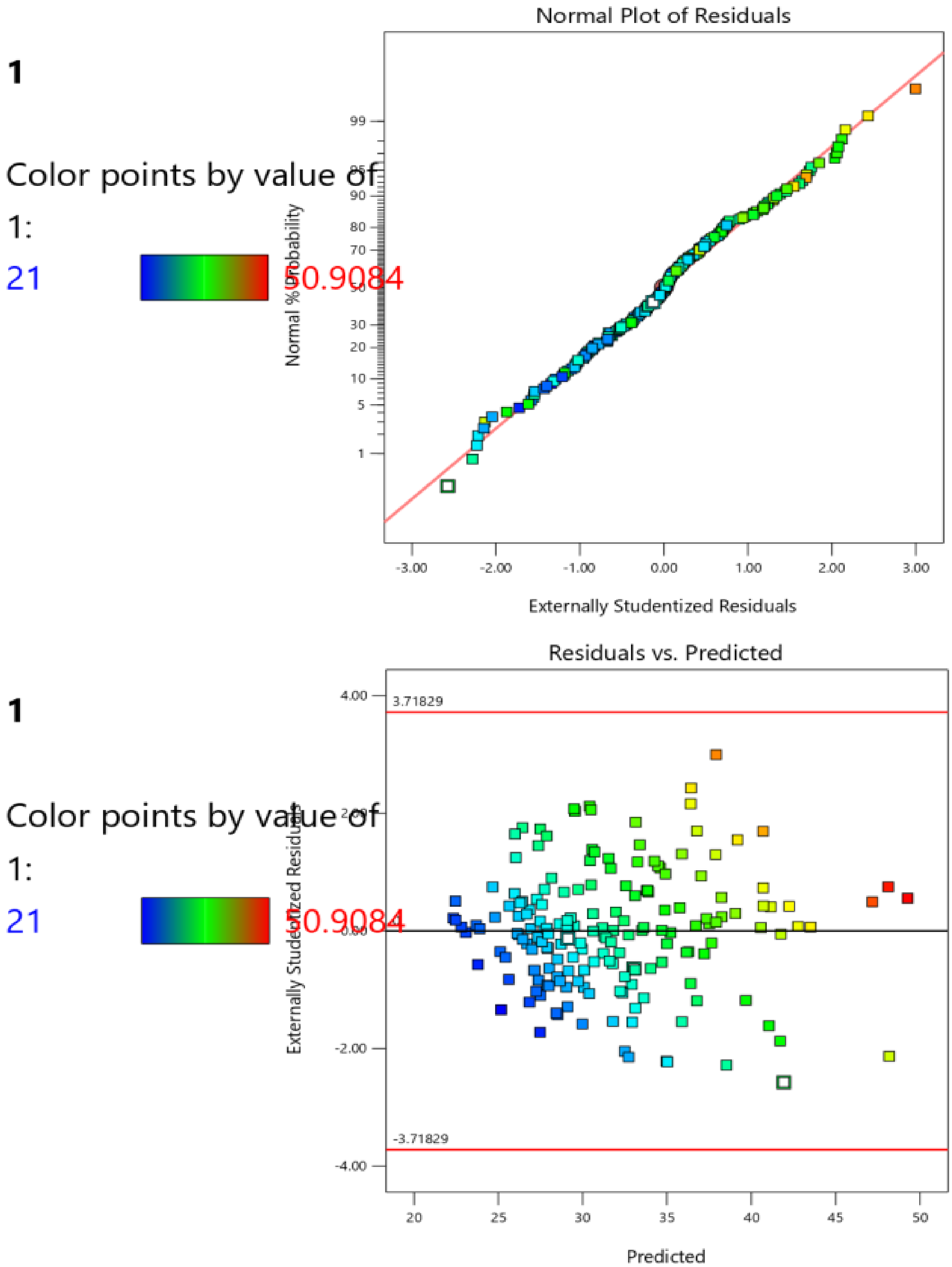


Figure 4.32: Normal probability plot of residuals and predicted output for the hearing threshold at 1 kHz

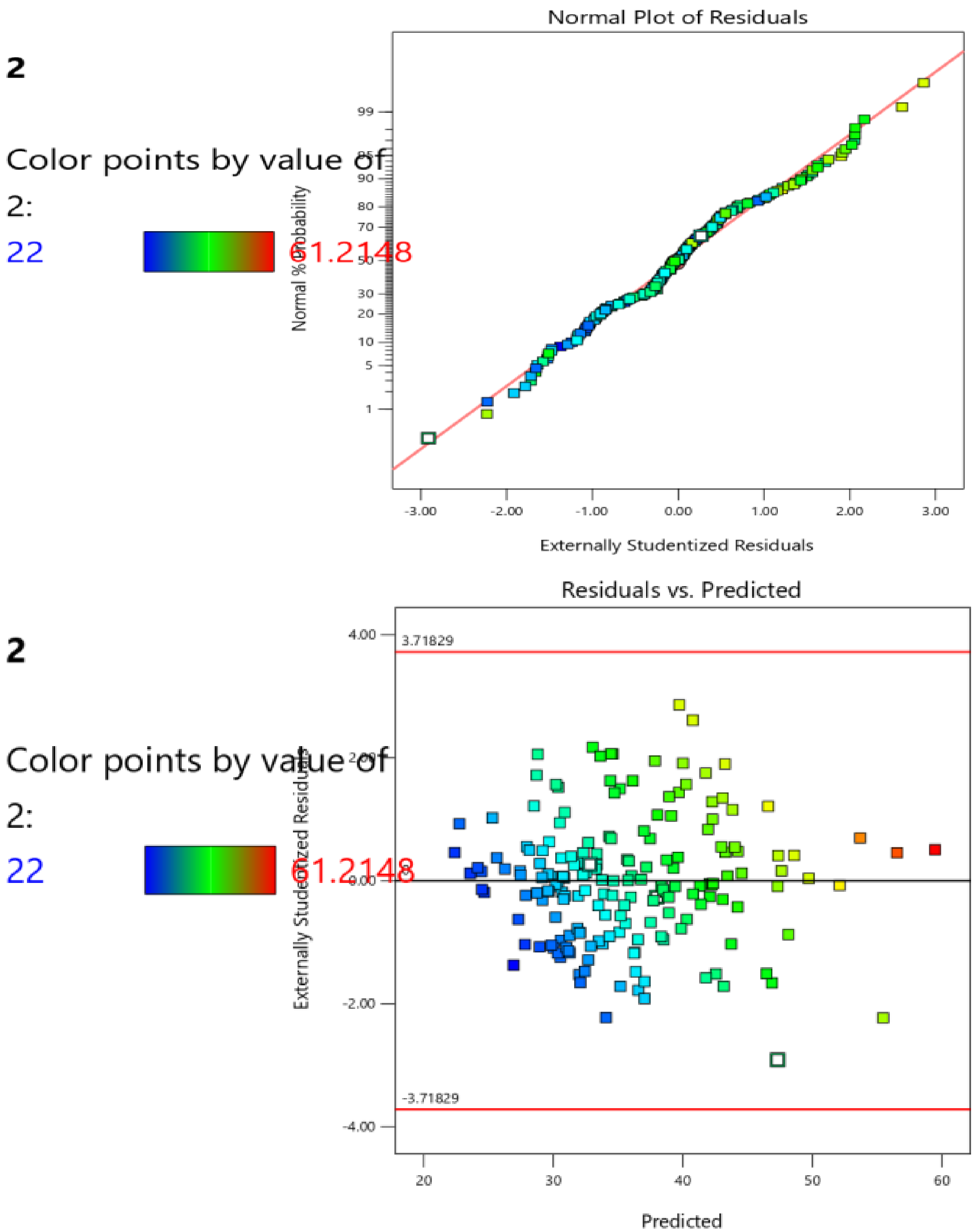


Figure 4.33: Normal probability plot of residuals and predicted output for the hearing threshold at 2 kHz

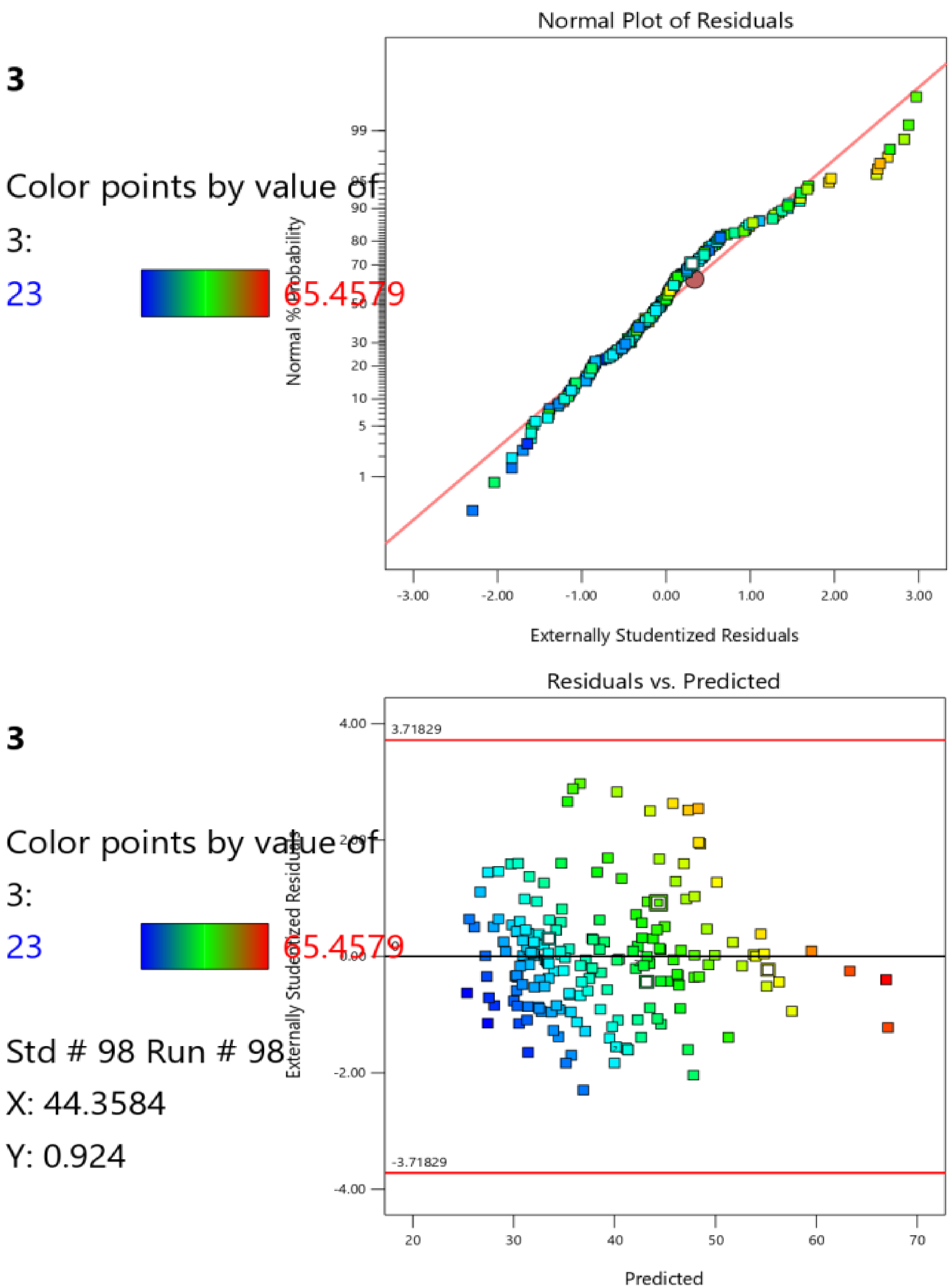


Figure 4.34: Normal probability plot of residuals and predicted output for the hearing threshold at 3 kHz

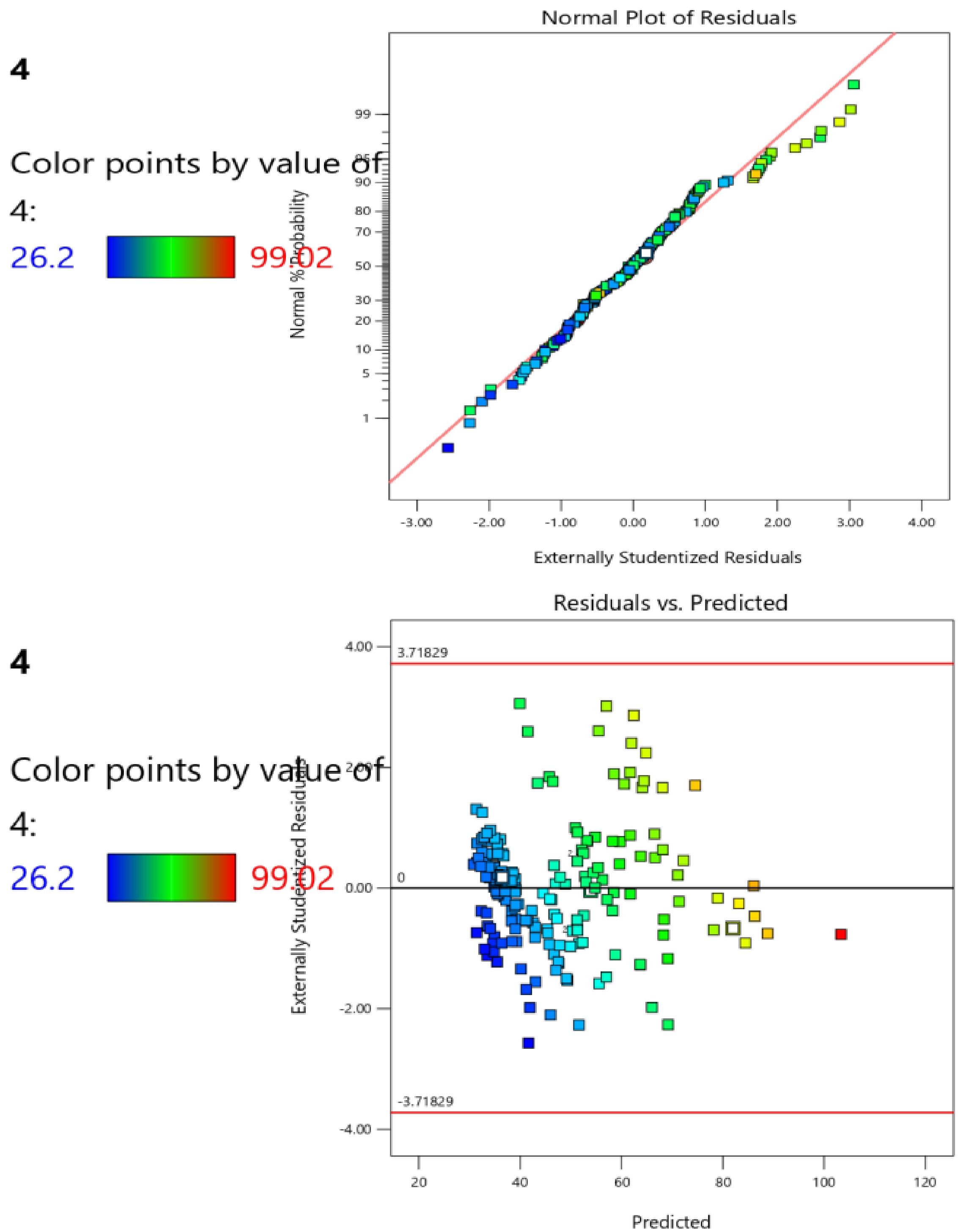


Figure 4.35: Normal probability plot of residuals and predicted output for the hearing threshold at 4 kHz

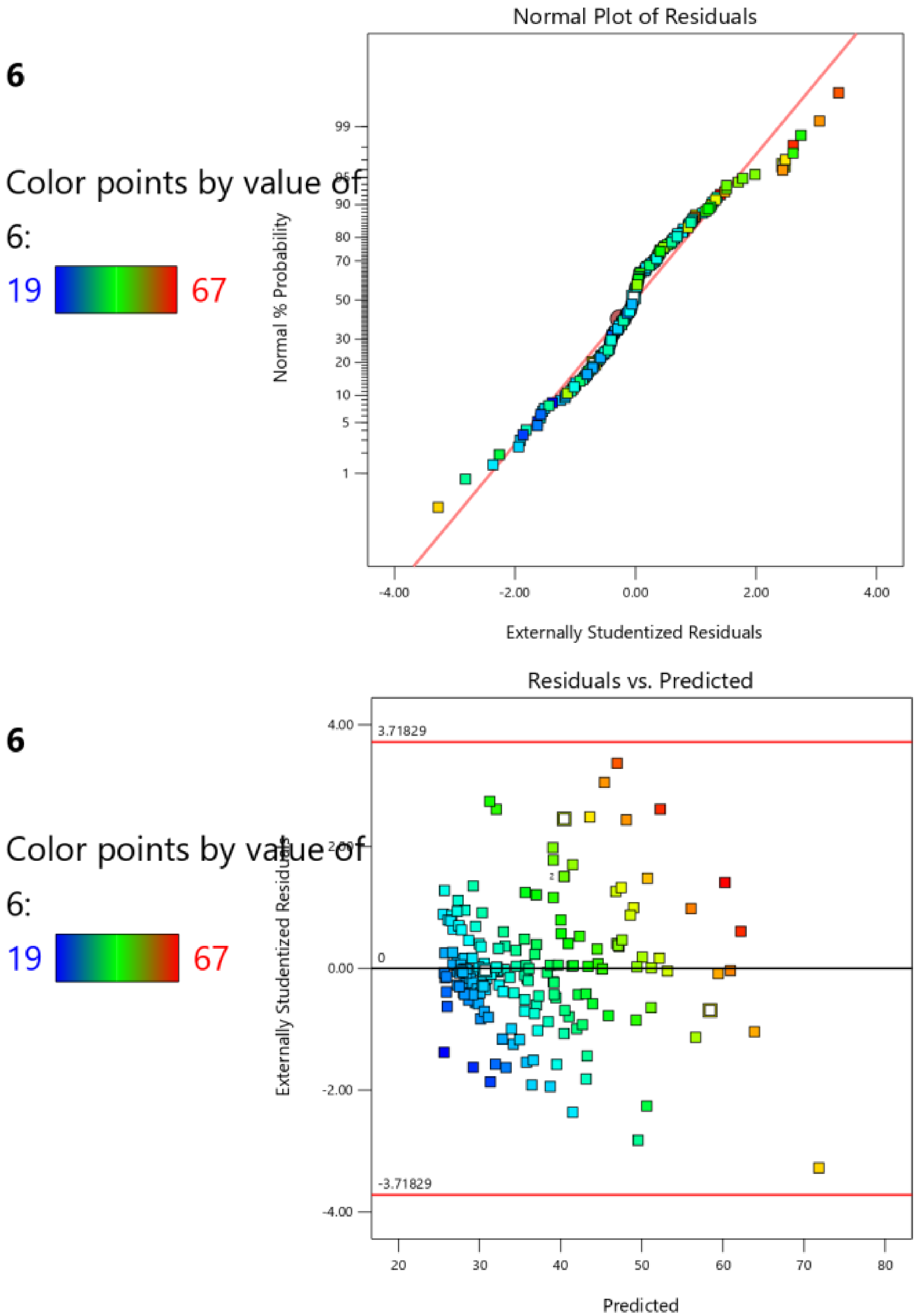


Figure 4.36: Normal probability plot of residuals and predicted output for the hearing threshold at 6 kHz

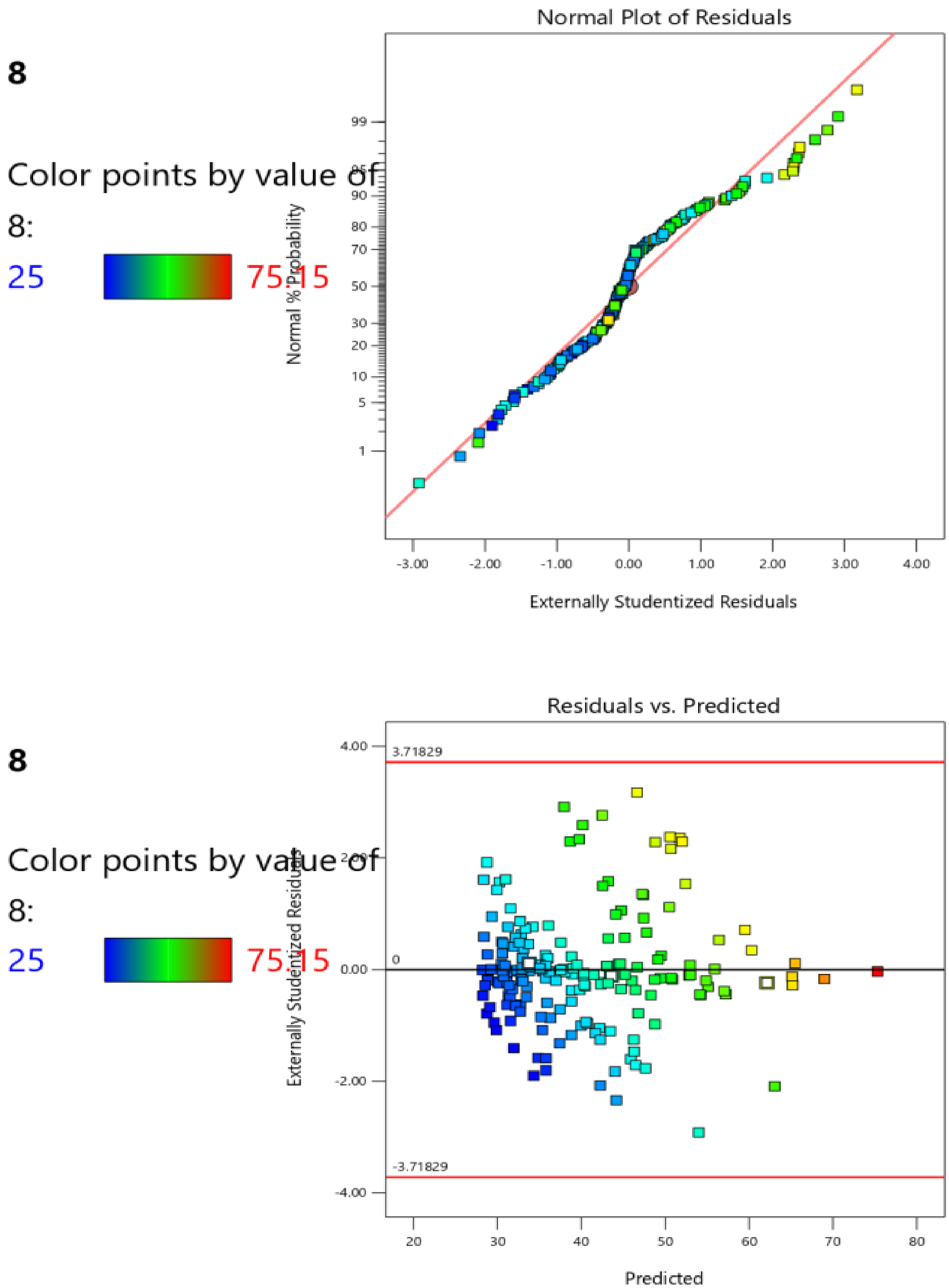


Figure 4.37: Normal probability plot of residuals and predicted output for the hearing threshold at 8 kHz

4.8 Effect of Single Factors on the Hearing Threshold at Various Frequencies

(A) Hearing threshold at frequency 250 Hz

As shown in Figure 4.38, the hearing threshold increases with the age of the workers, while it decreases with the year of exposure and the noise level. This implies that none of age, years of exposure and noise level can be considered as the most contributory factor. More, so the exhaustive search was unable to determine the most significant factor. Therefore effects of any of the 3 factors on hearing threshold could not be ascertained at this frequency.

(B) Hearing threshold at frequency 500 Hz

As shown in Figure 4.39, the hearing threshold increases with the age of the workers, year of exposure and the noise level. It can be deduced that as much as the quarry workers are exposed to the noisy workstations, the more they will have difficulty in their hearing system. The contour and 3D response surface plots which aid visualisation of variation for noise level and age interaction effect on hearing threshold are shown in Figure 4.40.

(C) Hearing threshold at frequency 1 kHz

Figure 4.41, shows that the hearing threshold increases with the age of the workers, year of exposure and the noise level. Continuous exposure to the noise also increases the workers hearing threshold at this frequency. There was no observed significant factor interaction.

(D) Hearing threshold at frequency 2 kHz

As shown in Figure 4.42, the hearing threshold increases with the age of the workers, year of exposure and the noise level. Continuous exposure to the noise also increases the workers hearing threshold at this frequency. There was no significant factors interaction.

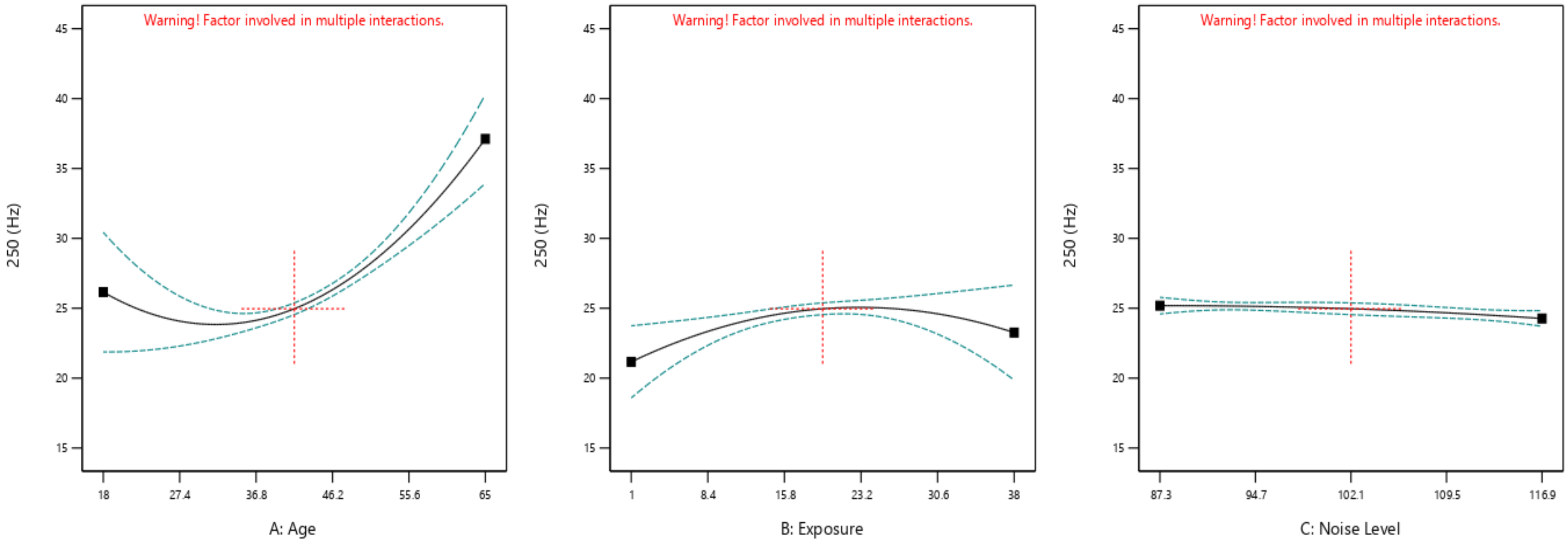


Figure 4.38: Effect of one factor on the hearing threshold at 250 Hz

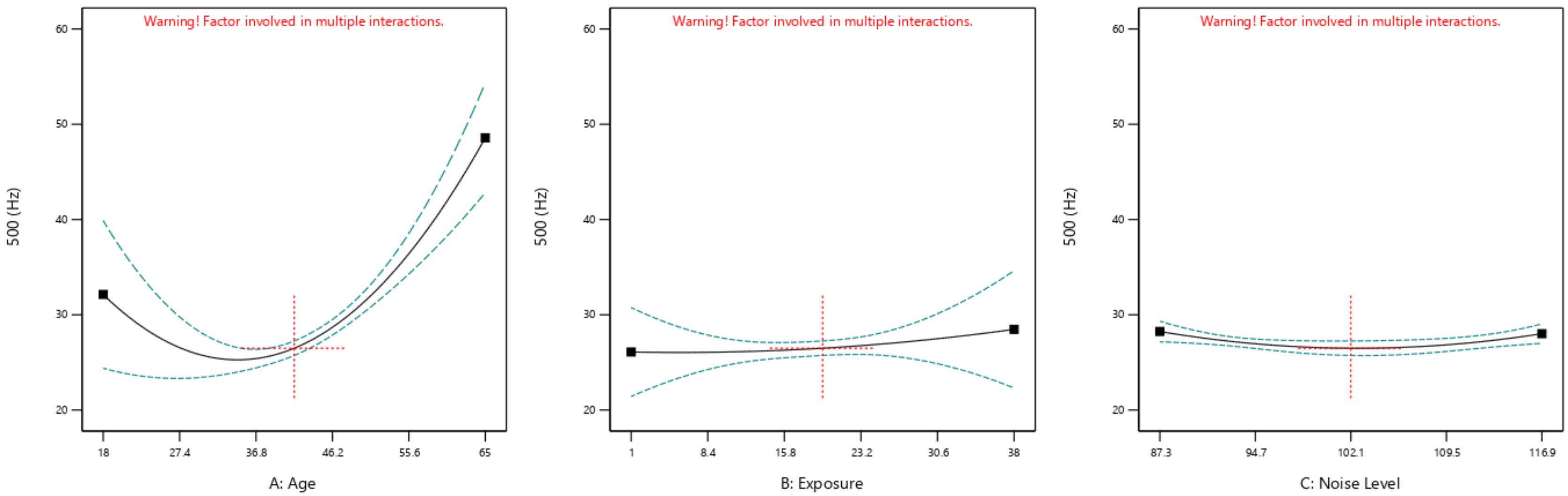


Figure 4.39: Effect of one factor on the hearing threshold at 500 Hz

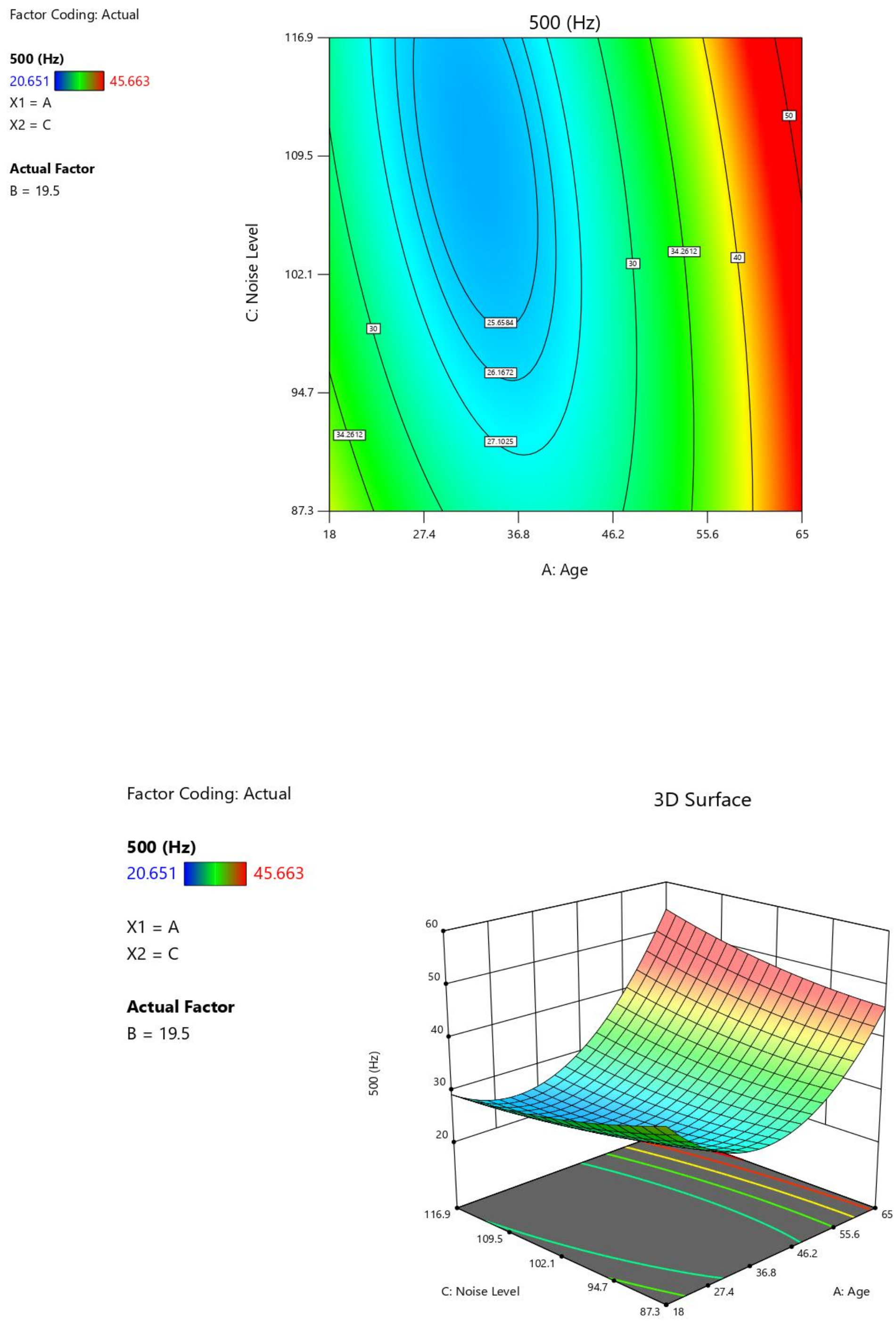


Figure 4.40: Response surface plots of age and noise level on the hearing threshold at 500 Hz

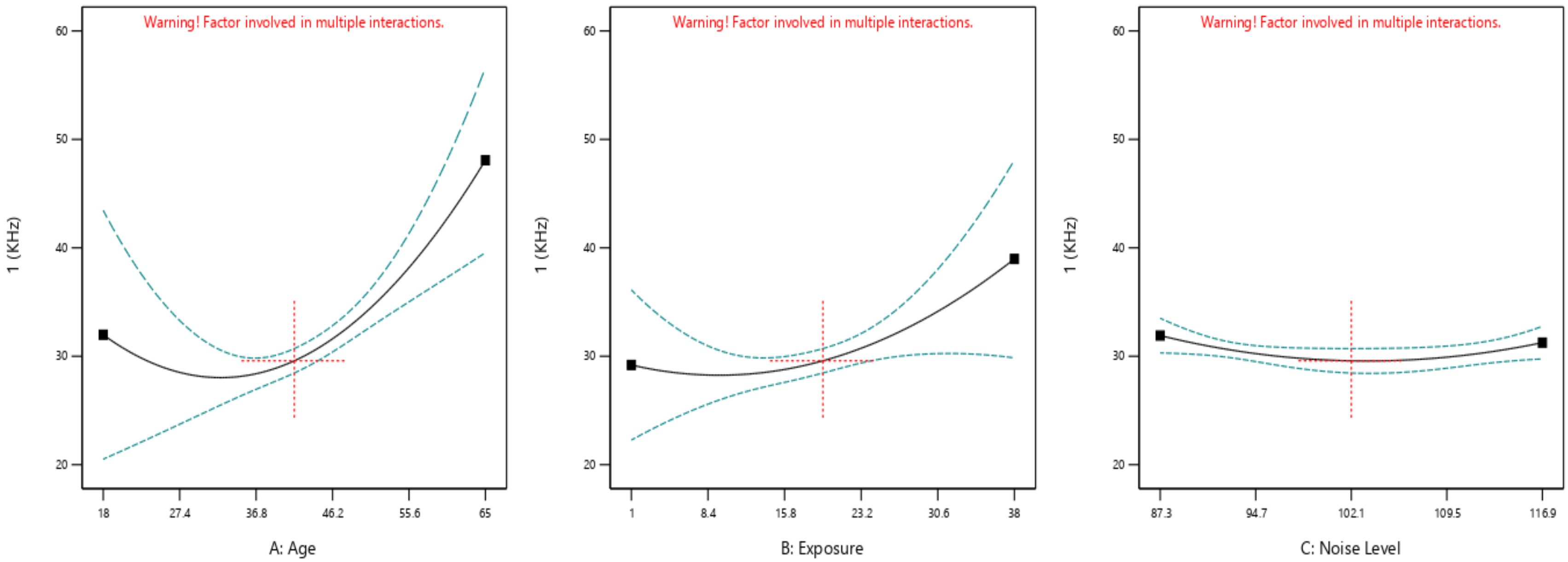


Figure 4.41: Effect of one factor on the hearing threshold at 1 kHz

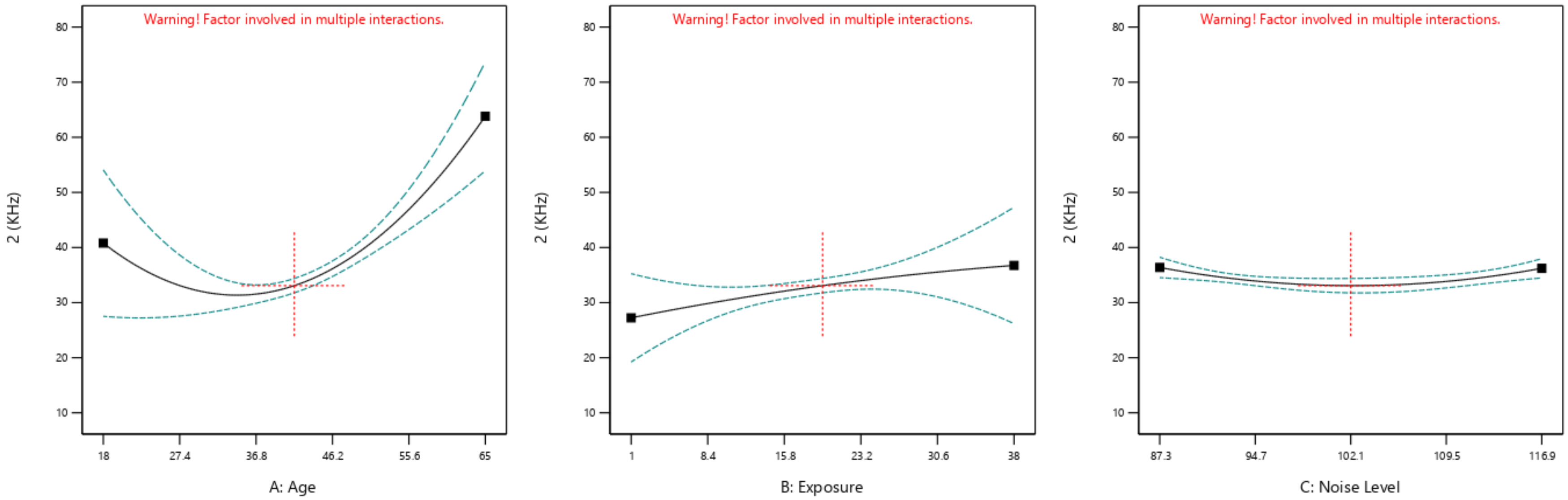


Figure 4.42: Effect of one factor on the hearing threshold at 2 kHz

(E) Hearing threshold at frequency 3 kHz

As shown in Figure 4.43, the hearing threshold increases with the age of the workers and noise level, while decreasing as year of exposure increases. Since age is the most significant contributors to the hearing threshold according to the exhaustive search test, therefore the statement that hearing threshold decreases as years of exposure increases should be discarded. There is no significant factors interaction.

(F) Hearing threshold at frequency 4 kHz

As shown in Figure 4.44, the hearing threshold increases with the age of the workers and years of exposure while it decreases as the noise level increases. The statement involved noise level in this context should be discarded. The contour and 3D response surface plots which aid visualisation of variation for age and years of exposure interaction effect on hearing threshold were given in Figure 4.45.

(G) Hearing threshold at frequency 6 kHz

As shown in Figure 4.46, the hearing threshold increases with the age of the workers, year of exposure and the noise level. Continuous exposure to the noise also increases the workers hearing threshold at this frequency. There is no significant factors interaction.

(H) Hearing threshold at frequency 8 kHz

As shown in Figure 4.47, the hearing threshold increases with the age of the workers, year of exposure and the noise level. Continuous exposure to the noise also increases the workers hearing threshold at this frequency. There is no significant factors interaction.

4.9 Comparative statistics for hearing threshold of real and control experiments

The control experimental group indicates how the models resulting from the experiments are able to explain the hearing thresholds of the subjects in different environments. In the control experimental groups (Appendix J) are subjects (workers) that were not exposed to high level noise in the production section of the quarries. In the real experimental groups are subjects that were exposed to high noise level in the production section of the quarry.

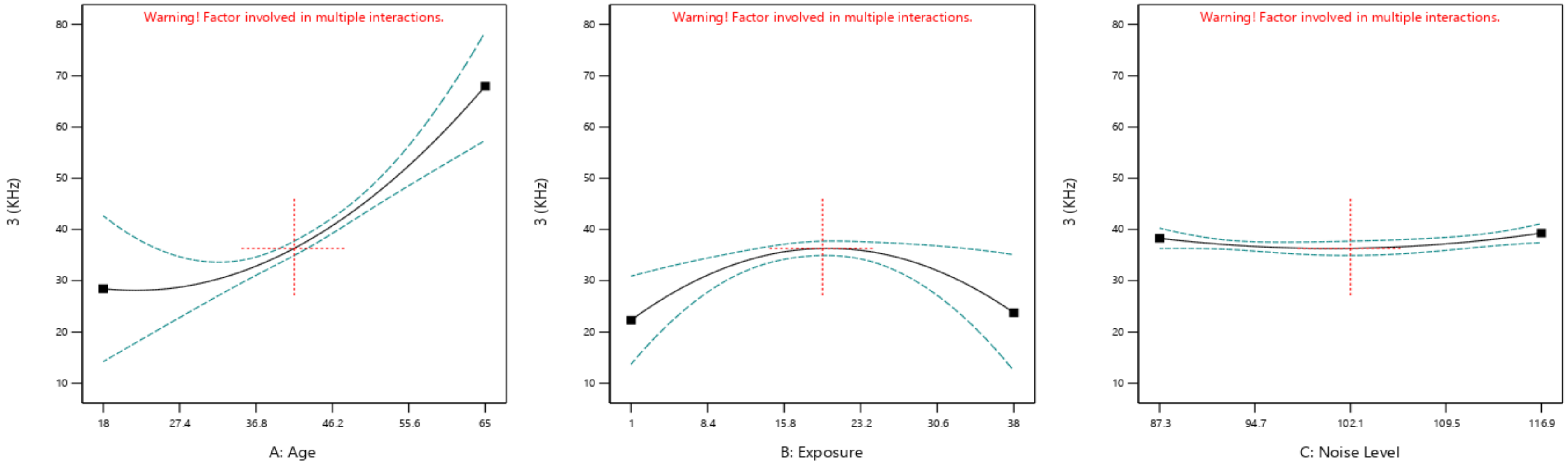


Figure 4.43: Effect of one factor on the hearing threshold at 3 kHz

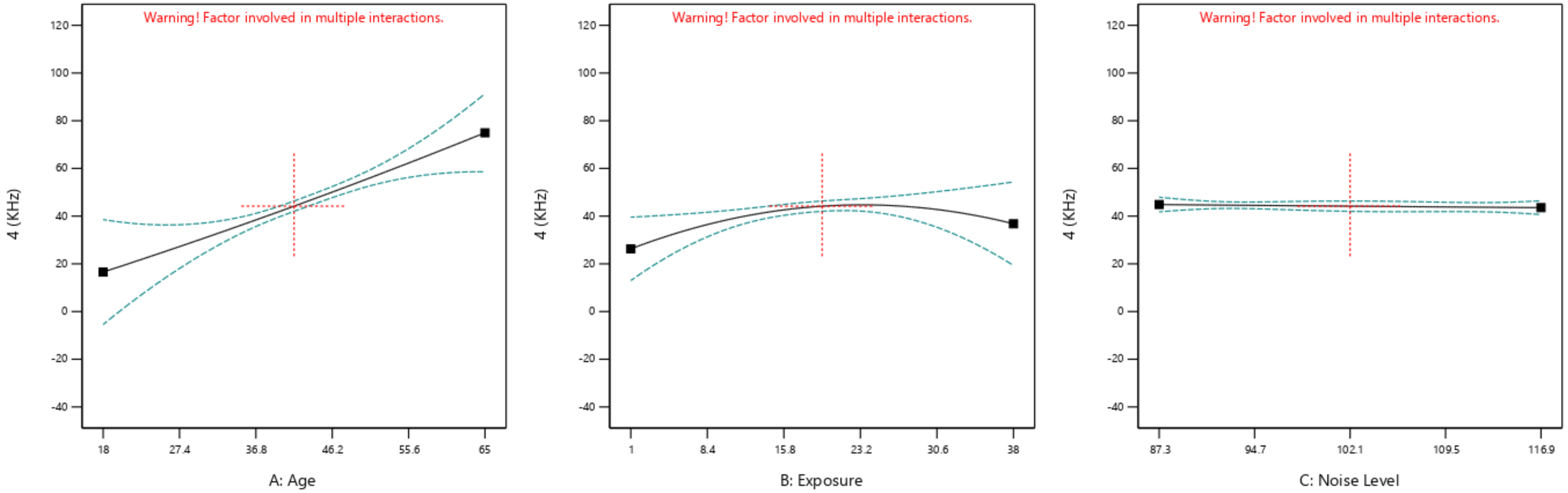
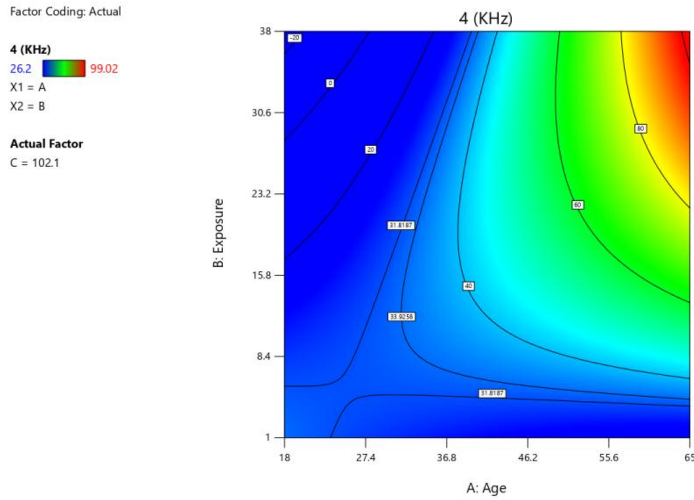


Figure 4.44: Effect of one factor on the hearing threshold at 4 kHz



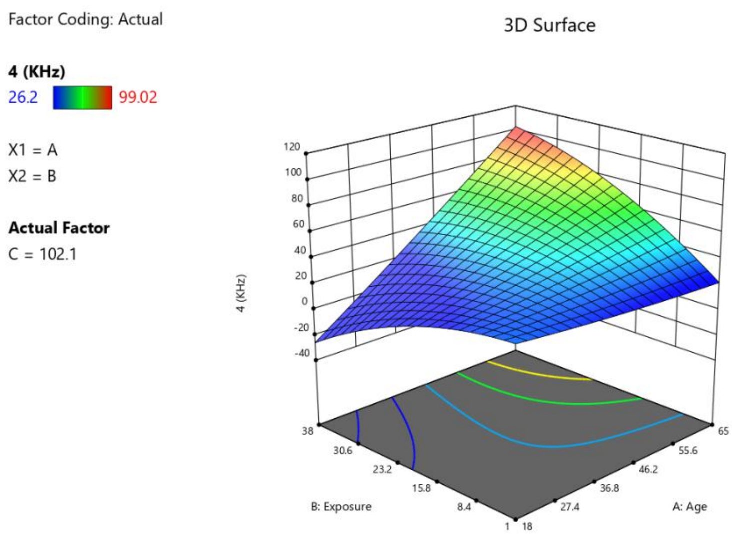


Figure 4.45: Response surface plots of age and noise level on the hearing threshold at 4 kHz

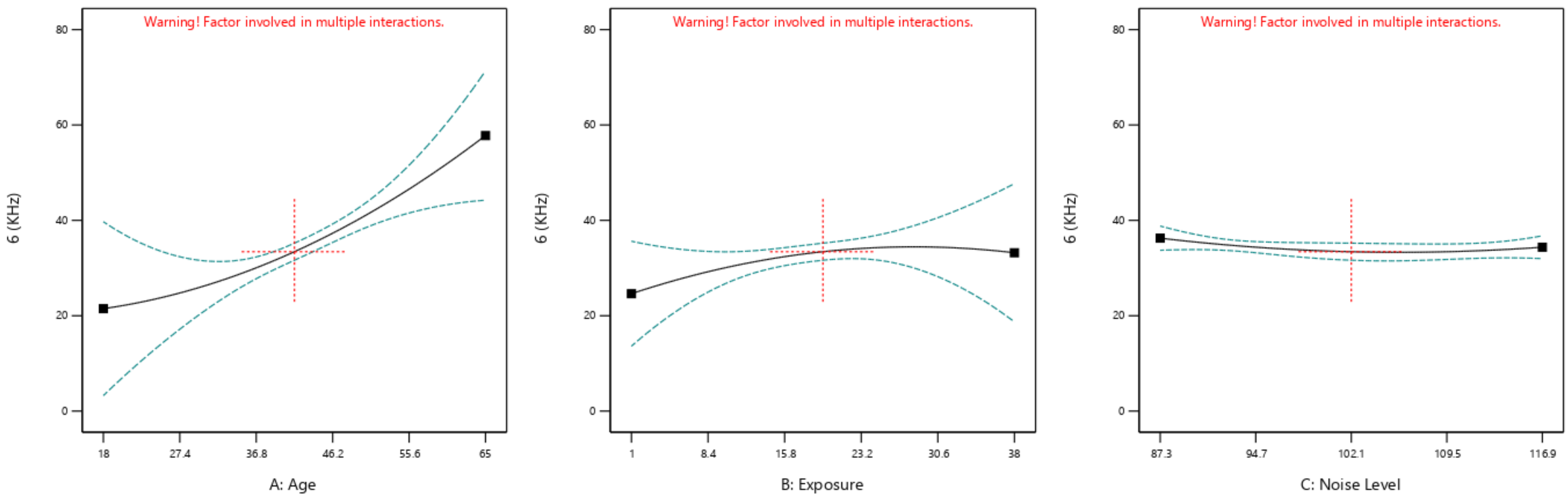


Figure 4.46: Effect of one factor on the hearing threshold at 6 kHz

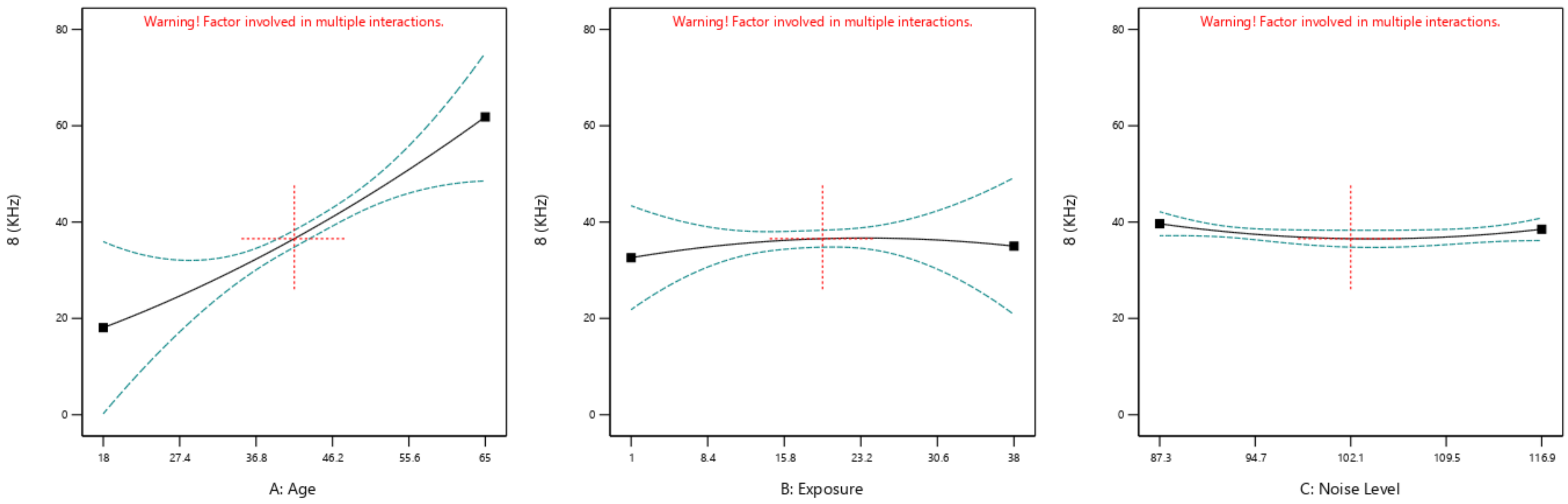


Figure 4.47: Effect of one factor on the hearing threshold at 8 kHz

Thus, the significant p-value and R^2 as shown in Table 4.20 for the two groups suggest that, for each model, the age, years of exposure to noise and noise level are potent factors to account for the changes in the hearing threshold of workers that are exposed to noise and the workers that are not exposed to noise in the quarries.

In the real experiment, workers in this group exhibit higher hearing threshold levels than the workers in the control group. This also shows that there is occupational noise effect on the hearing threshold of workers in the noisy workstations.

4.10 Robustness of the models

The results of the models' validation exercises conducted in order to find out how well the models performed in making predictions, the model has to be validated. The outcomes of the two types of validation exercises performed internal validation (that is the adequacy of the models was verified), and external validation are here presented.

4.10.1 Adequacy of the models

The software (Expert Design, Version 6.0.8) itself compared the measured hearing threshold of all the categories of the quarry workers with the predicted values. The measured values were in agreement with the predicted values as presented in Appendix K. This is 'self-validation' mechanism of the software. This demonstrated that the response models were adequate.

4.10.2 External validation of the models

Apart from 'self-validation' mechanism inbuilt into the software, external validation of the models was performed. This was done by measuring the responses (hearing threshold) and the input variables (age, years of exposure and noise level) from different quarry workers that did not participate in activities that led to the development of the predictive models. The independent variables (age, years of exposure and noise level) were fed into the models using Microsoft Excel 2010 professional software. The measured values and the predicted values were in the same order as shown in Appendix L. This demonstrated that the response models were effective.

Table 4.20: Summary of ANOVA for quadratic models and statistics for hearing threshold of real and control experiments

Frequency	Real Experiment			Control Experiment			p -value
	Mean Hearing Threshold (dB)	F-value	R^2	Mean Hearing Threshold (dB)	F-value	R^2	
250Hz	25.20	95.09	0.8302	22.82	99.79	0.9656	< 0.0001
500Hz	28.36	70.21	0.7831	24.90	81.48	0.9582	< 0.0001
1kHz	31.72	55.79	0.7415	27.00	30.96	0.8970	< 0.0001
2kHz	35.73	66.83	0.7746	29.22	30.61	0.8959	< 0.0001
3kHz	38.81	88.17	0.8193	31.34	26.08	0.9726	< 0.0001
4kHz	47.77	106.30	0.8454	34.56	69.16	0.9511	< 0.0001
6kHz	36.70	65.29	0.7705	27.85	36.93	0.9122	< 0.0001
8kHz	40.27	73.01	0.7897	30.87	33.41	0.9038	< 0.0001

4.10.3 Predictive performance of the models

R square and coefficient of variation (C.V.) are often used to assess the predictive performance of a regression model (Agha and Alnahhal, 2012). A high R square value and low C.V. (expressed as a percentage) are sought and desirable. According to Liyana-Pathirana and Shahidi (2005), high value of C.V. indicates that the ratio of root mean square error is very large relative to the mean of the dependent variable and thus, renders the model unreliable. In this study, eight models were developed and the Adjusted R squares for the models were ranging from 73 – 84% in all. Therefore C.V. < 10% has been suggested as appropriate for predictive models. In this study, the values of C.V. were less than 5.00% for all the models (Table 4.21), and the frequency 4 kHz have lowest of 2.56. Thus, it could be said that the models exhibit high predictive ability.

In general, all the models showed good predictive ability as can be noted in Tables 4.19. Seven of the models have Adjusted R squares value of over 75%. This shows that the models can be reliably used as predictive models.

4.11 Selection of values of age, years of exposure and noise level for the safe hearing threshold

In order to find the values of age, years of exposure and noise level which can accommodate the safe hearing threshold values of 25 – 30dB for quarry workers, Table 4.22 show the response of the MATLAB interface of Design Expert 6.0.8 from the optimisation process of the variables combination for frequency 250 Hz – 8 kHz. The lower and upper limit of age (18- 65 years), years of exposure (1-38 years), Noise level (87.3-116.9dB) and hearing threshold range of 25-30dB as safe hearing threshold for the optimisation process. The summary of the results in Figures 4.48 - 4.55 are described in Table 4.22.

The running of this optimisation software produced the defaults of ramps view of the iteration and the best settings of combination of the 3 factors and the desirability of the predicted safe hearing threshold. The Ramp of optimisation results for the combinations of factors (age, years of exposure and noise level) for the safe hearing threshold at frequency 0.25 – 8 kHz are shown in Figures 4.48 – 4.55.

Table 4.21: Summary of the statistics of the models across the frequency

Response Model	Frequency	R^2	Adj. R^2	Pred. R^2	Adeq. Precision	C .V. (%)
1	250Hz	0.8302	0.8215	0.8074	50.4099	4.77
2	500Hz	0.7831	0.7720	0.7604	44.4930	4.21
3	1kHz	0.7415	0.7282	0.7109	35.8918	4.74
4	2kHz	0.7746	0.7630	0.7462	42.705	3.25
5	3kHz	0.8193	0.8100	0.7951	44.8068	2.75
6	4kHz	0.8454	0.8374	0.8206	50.3536	2.56
7	6kHz	0.7705	0.7587	0.7291	38.8199	3.18
8	8kHz	0.7897	0.7789	0.7667	40.2909	4.52

Table 4.22: Optimization Response Output - Hearing Threshold at 250 Hz to 8 kHz

Factor	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Age	is in range	18	65	1	1	3
B:Exposure	is in range	1	38	1	1	3
C:Noise Level	is in range	87.3	116.9	1	1	3
250	is in range	25	30	1	1	3
500	is in range	25	30	1	1	3
1	is in range	25	30	1	1	3
2	is in range	25	30	1	1	3
3	is in range	25	30	1	1	3
4	is in range	25	30	1	1	3
6	is in range	25	30	1	1	3
8	is in range	25	30	1	1	3

Range is between 25 and 30dB

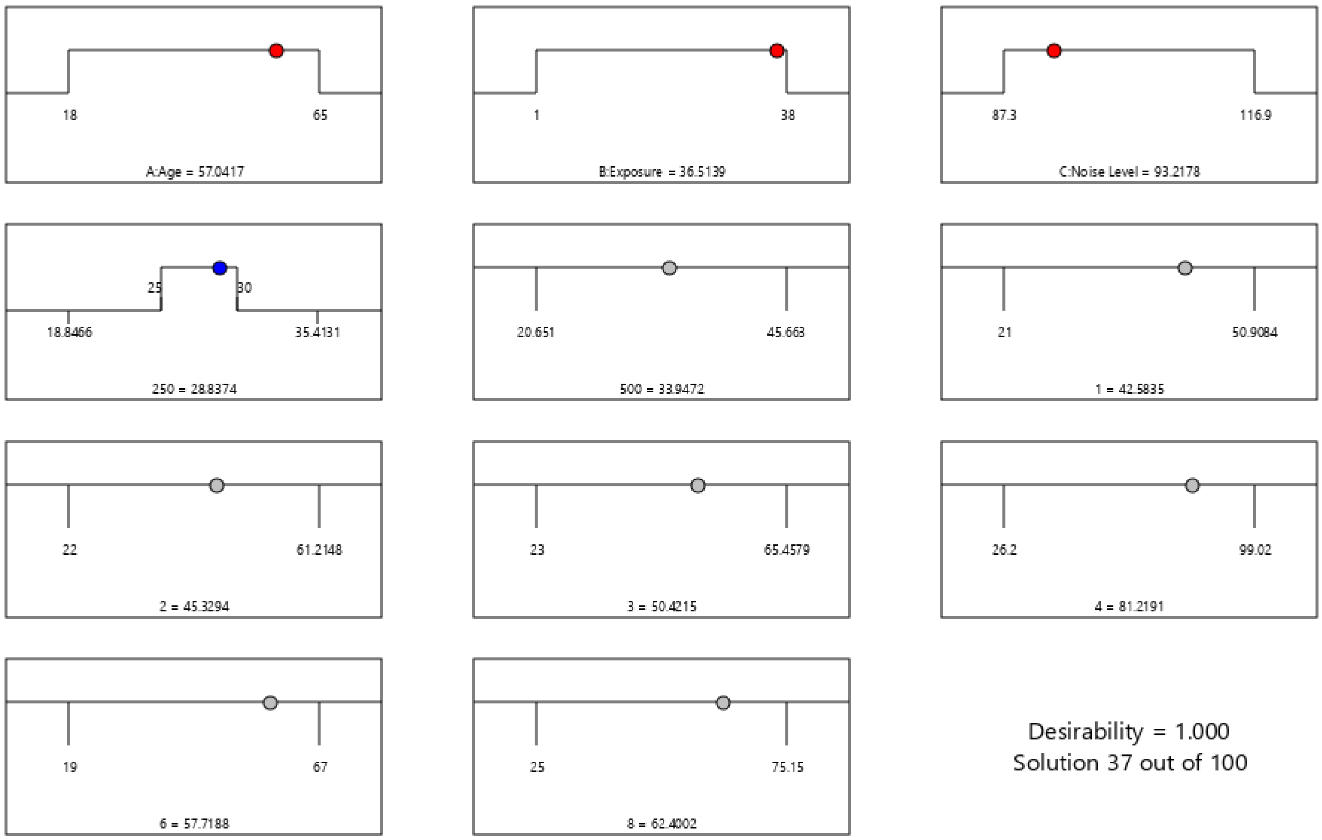


Figure 4.48: Ramp of optimization result for hearing threshold at 250 Hz

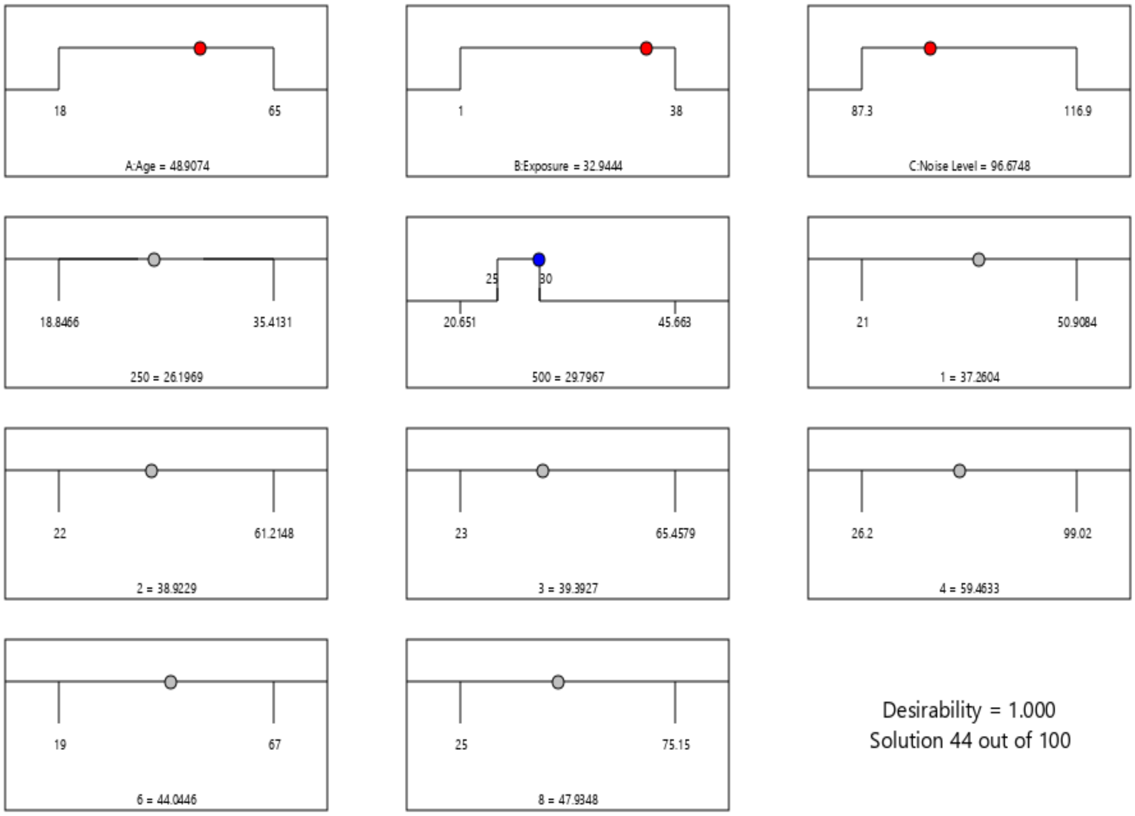


Figure 4.49: Ramp of optimisation result for hearing threshold at 500 Hz

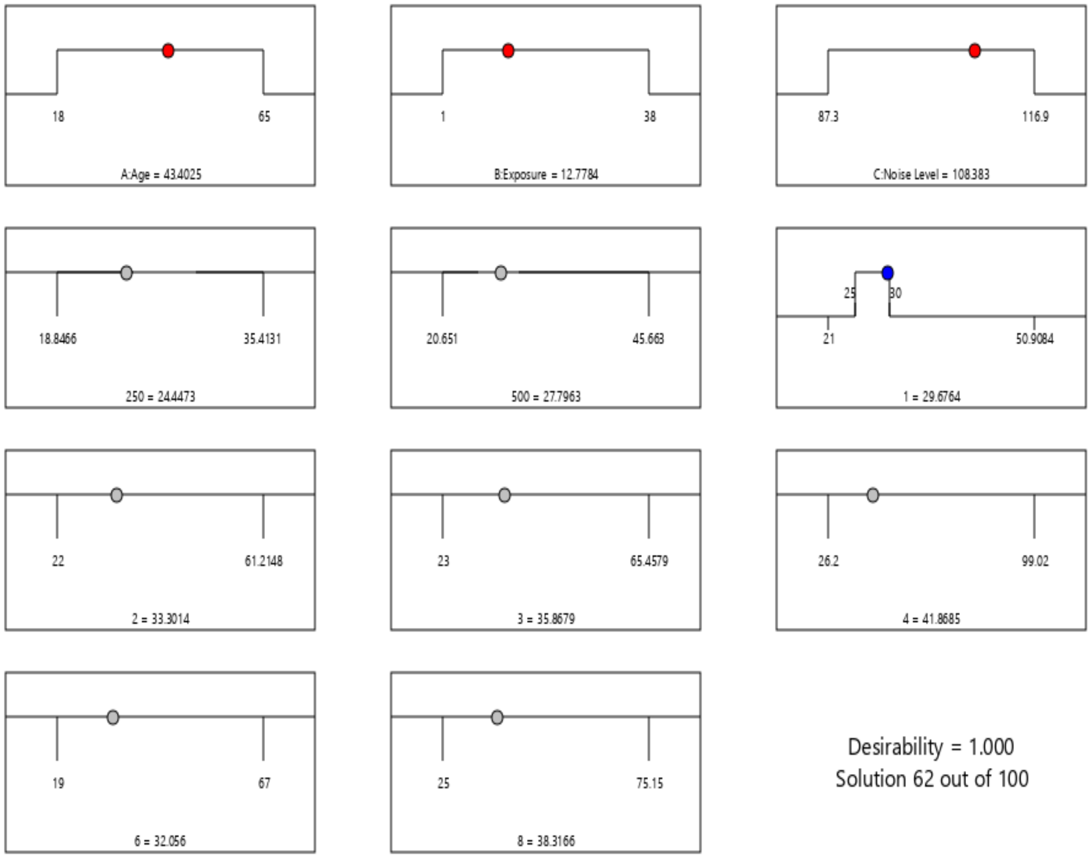


Figure 4.50: Ramp of optimisation result for hearing threshold at 1 kHz

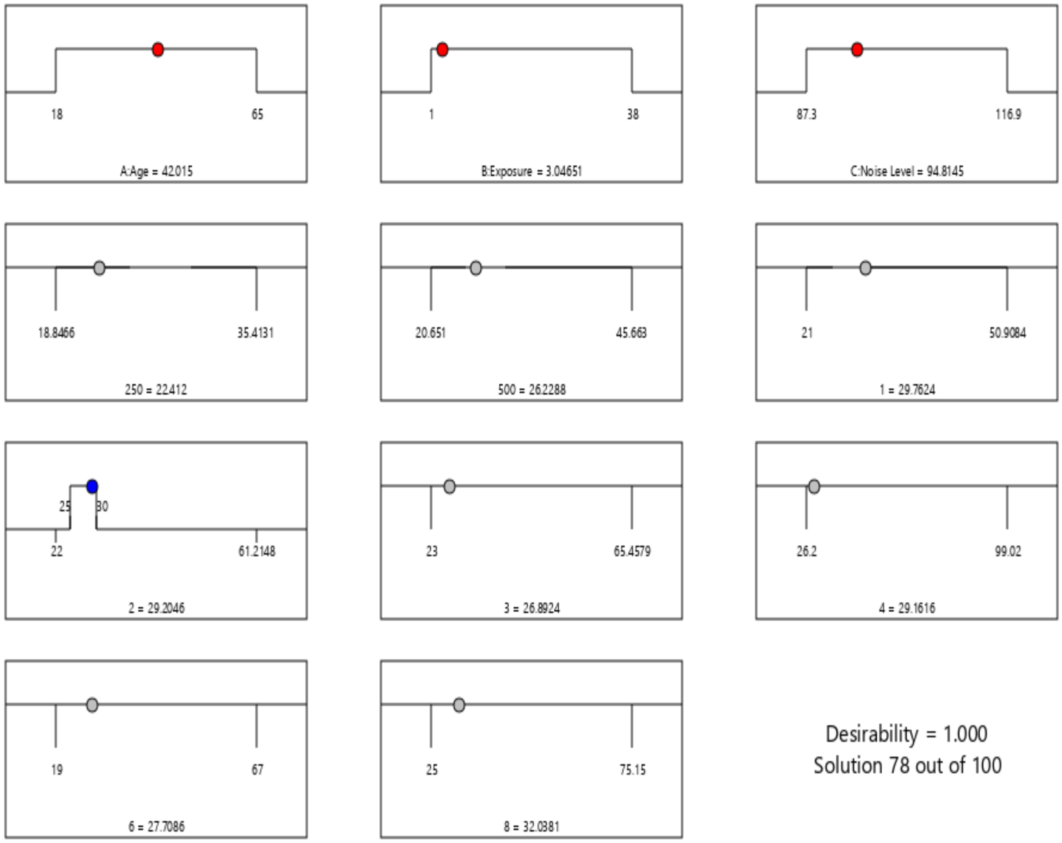


Figure 4.51: Ramp of optimisation result for hearing threshold at 2 kHz

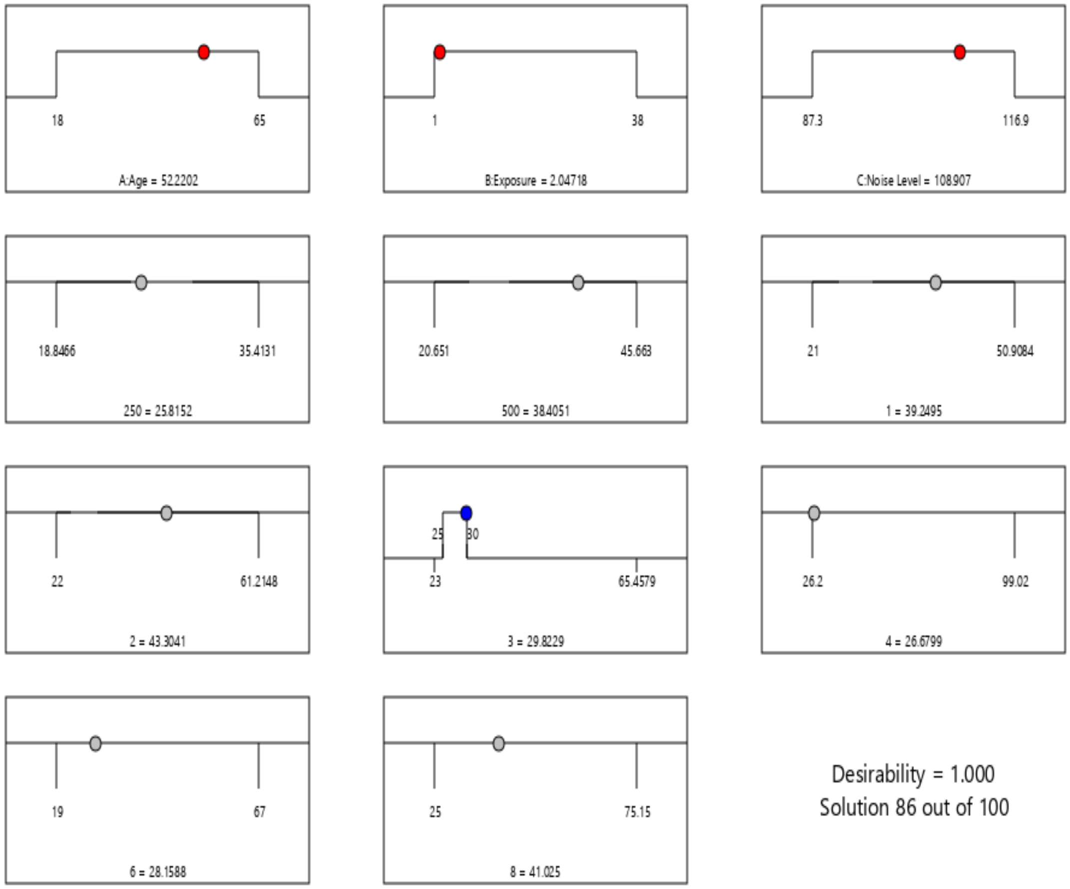


Figure 4.52: Ramp of optimisation result for hearing threshold at 3 kHz

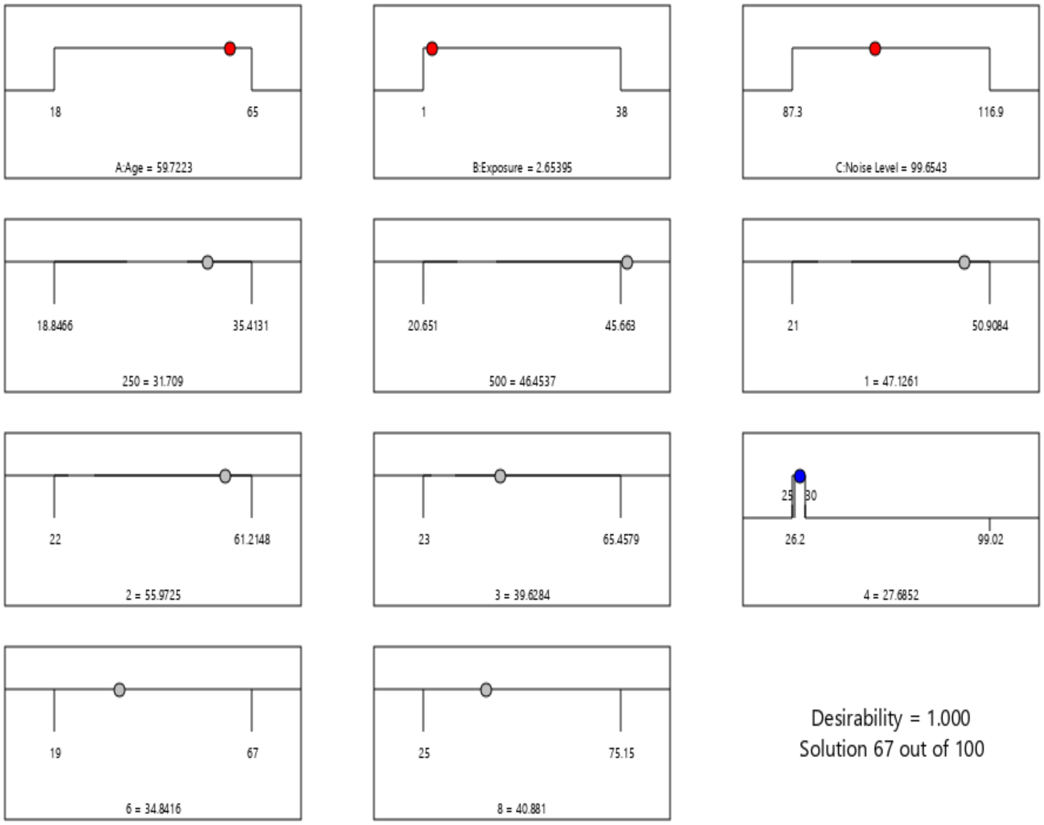


Figure 4.53: Ramp of optimisation result for hearing threshold at 4 kHz

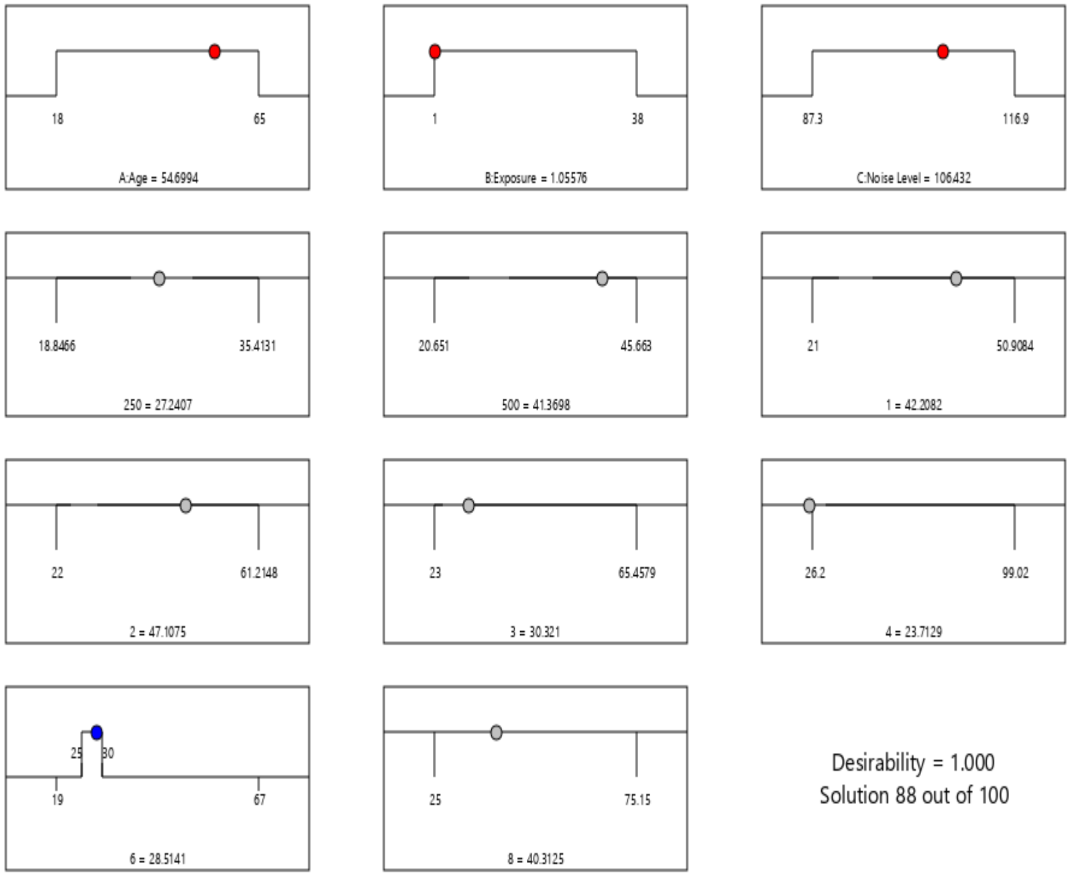


Figure 4.54: Ramp of optimisation result for hearing threshold at 6 kHz

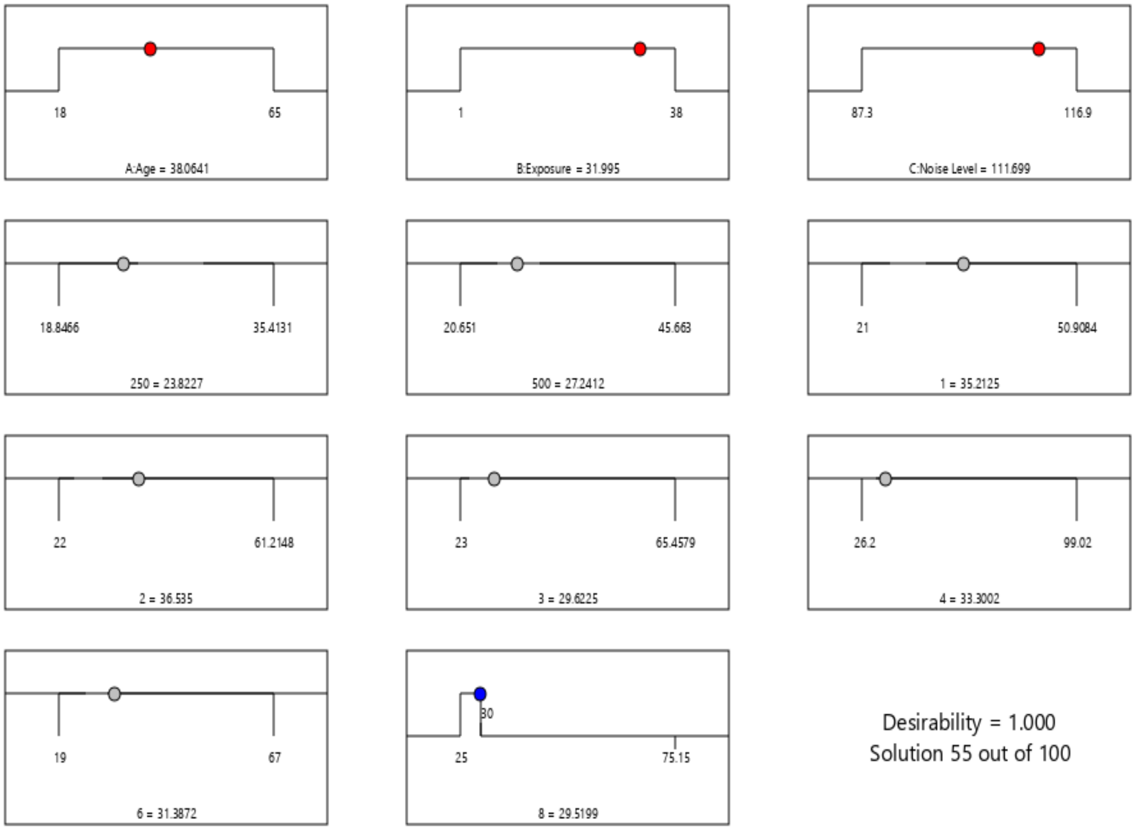


Figure 4.55: Ramp of optimisation result for hearing threshold at 8 kHz

4.12 Age, Years of Exposure and Noise Level that can Accommodate Safe Hearing Threshold

Design Expert 6.0.8 was used to find the values of factors which can produce the safe hearing threshold of the quarry workers. The combinations of the parameters were subjected to optimisation process of MATLAB interface of Design Expert 6.0.8 at each frequency of 250 Hz, 500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz and 8 kHz. The only feasible factors combination from the optimsation ramp results (figure 4.55) is at frequency 8 kHz with age, years of exposure and noise level are 38 years, 32 years and 111.7 dB respectively.

Age was uncovered as the major determinant in predicting hearing threshold of quarry workers. Therefore, when conducting the optimisation experiment, using the Design Expert Software 6.0.8 for the analysis, the safe design points for age, years of exposure and noise level is 38 years, 32 years and 111.7dB respectively (Table 4.23).

The study recommendation for the point of entry to quarry work is 18 years. By the time the quarry worker of age 38 years had 32 years of exposure; the worker must have started the job at the age of (38-18) years, which was 20 years then. In this vein, by the time the worker of 20 years of age have 32 years of noise exposure in the quarry, he must have attained (20+32) years of age. Therefore, the optimal age and years of exposure for the quarry worker in service will be 52 years or less; with 32 years or less respectively. The workers at the production section in the quarry will have safe hearing threshold till the age of 52 years or less (Appendix M). Such workers working at production section should be regularly rotated in less noisy workstation areas to reduce the noise exposure duration.

Therefore, if a quarry worker must maintain between the range of 25-30dB of safe hearing threshold, the age of the workers should be 52 years or less, with 32 years or less working exposure in the quarry; in order to enhance these condition, hearing protective device should not be left out.

Thus, the expression as shown in equation (4.9) can be used to explain the relationship between the present age of the worker in the quarry and the optimal year of exposure to the noise.

$$(X - 18) + Y \leq 52 \qquad (4.9)$$

Table 4.23: Summary of the values of age, years of exposure and noise level at 250 Hz-8 kHz for safe hearing threshold values of 25-30 dB

Frequency	Age (Years)	Exposure (Years)	Noise level (dB)
250Hz	57	36.5	93.2
500Hz	49	33	96.7
1kHz	43	13	108.4
2kHz	42	3	94.8
3kHz	52	2	108.9
4kHz	60	3	99.7
6kHz	55	1.05	106.4
8kHz	38*	32*	111.7*

*Safe values

Where,

X represents the present age of the workers and Y represent the optimal years of exposure to the noise.

4.13 Effects of Age, Years of Exposure and Noise Level on Hearing Threshold over Time

Paired sample Pearson correlation, Coefficient of mean difference and paired sample T-test were conducted in order to determine the effects of age, years of exposure and noise level on hearing threshold over the time (Appendix N).

4.13.1 Paired Sample Pearson Correlation Coefficient of Mean Difference Between Hearing Threshold at different Frequencies

Table 4.24 shows the significant correlations between hearing loss in the first year of measurement and second year of measurement at all frequencies. The significant Pearson correlation coefficients indicated that hearing threshold suffered by the quarry workers in the first year is a significant baseline for hearing threshold in the second year. Thus, a quarry worker who has an increased in hearing threshold in the second year when compared with the first year measurement also indicated that as the age of the workers increase, there is an increase in hearing threshold. The correlation coefficient (0.795) is highest under the frequency 4 kHz and lowest (0.166) under frequency 6 kHz.

4.13.2 Paired Sample Statistics of the First and Second Year of Mean Hearing Threshold of the Respondents at different Frequencies

Table 4.25 shows the paired sample statistics of the first and second year of mean hearing threshold of the subjects at all frequencies. For each frequency, the mean hearing threshold in the second year was observed to be higher than the mean hearing threshold in the first year of measurement with the same subjects. This is an indication that the hearing threshold has worsened during the one year interval.

Table 4.24: Paired sample Pearson correlation coefficient of mean differences between hearing threshold in the first year and second year of measurement at various frequencies

		Correlation	Sig.
Pair 1	Hearing_Threshold_250Hz after 1year and Hearing_Threshold_250Hz in the base year.	0.436	0.00*
Pair 2	Hearing_Threshold_500Hz after 1year and Hearing_Threshold_500Hz in the base year.	0.821	0.00*
Pair 3	Hearing_Threshold_1kHz after 1year and Hearing_Threshold_1kHz in the base year.	0.770	0.00*
Pair 4	Hearing_Threshold_2kHz after 1year and Hearing_Threshold_2kHz in the base year.	0.742	0.00*
Pair 5	Hearing_Threshold_3kHz after 1year and Hearing_Threshold_3kHz in the base year.	0.705	0.00*
Pair 6	Hearing_Threshold_4kHz after 1year and Hearing_Threshold_4kHz in the base year.	0.795	0.00*
Pair 7	Hearing_Threshold_6kHz after 1year and Hearing_Threshold_6kHz in the base year.	0.166	0.02*
Pair 8	Hearing_Threshold_8kHz after 1year and Hearing_Threshold_8kHz in the base year.	0.664	0.00*

N = 185; *Significant at $p < 0.05$

Table 4.25: Paired sample statistics of mean hearing threshold of the respondents in the first and second year at various frequencies

		Mean	Std. Deviation	Std. Error Mean
Pair 1	HT_250Hz after 1yr	27.59	4.381	0.317
	HT_250Hz in the base year.	24.23	7.870	0.569
Pair 2	HT_500Hz after 1yr	31.79	5.662	0.410
	HT_500Hz in the base year.	27.09	5.051	0.365
Pair 3	HT_1kHz after 1yr	36.93	6.559	0.475
	HT_1kHz in the base year.	30.32	6.587	0.477
Pair 4	HT_2kHz after 1yr	42.71	7.564	0.547
	HT_2kHz in the base year.	33.64	8.307	0.601
Pair 5	HT_3kHz after 1yr	50.07	9.222	0.667
	HT_3kHz in the base year.	37.66	9.973	0.722
Pair 6	HT_4kHz after 1yr	65.02	13.979	1.012
	HT_4kHz in the base year.	46.49	15.544	1.125
Pair 7	HT_6kHz after 1yr	45.94	12.610	0.912
	HT_6kHz in the base year.	36.59	12.157	0.880
Pair 8	HT_8kHz after 1yr	48.72	12.139	0.878
	HT_8kHz in the base year.	39.23	11.839	0.857

HT: Hearing Threshold; N = 185

4.13.3 Paired Sample t test for Differences in the Hearing Threshold in the First and Second year

Table 4.26 displays the results of Paired Sample t test for differences in the hearing threshold in the first and second years. The t values for all differences under the frequencies are significant. Hence, the hypothesis that there are no significant differences, that is differences are zeros, in the average hearing threshold in the first year of measurement and second year of measurement is negated. There are differences in the hearing threshold exhibited by the same quarry workers in the first year and second year and these differences are not due to a mere statistical chance; they are due to real effect of factors that continuously contribute to hearing threshold. The differences are due to higher hearing threshold exhibited by the workers in the second year.

4.14 Results of Ergonomic Evaluation of Hearing Threshold Predictors

From the foregoing analysis, the following hypothesis are accepted or rejected:

H_o: Age of workers, years of exposure and noise level cannot significantly predict hearing threshold of workers.

H_I: Age of workers, years of exposure and noise level significantly predict hearing threshold of the workers.

Decision rule: Accept H_o if p-value > α (=0.05) or reject H_o if p-value < 0.05.

Frequency 250 Hz

Decision: Age of the workers (p-value < 0.0001) and noise level (p - value 0.0029) of the workers are significant.

Conclusion: Age of the workers and noise level can significantly predict hearing threshold of workers at frequency 250 Hz.

Frequency 500 Hz

Decision: Age has p-value < 0.0001, the interaction of age and noise level (p - value 0.0012) of the workers is significant.

Conclusion: Age of workers, the interaction of age and noise level significantly predict hearing threshold of the workers at frequency 500 Hz.

Table 4.26: Paired sample t - test for differences in the hearing threshold in the first and second year

		Paired differences					T	df	Sig.
			Std. Deviation	Std.Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Hearing Threshold_250 Hz after 1year Hearing Threshold_250 Hzin the base year	3.361	7.147	0.517	2.341	4.381	6.500	184	0.000*
Pair 2	Hearing Threshold_500 Hz after 1year Hearing Threshold_500 Hz in the base year	4.696	3.256	0.236	4.232	5.161	19.933	184	0.000*
Pair 3	Hearing Threshold_1 kHz after 1year Hearing Threshold_1 kHz in the base year	6.613	4.458	0.323	5.976	7.249	20.502	184	0.000*
Pair 4	Hearing Threshold_2 kHz after 1year Hearing Threshold_2 kHz in the base year	9.063	5.738	0.415	8.244	9.882	21.829	184	0.000*
Pair 5	Hearing Threshold_3 kHz after 1year Hearing Threshold_3 kHz in the base year	12.403	7.409	0.536	11.346	13.461	23.136	184	0.000*
Pair 6	Hearing Threshold_4 kHz after 1year Hearing Threshold_4 kHz in the base year	18.524	9.575	0.693	17.157	19.890	26.738	184	0.000*
Pair 7	Hearing Threshold_6 kHz after 1year Hearing Threshold_6 kHz in the base year	9.351	15.996	1.157	7.068	11.634	8.079	184	0.000*
Pair 8	Hearing Threshold_8 kHz after 1year Hearing Threshold_8 kHz in the base year	9.492	9.832	0.711	8.089	10.895	13.342	184	0.000*

N = 185;*Significant at *p*< 0.05

Frequency 1 kHz

Decision: Age of the workers (p-value <0.0001) and years of exposure (p – value 0.0019) are significant.

Conclusion: Age of the workers and years of exposure significantly predict hearing threshold of workers at frequency 1 kHz.

Frequency 2 kHz

Decision: Age of the workers (p-value < 0.0001); and years of exposure (p – value 0.0090) are significant.

Conclusion: Age and years of exposure significantly predict hearing threshold of workers at frequency 2 kHz.

Frequency 3 kHz

Decision: Age (p – value < 0.0001) is significant.

Conclusion: Age of the workers significantly predict hearing threshold of workers at frequency 3 kHz.

Frequency 4 kHz

Decision: Age (p – value < 0.0001); interaction of age and years of exposure (p –value 0.0143) are significant.

Conclusion: Age; and interaction of age and years of exposure of the workers significantly predict hearing threshold of workers at frequency 4 kHz.

Frequency 6 kHz

Decision: Age of the workers (p – value <0.0001) is significant.

Conclusion: Only Age of the workers can significantly predict the hearing threshold of workers at frequency 6 kHz.

Frequency 8 kHz

Decision: Age of the workers (p – value <0.001) is significant.

Conclusion: Only Age of the workers can significantly predict the hearing threshold of workers at frequency 8 kHz.

It can be seen that only age of the quarry workers predict hearing threshold at all frequencies between 250 Hz to Frequency 8 kHz.

4.15 Discussion of Results

This present study investigated the physiological response of quarry workers working in noisy environment. Results are as follows:

4.15.1 Noise Magnitude of the Machinery used in Quarry Operation

The amount of noise emitted by various equipment which workers were exposed to during work in selected quarries were measured. The noise measurement values in this study 28.4 dBA in the administrative section, and range of 87.3 dBA to 116.98 dBA in the production section.

The quarry workers exhibited a mean hearing threshold value of 45.6 dB, 75% had hearing threshold level higher than 25 dBA. The differences between the mean values of hearing threshold level of the respondents of the four quarries were not significant (F=1.068, p = 0.364) which indicated that all the quarries workers were subjected to about the same working conditions and environmental noise (Appendix I).

4.15.2 Predictive Models

The developed 8 predictive models at various frequencies show that:

(A) Frequency 250 Hz

Age of workers and noise level can independently significantly predict the quarries worker hearing threshold at this frequency. The entire diagnostic test proved the appropriateness of the model. Hearing threshold increases with the age of the workers, while decreasing with the years of exposure and the noise level.

(B) Frequency 500 Hz

Age of workers and noise level; and the interaction of age and noise level can significantly predict the hearing threshold of quarry workers at this frequency. Models were appropriate for the prediction.

(C) Frequency 1 kHz

Age and years of exposure can significantly predict the hearing threshold of quarry workers at frequency 1 kHz. The entire diagnostic test proved the model as reliable one.

(D) Frequency 2 kHz

Age of workers and years of exposure can significantly predict the hearing threshold of quarry workers at frequency 1 kHz. A reliable model was established. The entire diagnostic test proved the model as reliable one.

(E) Frequency 3 kHz

Age of workers only can significantly predict the hearing threshold of the quarry workers at his frequency. A reliable model was established. The entire diagnostic test proved the model as reliable one.

(F) Frequency 4 kHz

Age of workers and years of exposure; and the interaction of age and years of exposure significantly predicted the hearing threshold of the quarry workers at this frequency. A reliable model was established. The entire diagnostic test proved the model as reliable.

(G) Frequency 6 kHz

Only Age of the workers can predict the hearing threshold of the quarry workers at this frequency. A reliable model was established. The entire diagnostic test proved the model as reliable one.

(H) Frequency 8 kHz

Age of workers only significantly predicted the hearing threshold of the quarry workers at this frequency. Models were appropriate for the prediction.

Conclusively, the models obtained showed that age of workers can predict the hearing threshold across all frequencies, while years of exposure can predict the hearing threshold at 1 kHz, 2 kHz and 4 kHz only, and noise level can predict the hearing threshold at the frequency 250 Hz and 500 Hz.

4.15.3 Combination of values of age, years of exposure and noise level that produce safe hearing threshold

Based on the data collected and used in this work, for a quarry worker to maintain the safe hearing threshold of 25-30 dB in the quarry, the optimal age of the workers should be 52 years or less, with working exposure of 32 years or less. This implies that older workers above 52 years should not be subjected to the high noise level zone in the quarry for too long. Their operation could be alternated with other area where noise intensity is not high.

4.15.4 Effects of Age, Years of Exposure and Noise Level with Hearing Threshold over Time at Different Frequencies

The results of paired sample correlation shows that a quarry worker with a high hearing threshold in the first year also had an increased hearing threshold in the second year with the highest correlation coefficient 0.795 at frequency 4 kHz and lowest 0.166 at frequency 6 kHz (Table 4.24). More so, paired sample statistics of mean difference between hearing threshold in the first and second year of experiment indicated that at each frequency, the mean hearing threshold in the second year was greater than the mean hearing threshold in the first year (Table 4.25). It can be concluded that the hearing threshold has worsened during the one year. Also, paired samples t-test for differences in the hearing threshold in the first and second year at all frequencies are significant. Hence there are differences in the hearing threshold exhibited by the quarry workers in the first and second year (Table 4.26). The differences were due to a higher hearing threshold exhibited by the workers in the second year; which was due to real effect of factors that continuously contributes to hearing threshold.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

This study was conducted to develop suitable models to determine the synergistic influence of age, years of exposure and noise level on the hearing threshold of workers. Two hundred and four and one hundred and eighty five workers from the same initial 204subjects from four different four quarries volunteered for audiometry tests in 2018 and 2019 respectively. The multifactor effect of the factors as they influence hearing threshold was analysed using Adaptive Neural-Fuzzy Inference System (ANFIS) and regression analysis at eight different hearing frequencies between 0.25 and 8. 00 kHz.

5.2 Conclusion

The following conclusions were drawn based on the activities undertaken in the study,:

1. The equipment used in quarry operations produce 87.3 - 116.9 dBA noise level which was greater than the acceptable threshold sound level; except in the administrative section where the noise level was 28.4 dBA.
2. The differences between the noise levels in the administrative block and quarry sections are due to the greater exposure of the workers at quarry section to high noise level and hence the higher hearing threshold than the administrative workers.
3. The eight hearing threshold predictive models of the quarry workers between the studied frequencies models showed good predictive capability and models satisfactorily.
4. Thus, having known the parameters of the 3 main factors effects aforementioned, the hearing threshold of a worker at various frequencies can be determined.
5. The safe settings of the studied factors (age of workers, years of exposure and noise level) that can accommodate relatively safe hearing threshold at various frequencies were found obtained as 52 years, 32 years of exposure and optimal noise level of 112 dB will ensure the safe hearing threshold of 25-30 dB at 8 working hours of exposure.

6. The hearing threshold of workers between the baseline year and the second year; continuously worsened.

7. Thus having known the age of the workers, years of exposure of the workers and the noise level of the workstation, the quarry workers employee can find these findings useful when recruiting workers in order to ensure a safe working environment for the worker's hearing status.

5.3 Recommendations

(i) Further research can consider the effect of other indices such as race of the workers' medical history, quarry equipment age, maintenance practices and individual biological tolerance for noise.

(ii) More longitudinal years of experimental period like 5 years may be embraced.

(iii)Further study can consider other locations and compare the performance of the models to the ones presented in this study.

(iv) Further research is needed in workstation with noise of higher frequencies apart from those investigated in this work.

(v) This type of study should be carried out on quarry workers in order to compare workers that embraced the usage of PPE and others which did not.

(vi) Consideration of some workers life style like smoking, alcohol consumption, chemicals and dust exposure can be considered in the future study.

5.4 Contributions to Knowledge

1. This study established that the hearing threshold of the quarry workers can be determined when the age, years of exposure and noise level which they are exposed to are known. Thus, the three parameters are the useful input variable for predictive models for design purposes for the workstations.

2. Furthermore, the study presented eight models for the prediction, which can aid the selection of fit workers to a safe workstation.

3. The audiogram of the quarry workers can be determined by using the developed models, the stress and rigour that may ensue would be ameliorated or completely eliminated.

4. This study also enhances the safe utilisation of manpower. A safe and healthy workstation for workers can be determined when the age of the workers; years of exposure and noise level are known as well as applying engineering control in attenuating the high noise exposure usually emanated from the quarry.

5. The data collected in this research work were limited to those needed for Ergonomic design for the quarry workstation. The data may be suitable for the design of other noisy workstation, hence similar studies which will collect complete and comprehensive ergonomic data across the country are recommended. This will serve as database for the quarry workers in general.

6. The models presented in this study can be reliably used to create database for the ergonomic design of the quarry workers.

REFERENCES

Abbasi, B. and Mahlooji, H. 2012. Improving response surface methodology by using artificial neural network and simulated annealing. *Expert Systems with Applications 39*. 3: 3461-3468. doi:https://doi.org/10.1016/j.eswa.2011.09.036

Abdulkadir, S. J., Alhussian, H., Nazmi, M. and Elsheikh, A. A. 2018. Long Short Term Memory Recurrent Network for Standard and Poor's 500 Index Modelling. *International Journal of Engineering & Technology 7*. 4: 25-29. doi:https://doi.org/10.14419/ijet.v7i4.15.21365

Acoustical Surfaces. 2013. Top 10 Noisiest Jobs. Retrieved 28 February, 2023 https://www.acousticalsurfaces.com/blog/acoustics-education/top-10-noisiest-jobs/

Adeniyi, A. 2021. Job absorption capacity of Nigeria's mining and quarrying sector. *Journal of Business Administration Research 10*. 1: 51-61.

Agha, S.R. amd Alnahhal, M. 2012. Neural network andmultiple linear regression to predict school children dimensions from Ergonomic school furniture design. Applied Ergonomics.43(6): 979-984. DOI: 10.1016/j.apergo.2012.01.007.

Ahmed, H. O., Dennis, J. H., Badran, O., Ismail, M., Ballal, S. G., Ashoor, A. and Jerwood, D. 2001. High-frequency (10-18 kHz) hearing thresholds: reliability, and effects of age and occupational noise exposure. *Occup Med (Lond) 51*. 4: 245-258. doi:10.1093/occmed/51.4.245

Akanbi, O. G., Oriolowo, K.T., Oladejo, K. A., Abu, R., Mogbojuri, A.O. and Ogunlana, R. 2021. Models for Estimating the Hearing Threshold of Quarry Workers at High Frequencies. *Nigerian Journal of Environmental Sciences and Technology 5*: 140-151. doi:10.36263/nijest.2021.01.0254

Akanbi, O. G. and Oriolowo, K. T. 2016. Modeling the prevention of transformation of pressbycusis to noise induced hearing loss. *Journal of Business Administration Research Nigerian Institute of Industrial Engineers (NIIE)*. 6: 47-58.

Akinluyi, F. O., Awoniran, D. R., Oladejo, S. O. and Ogunniyi, O. S. 2019. Environmental evaluation of quarry operation in Akure metropolis, Ondo state, Nigeria *Ethiopian Journal of Environmental Studies & Management 12*. 2: 229-237. doi:https://ejesm.org/doi/v12i2.10

Al-Maghrabi, M.N. N., Shewakh, W. M. and Haleem, A. 2013. Degradation of industrial performance due to environmental factors "impact of noise on mining and manufacturing workers". *International Journal of Mechanical and Production Engineering Research and Development 3*. 2: 147-154.

Allen, P. D. and Eddins, D. A. 2010. Presbycusis phenotypes form a heterogeneous continuum when ordered by degree and configuration of hearing loss. *Hear Res 264*. 1-2: 10-20. doi:10.1016/j.heares.2010.02.001

Aluclu, I., Dalgic, A. and Toprak, Z. F. 2008. A fuzzy logic-based model for noise control at industrial workplaces. *Appl Ergon 39*. 3: 368-378. doi:10.1016/j.apergo.2007.08.005

Amedofu, G. K. 2002. Hearing-impairment among workers in a surface gold mining company in Ghana. *Afr J Health Sci 9*. 1-2: 91-97. doi:10.4314/ajhs.v9i1.30759

Amirian, M. (2019). *Mitigating sub-synchronous resonance using static var compesator (SVC) enhanced with adaptive neuro-fuzzy inference systems (ANFIS) controller*. Paper presented at the Proceedings of 27th Iranian Conference on Electrical Engineering (ICEE), Iran.

Anastasiadou, S. and Al Khalili, Y. 2022. Hearing Loss. Retrieved 3 June, 2022, from StatPearls Publishing https://www.ncbi.nlm.nih.gov/books/NBK542323/

ANSI (2004). Methods for manual pure-tone-threshold audiometry (ANSI S3.21-2004). New York.

Aremu, M. O., Oke, E. O., Arinkoola, A. O. and Salam, K. K. 2014. Development of optimum operating parameters for bioelectricity generation from sugar wastewater using response surface methodology. *Journal of Scientific Research & Reports 3*. 15: 2098-2109.

Asfahl, C. R. 2004. *Industrial Safety and Health Management*: Prentice Hall.

ASHA, 1990. American Speech-Language-Hearing-Association. Guidelines for manual pure tone threshold audiometry. Retrieved from www.asha.org/policy Jan. 07, 2021.

ASHA, 2004. American Speech-Language-Hearing-Association. Guidelines for manual pure tone threshold audiometry. Retrieved from www.asha.org/policy Feb. 11, 2022.

Aslan, Z., Erdemir, G., Feoli, E., Giorgi, F. and Okcu, D. 2019. Effects of Climate Change on Soil Erosion Risk Assessed by Clustering and Artificial Neural Network. *Pure and Applied Geophysics 176*. 2: 937-949. doi:10.1007/s00024-018-2010-y

Asmara, Y. 2013. The Use of Response Surface Methodology to Predict CO2 Corrosion Model Empirically.

Awolu, O., Oloniyo, R. and Ayodele, B. S. 2013. Optimization of solvent extraction of oil from neem (Azadirachta indica) and its characterizations. *Journal of Scientific Research & Reports 2*. 1: 304-314.

Bainbridge, K. E. and Wallhagen, M. I. 2014. Hearing loss in an aging American population: extent, impact, and management. *Annu Rev Public Health 35*: 139-152. doi:10.1146/annurev-publhealth-032013-182510

Barati-Harooni, A., Najafi-Marghmaleki, A. and Mohammadi, A. H. 2016. ANFIS modeling of ionic liquids densities. *Journal of Molecular Liquids 224*: 965-975. doi:https://doi.org/10.1016/j.molliq.2016.10.050

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S. and Stansfeld, S. 2014. Auditory and non-auditory effects of noise on health. *Lancet 383*. 9925: 1325-1332. doi:10.1016/s0140-6736(13)61613-x

Bisong, S. A., Umana, A. N., Onoyom-Ita, V. and Osim, E. E. 2004. Hearing acuity loss of operators of food grinding machines in Calabar, Nigeria. *Nigerian Journal of Physiological Sciences 19*. 1-2: 20-27. doi:10.4314/njps.v19i1.32631

Boateng, C. A. and Amedofu, G. K. 2004. Industrial noise pollution and its effects on the hearing capabilities of workers: a study from sawmills, printing presses and corn mills. *African Journal of Health Sciences* 11.1: 524-530.

Bobadilla, M., Lostado-Lorza, R., Escribano-Garcia, R., Somovilla Gómez, F. and Vergara, E. 2017. An Improvement in Biodiesel Production from Waste Cooking Oil by Applying Thought Multi-Response Surface Methodology Using Desirability Functions. *Energies 10*: 130. doi:10.3390/en10010130

Boman, E., Enmarker, I. and Hygge, S. 2005. Strength of noise effects on memory as a function of noise source and age. *Noise Health 7*. 27: 11-26. doi:10.4103/1463-1741.31636

Bonissone, P. P. 2002. Adaptive Neural Fuzzy Inference System (ANFIS): Analysis and Applications. Retrieved 8 June, 2022 https://www.scribd.com/document/21954114/Adaptive-Neural-Fuzzy-Inference-Systems-ANFIS-Analysis-and-Applications

Bouloiz, H., Garbolino, E. and Tkiouat, M. 2013. Modeling of an Organizational Environment by System Dynamics and Fuzzy Logic. *Open Journal of Safety Science and Technology Vol.03No.04*: 9. doi:10.4236/ojsst.2013.34012

Burtka, C. and Chick, K. 1997. *Non –Industrial Noise levels*. San Diego: London Singular Publishing group Inc. .

Caponetto, R., Lavorgna, M., Martinez, A. and Occhipinti, L. (1997, 21-23 May 1997). *GAs for fuzzy modeling of noise pollution.* Paper presented at the Proceedings of 1st International Conference on Conventional and Knowledge Based Intelligent Electronic Systems. KES '97.

Civelekoglu, G., Perendeci, A., Yigit, N. O. and Kitis, M. 2007. Modeling Carbon and Nitrogen removal in an industrial wastewater treatment plant using an adaptive network-based fuzzy inference system. *Clean 35*. 6: 617– 625. doi:10.1002/clen.200700076

Correia, A. W., Peters, J. L., Levy, J. I., Melly, S. and Dominici, F. 2019. Residential exposure to aircraft noise and hospital admissions for cardiovascular diseases: multi-airport retrospective study. *BMJ : British Medical Journal 347*: f5561. doi:10.1136/bmj.f5561

Cunningham, L. L. and Tucci, D. L. 2017. Hearing Loss in Adults. *N Engl J Med 377*. 25: 2465-2473. doi:10.1056/NEJMra1616601

Derringer, G. C. and Suich, R. C. 1980. Simultaneous Optimization of Several Response Variables. *Journal of Quality Technology 12*: 214-219.

Do, B., Robinet, S., Praudeau, D. and Guoyon, F. 2001. Application of central composite design for optimisation of the chromatographic separation of monomethylarsonate and dimethylarsinate and of selenomethiomine and selenite by ion- pair chromatography coupled with plasma mass apectrometric detection. *Analyst* 12.6:594-601.

Dua, D., and Taniskidou, E.K. 2017. UCI Machine learning repository. University of California, school of information and computer science, Irvine, CA. Retrieved July 20, 2021, from http://archive.ics.uci.edu/ml.

Diniz, F. M. and Martin, A. M. 1996. Use of response surface methodology to describe the combined effect of Ph temperature and E/S ratio on the hydrolysis of Dogfish (Squalus Acanthias) muscle. *International Journal of Food Science and Technology 31*. 5: 419-426. doi:https://doi.org/10.1046/j.1365-2621.1996.00351.x

El-Tayeb, N. S. M., Yap, T. C. and Brevern, P. 2010. Wear characteristics of titanium alloy Ti54 for cryogenic sliding applications. *Tribology International 43*: 2345-2354.

England, B. and Larsen, J. B. 2014. Noise levels among spectators at an intercollegiate sporting event. *Am J Audiol 23*. 1: 71-78. doi:10.1044/1059-0889(2013/12-0071)

Ferilla, F., Mazziotti, D., Celso, G., Michelis, I., Stanici, V., and Veglis, F. 2010. Optimisation of the transesterification reaction in biodiesel production. *Fuel* 89. 1: 36-42.

Fernandez, F. J., Seco, A., Ferrer, J. and Rodrigo, M. A. 2009. Use of neurofuzzy networks to improve wastewater flow-rate forecasting. *Environmental Modelling & Software 24*. 6: 686-693. doi:https://doi.org/10.1016/j.envsoft.2008.10.010

Fink, D. 2019. A new definition of noise. *Acoustical Society of America 39*. 05002: 1-12. doi:10.1121/2.0001186

Gharakhani, M., Alizadeh, M., Fotoohi, E. and Rada, R. 2011. Design and analysis of experiments in ANFIS modeling for stock price prediction. *EtInternational Journal of Industrial Engineering Computations 2*. 2: 409-418. doi:10.5267/j.ijiec.2011.01.001

Gheisari, M., Wang, G. and Bhuiyan, M. Z. A. 2017. *A survey on deep learning in big data*. Paper presented at the international conference on computational science and engineering (CSE) and IEEE international conference on embedded and ubiquitous computing (EUC). Conference paper. July 2017. DOI: 10.1109/CSE-EUC.2017.215.

Gómez, F. S., Lorza, R. L., Bobadilla, M. C. and García, R. E. 2017. Improving the Process of Adjusting the Parameters of Finite Element Models of Healthy Human Intervertebral Discs by the Multi-Response Surface Method. *Materials (Basel) 10*. 10. doi:10.3390/ma10101116

Government of Alberta. 2009. Workplace Health and Safety: Noise at the worksite. Retrieved 3 June, 2022, from Government of Alberta, Employment and Immigration https://open.alberta.ca/publications/hs003-hearing-sight

Gyamfi, C. K., Amankwaa, I., Owusu Sekyere, F. and Boateng, D. 2016. Noise Exposure and Hearing Capabilities of Quarry Workers in Ghana: A Cross-Sectional Study. *J Environ Public Health 2016*: 7054276. doi:10.1155/2016/7054276

He, S., Smargiassi, A., Low, N., Bilodeau-Bertrand, M., Ayoub, A. and Auger, N. 2019. Residential noise exposure and the longitudinal risk of hospitalization for depression after pregnancy: Postpartum and beyond. *Environmental Research 170*: 26-32. doi:https://doi.org/10.1016/j.envres.2018.12.001

Healthy hearing.com. 2020. Understanding the degrees of hearing loss and hearing losss levels. Retrieved Jan. 3, 2022, from *https: // www.healthyhearing. com/report/41775- Degrees-of-hearing-loss.*

Hoffman, H. J., Dobie, R. A., Losonczy, K. G., Themann, C. L. and Flamme, G. A. 2017. Declining Prevalence of Hearing Loss in US Adults Aged 20 to 69 Years. *JAMA Otolaryngol Head Neck Surg 143*. 3: 274-285. doi:10.1001/jamaoto.2016.3527

Holman, J. A., Drummond, A., Hughes, S. E. and Naylor, G. 2019. Hearing impairment and daily-life fatigue: a qualitative study. *International Journal of Audiology 58*. 7: 408-416. doi:10.1080/14992027.2019.1597284

Huiping, L., Guoqun, Z., Shanting, N. and Yiguo, L. 2007. Technologic parameter optimization of gas quenching process using response surface method. *Computational Materials Science 38*. 4: 561-570. doi:https://doi.org/10.1016/j.commatsci.2006.03.014

Humes, L. E. 2019. The World Health Organization's hearing-impairment grading system: an evaluation for unaided communication in age-related hearing loss. *Int J Audiol 58*. 1: 12-20. doi:10.1080/14992027.2018.1518598

Ighalo, J. O., Adelodun, A., Adeniyi, A. and Igwegbe, C. 2020. Modelling the Effect of Sorbate-Sorbent Interphase on the Adsorption of Pesticides and Herbicides by Historical Data Design. *Iranica Journal of Energy & Environment 11*: 253-259. doi:10.5829/ijee.2020.11.04.02

Ilse, M., Tomczak, J. M. and Welling, M. 2020. Chapter 22 - Deep multiple instance learning for digital histopathology. In S. K. Zhou, D. Rueckert, & G. Fichtinger (Eds.), *Handbook of Medical Image Computing and Computer Assisted Intervention* (pp. 521-546) Academic Press.

Industrial Accident Prevention Association. 2008. Hearing conservation. Retrieved 19 September, 2013, from Industrial Accident Prevention Association www.iapa.ca.2hearing

Ismail, A. F., Daud, A., Ismail, Z. and Abdullah, B. 2013. Noise-induced hearing loss among quarry workers in a north-eastern state of malaysia: a study on knowledge, attitude and practice. *Oman Med J 28*. 5: 331-336. doi:10.5001/omj.2013.96

Jang, J. S. R. 1993. ANFIS: adaptive-network-based fuzzy inference system. *IEEE Transactions on Systems, Man, and Cybernetics 23*. 3: 665-685. doi:10.1109/21.256541

Jeirani, Z., Mohamed Jan, B., Si Ali, B., Noor, I. M., See, C. H. and Saphanuchart, W. 2013. Prediction of the optimum aqueous phase composition of a triglyceride microemulsion using response surface methodology. *Journal of Industrial and Engineering Chemistry 19*. 4: 1304-1309. doi:https://doi.org/10.1016/j.jiec.2012.12.032

Johnson, J. 2023. Types of machinery in the quarry industry. Retrieved 28 February, 2023 https://smallbusiness.chron.com/types-machinery-quarry-industry-55491.html

Kamil, R. J. and Lin, F. R. 2015. The effects of hearing impairment in older adults on communication partners: a systematic review. *J Am Acad Audiol 26*. 2: 155-182. doi:10.3766/jaaa.26.2.6

Kansedo, J., Lee, K.T., and Bhatia, S., 2009. Biodiesel production from palm oil via heterogeneous transesterification. *Biomass Bioenergy* 33.2: 271-276.

Karaboga, D. and Kaya, E. 2016. An adaptive and hybrid artificial bee colony algorithm (ABC) for ANFIS training. *Applied Soft Computing 49*: 423-436. doi:https://doi.org/10.1016/j.asoc.2016.07.039

Karaboga, D. and Kaya, E. 2019. Adaptive network based fuzzy inference system (ANFIS) training approaches: a comprehensive survey. *Artificial Intelligence Review 52*. 4: 2263-2293. doi:10.1007/s10462-017-9610-2

Kerketta, S., Gartia, R. and Bagh, S. 2012a. Assessment of Noise Induced Hearing Loss of the Mine Workers of a Chromite Mines at Sukinda, Orissa, India. *Noise & Vibration Worldwide 43*. 2: 28-36. doi:10.1260/0957-4565.43.2.28

Kerketta, S., Gartia, R. and Bagh, S. 2012b. Hearing Threshold, Loss, Noise Levels and Worker's Profiles of an Open Cast Chromite Mines in Odisha, India. *Malays J Med Sci 19*. 4: 63-71.

Kisi, O., Shiri, J., Karimi, S. and Adnan, R. M. 2018. Three Different Adaptive Neuro Fuzzy Computing Techniques for Forecasting Long-Period Daily Streamflows. In S. S. Roy, P. Samui, R. Deo, & S. Ntalampiras (Eds.), *Big Data in Engineering Applications* (pp. 303-321). Singapore Springer Singapore.

Kolarik, W. J., Woldstad, J. C., Lu, S. and Lu, H. 2004. Human performance reliability: on-line assessment using fuzzy logic. *IIE Transactions 36*. 5: 457-467. doi:10.1080/07408170490426161

Kuhn, M. 2013. Desirability: Desirability function optimisation and ranking. R package version. Retrieved 7 Augusty, 2020 http://: CRAN. R-project.org/package=desirability

Kulabako, V. 2019. *Noise produced from mechanised quarrying and occupational hazards at Stirling quarry.* (B.Sc.). Makere University. 41.

Le, T. N., Straatman, L. V., Lea, J. and Westerberg, B. 2017. Current insights in noise-induced hearing loss: a literature review of the underlying mechanism, pathophysiology, asymmetry, and management options. *Journal of Otolaryngology - Head & Neck Surgery 46*. 1: 41. doi:10.1186/s40463-017-0219-x

Li, G., Wang, H., Aryasomayajula, S., Grandhi, R. 2000. Two level optimisation of airframe structures using response surface approximation. *Stuructural and Multidisciplinary Optimisation* 20. 2: 116-124.

Lin, F. R., Metter, E. J., O'Brien, R. J., Resnick, S. M., Zonderman, A. B. and Ferrucci, L. 2011. Hearing loss and incident dementia. *Arch Neurol 68*. 2: 214-220. doi:10.1001/archneurol.2010.362

Liyana - Pathirana, C. and Shashida, F. (2005). Optimisation of extraction of phenolic compounds from wheat using response surface methodology. Food Chemistry. 93(1). 47-56.

Lostado-Lorza, R., Calvo, M., Berlanga-Labari, C. and Rivero, P. 2018. Using the Multi-Response Method with Desirability Functions to Optimize the Zinc Electroplating of Steel Screws. *Metals 8*. doi:10.3390/met8090711

Maccà, I., Scapellato, M. L., Carrieri, M., Maso, S., Trevisan, A. and Bartolucci, G. B. 2015. High-frequency hearing thresholds: effects of age, occupational ultrasound and noise exposure. *Int Arch Occup Environ Health 88*. 2: 197-211. doi:10.1007/s00420-014-0951-8

Mallick, Z., Kaleel, A. H. and Siddiquee, A. N. 2009. An expert system for predicting the effect of noise, pollution on grass trimming task using fuzzy modeling. *International Journal of Applied Environmental Science 4*. 4: 389-403.

Majumdar, A., and Goyal, A. 2008. Enhanced production of exocellular Glucansucrase from Leuconostoc Dextranicum NRRL B-1146 using response surface method. *Bioresour Technology* 99. 9: 3685 – 3691.

MATLAB Toolbox 2009. Fuzzy Inference System Demo.

Mener, D. J., Betz, J., Genther, D. J., Chen, D. and Lin, F. R. 2013. Hearing loss and depression in older adults. *J Am Geriatr Soc 61*. 9: 1627-1629. doi:10.1111/jgs.12429

Mick, P., Kawachi, I. and Lin, F. R. 2014. The association between hearing loss and social isolation in older adults. *Otolaryngol Head Neck Surg 150*. 3: 378-384. doi:10.1177/0194599813518021

Mingzhi, H., Jinquan, W., Yongwen, M., Yan, W., Weijiang, L. and Xiaofei, S. 2009. Control rules of aeration in a submerged biofilm wastewater treatment process using fuzzy neural networks. *Expert Systems with Applications 36*. 7: 10428-10437. doi:https://doi.org/10.1016/j.eswa.2009.01.035

Mohammadi, R., Nassiri, M. and Jafari, S. P. 2009. Risk assessment of workers exposed to noise pollution in a textile plant. *Int J Environ Sci Tech* 6.4: 591-596.

Montgomery, D. and Runger, G. 2007. *Applied statistics and probability for engineers* (4 ed.): John Wiley and Sons, Incorporated.

Montgomery, D. C. 2012. *Design and Analysis of Experiments, 8th Edition*: John Wiley & Sons, Incorporated.

Mulugate, S. 1992. Noise levels in the Ethiopian woodworking industries. *African Newsletter on Occupational Health and Safety* 2.1: 14-17.

Murnleitner, E., Becker, T. M. and Delgado, A. 2002. State detection and control of overloads in the anaerobic wastewater treatment using fuzzy logic. *Water Res 36*.1: 201-211. doi:10.1016/s0043-1354(01)00186-5

Myers, R. H., Montgomery, D. C. and Anderson-Cook, C. M. 2009. *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*: Wiley.

Nanda, S. K. 2012. *Noise Impact Assessment and Prediction in Mines using Soft-Computing Techniques.* (Ph.D). National Institute of Technology, Rourkela. 286.

Nardi, P.M. 2003. Doing survey research: A guide to qualitative methods: Boston, M.A.: Allyn and Bacon.

National Bureau of Statistics. 2019. State disaggregated mining and quarrying Data (2018). Retrieved 28 February, 2023 https://www.nigerianstat.gov.ng/pdfuploads/State_Disaggregated_Mining_and_Quarrying_Data_-_2018.pdf

Neuman, W. L. 2007. Basics of social research: Qualitative and quantitative approaches. 2nd ed. Boston, M.A. : Allyn and Bacon.

Nguyen, T.L., Kavuri, S. and Lee, M. 2019. A multimodal convulutional neuro – fuzzy network for emotion understanding of movie clips. *Neural Networks* 118: 208-219.

Occupational Health and Safety. (OHS) 2014. Western University hearing protection program. Retrieved 3 June, 2022, from Occupational Health and Safety https://www.uwo.ca/hr/form_doc/health_safety/doc/procedures/hearing_protection_program.pdf

Ochmann, M., and Piscoya, R. 2021. *Theory and Application of Acoustic Sources Using Complex Analysis: Complex Acoustic Sources, Green's Functions and Half-Space Problems, Acoustic Radiation and Scattering Using Equivalent Source and Boundary Element Methods*: Springer Nature Singapore.

Oehlert, G. W. 2000. *Design and analysis of experiments: Response surface design*. New York: W.H. Freeman and Company.

Ojolo, S. J. and Ismail, S. O. (2011). *Mathematical Modelling of Effects of Noise on Machine Operators.* Paper presented at the International Conference on Innovations in Engineering and Technology (IET), Faculty of Engineering, University of Lagos, Akoka-Yaba, Lagos State, Nigeria.

Oladimeji, Y., Adepoju, S., Galadima, A. and Mohammad Fagge, A. 2019. Socio-economic impact of participation in mining and quarrying on poverty alleviation among rural farming households in Kwara state, Nigeria. Journal of Agriculture and Environment. *14*: 17-29.

Onder, M., Onder, S. and Mutlu, A. 2012. Determination of noise induced hearing loss in mining: an application of hierarchical loglinear modelling. *Environ Monit Assess 184*. 4: 2443-2451. doi:10.1007/s10661-011-2129-0

Ouis, D. 2002. Annoyance caused by exposure to road traffic noise: An update. *Noise and Health 4*. 15: 69-79.

Pai, T. Y., Wang, S. C., Lo, H. M., Chiang, C. F., Liu, M. H., Chiou, R. J. and Leu, H. G. 2009. Novel modeling concept for evaluating the effects of cadmium and copper on heterotrophic growth and lysis rates in activated sludge process. *Journal of Hazardous Materials 166*. 1: 200-206. doi:https://doi.org/10.1016/j.jhazmat.2008.11.009

Pandey, R. and Thote, N. R. (2005). *Dumper operators expose to noise-some investigations: in.* Paper presented at the proceedings of technological advancement and environmental challenges in mining and allied industries in the 21st century (TECMAC), India.

Passino, K. M. and Yurkovich, S. 1998. *Fuzzy control*. Menlo Park: Addison Wesley Longman.

Perendeci, A., Arslan, S., Tanyolac , A. and Elebi, S. S. 2007. Evaluation of input variables in adaptive-network based fuzzy inference system (ANFIS) modeling for an anaerobic wastewater treatment plant under unsteady conditions. *Journal of Environmental Engineering 133*. 7: 765-772.

Petković, J., Petrović, N., Dragović, I., Stanojević, K., Radaković, J. A., Borojević, T. and Kljajić Borštnar, M. 2019. Youth and forecasting of sustainable development pilars: An adaptive neuro-fuzzy inference system approach. *PLoS One 14*. 6: e0218855. doi:10.1371/journal.pone.0218855

Phillips, J. I., Heyns, P. S. and Nelson, G. 2007. Rock drills used in South African mines: a comparative study of noise and vibration levels. *Ann Occup Hyg 51*. 3: 305-310. doi:10.1093/annhyg/mel082

Pulsar Instruments. 2015. Noise Levels – 10 Most hazardous jobs for your hearing. Retrieved 28 February, 2023 https://pulsarinstruments.com/news/most-hazardous-jobs-your-hearing/

Salam, K., Agarry, S., Olatunde, A. and Shoremekun, I. 2015. Optimization of Operating Conditions Affecting Microbiologically Influenced Corrosion of Mild Steel Exposed to Crude Oil Environments Using Response Surface Methodology. *British Biotechnology Journal 7*. doi:10.9734/BBJ/2015/16810

Salam, K., Olatunde, A. and Aminu, M. 2018. Application of response surface methodology (RSM) For the modelling and optimization of sand minimum transport condition (MTC) in pipeline multiphase flow. *Petroleum and Coal 60*: 39-340.

Salam, K., Olatunde, A., Aminu, M. and Sanni, O. 2020. Modelling of mass transfer coefficient of CO2 in stirred tank bioreactors using Response Surface Methodology.

Salawu, O. G. and Sadiq, Y. O. 2020. Artisanal quarries in Kaduna metropolis with associated socio-economic benefits. *Science World Journal 15*. 4: 1-6. doi:10.1146/annurev-publhealth-032013-182510

Salleh, M. N. M., Talpur, N. and Hussain, K. 2017. *Adaptive Neuro-Fuzzy Inference System: Overview, Strengths, Limitations, and Solutions.* Paper presented at the Data Mining and Big Data, Cham.

Shang, J. S. and Tadikamalla, P. R. 1993. Output maximization of a CIM system: simulation and statistical approach. *International Journal of Production Research 31*. 1: 19-41. doi:10.1080/00207549308956711

Shukla, A., Harper, M., Pedersen, E., Goman, A., Suen, J. J., Price, C. and Reed, N. S. 2020. Hearing Loss, Loneliness, and Social Isolation: A Systematic Review. *Otolaryngol Head Neck Surg 162*. 5: 622-633. doi:10.1177/0194599820910377

Stevens, G., Flaxman, S., Brunskill, E., Mascarenhas, M., Mathers, C. D. and Finucane, M. 2011. Global and regional hearing impairment prevalence: an analysis of 42 studies in 29 countries. *Eur J Public Health 23*. 1: 146-152. doi:10.1093/eurpub/ckr176.

Stoeckle, S., Pah, N., Kumar, D. K. and McLachlan, N. 2001. *Environmental sound sources classification using neural networks.* Paper presented at the The Seventh Australian and New Zealand Intelligent Information Systems Conference, 2001.

Suskie, L.A.1996. Questionaire survey research: What works. 2nd ed. Tllahassee, FL: Association for Industrial Research.

Takagi, T. and Sugeno, M. 1985. Fuzzy identification of systems and its application to modeling and control. *IEEE Transactions on Systems, Man and Cybernetics* 15: 116-132.

Tala-Ighil, N., Fillon, M. and Maspeyrot, P. 2011. Effect of textured area on the performances of a hydrodynamic journal bearing. *Tribology International 44*. 3: 211-219. doi:https://doi.org/10.1016/j.triboint.2010.10.003

Talpur, N., Abdulkadir, S. J. and Hassan, M. H. (2020). *A deep learning based neuro-fuzzy approach for solving classification problems.* Paper presented at the Proceedings of International Conference on Computational Intelligence (ICCI) Universiti Teknologi PETRONAS (UTP) 8th-9th October 2020.

Tatar, A., Barati-Harooni, A., Najafi-Marghmaleki, A., Norouzi-Farimani, B. and Mohammadi, A. H. 2016. Predictive model based on ANFIS for estimation of thermal conductivity of carbon dioxide. *Journal of Molecular Liquids 224*: 1266-1274. doi:https://doi.org/10.1016/j.molliq.2016.10.112

Torija, A. J., Ruiz, D. P. and Ramos-Ridao, A. F. 2012. Use of back-propagation neural networks to predict both level and temporal-spectral composition of sound pressure in urban sound environments. *Building and Environment 52*: 45-56. doi:https://doi.org/10.1016/j.buildenv.2011.12.024

Tripathy, D. P. and Rao, D. S. 2017. Occupational noise-induced hearing loss of workers in a bauxite mine in India. *Noise Control Engineering Journal 65*. 3: 224-233. doi:https://doi.org/10.3397/1/376440

Tronto, I. F. D. B., Silva, J. D. S. D. and Sant'Anna, N. 2007.. *Comparison of Artificial Neural Network and Regression Models in Software Effort Estimation.* Paper presented at the International Joint Conference on Neural Networks. 12-17 Aug. 2007).

Ukpong, E. C. 2012. Environmental impact of aggregate mining by crush rock industries in Akamkpa Local Government Area of Cross River State. *Nigerian Journal of Technology 31*. 2: 131-138.

Vardhan, H., Karmakar, N. and Rao, Y. 2006. Assessment of heavy earth-moving machinery noise vis-a-vis routine maintenance. *Noise Control Engineering Journal - NOISE CONTR ENG J 54*: 64-78. doi:10.3397/1.2888383

Vardhan, H., Rao, Y. and Karmakar, N. 2004. Noise Analysis of Heavy Earth Moving Machinery Deployed in Opencast Mines and Development of Suitable

Maintenance Guidelines for its Attenuation - Part 3. *Noise & Vibration Worldwide 35*: 11-24. doi:10.1260/0957456042880336

Verkeyn, A., Botteldooren, D., Tre, G. D. and Caluwe, R. D. (2001, 25-28 July 2001). *Fuzzy modeling of traffic noise annoyance.* Paper presented at the Proceedings Joint 9th IFSA World Congress and 20th NAFIPS International Conference (Cat. No. 01TH8569).

Vohra, A. and Satyanarayana, T. 2002. Statistical optimisation of the medium components by response surface methodology to enhance Phytase production, Phychia Anomala. *Process Biochemistr 37*. 9: 999-1004.

W.H.O. 1991. Report of the Informal Working Group on Prevention of Deafness and Hearing Impairment Programme Planning, Geneva, 18-21 June 1991. Available from http://apps.who.int/iris/ WHO IRIS Retrieved 2 February, 2022, from World Health Organization https://apps.who.int/iris/handle/10665/58839

W.H.O. 1991. Deafness and hearing loss. Retrieved 3 June, 2022, from World Health Organisation https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearingloss#:~:text=Hearing%20loss%20and%20deafness,moderate%2C%20severe%2C%20or%20profound.

W.H.O. 2002. World Health Organisation report 2002: Reducing risks, promoting healthy life. Retrieved 3 June, 2022, from World Health Organisation https://www.who.int/publications/i/item/9241562072

W.H.O. 2003. World Health Organisation report 2003: World hearing day 2023. Retrieved 28 June, 2023, from World Health Organisation https://www.pacehospital.com.

Workman-Davies, C. L. 1989. Noise and hearing in a trackless-mining environment. *J. S. Afr. Inst. Min. Metal 89*. 7: 211-217.

Wu, L., Yick, K..l., Ng, S.P. and Yip, J. 2012. Application of the Box–Behnken design to the optimization of process parameters in foam cup molding. *Expert Systems with Applications 39*. 9: 8059-8065. doi:https://doi.org/10.1016/j.eswa.2012.01.137

Zaheeruddin, S. and Jain, V. K. 2008. An expert system for predicting the effects of speech interference due to noise pollution on humans using fuzzy approach. *Expert Systems with Applications 35*. 4: 1978-1988. doi:https://doi.org/10.1016/j.eswa.2007.08.104

Zaheeruddin, S., Jain, V. K. and Singh, G. V. 2006. A fuzzy model for noise-induced annoyance. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans 36*. 4: 697-705. doi:10.1109/TSMCA.2005.851348

Zaheeruddin, S. Singh, G. V. and Jain, V. K. 2003.. *Fuzzy modelling of human work efficiency in noisy environment.* Paper presented at the The 12th IEEE International Conference on Fuzzy Systems, 25-28 May 2003.

APPENDICES

Appendix A

SUMMARY OF WORKS ON THE EFFECT OF NOISE ON HEARING THRESHOLD

Table A1: Previous Work on Effect of Noise on Hearing Threshold

Author	Work	Factors Considered	Method	Result	Limitation
Workman-Davies (1989)	Noise and hearing in a trackless-mining environment	Age, noise level and NIHL	Audiometry, sound level meter, SPSS statistical analysis	At age of 30, 10% of workers had hearing loss greater than 25dB and about 7% greater than 40dB; whereas at age 50, the hearing loss continuing increasing.	Only highlighted the relationship between noise and age. Worker's years of exposure to noise was not considered. No predictive model for the hearing threshold.
Ahmed *et al.* (2001)	High frequency (10-18kHz) hearing thresholds: reliability and effects of age and occupational noise exposure.	Age, noise level, high frequency (10-18kHz) and conventional frequency (0.25-8kHz).	Audiometry, Multivariate analysis.	Age affects hearing threshold at both high and conventional frequency. Exposed subjects had higher hearing threshold than non-exposed subject at high frequency considered. Age was the primary predictor, and noise level was the secondary predictor of hearing threshold in high frequency range (10-18kHz). In contrast, noise level was the primary predictor and age was the secondary predictor of hearing threshold in conventional frequency range (0.25-8kHz).	Duration of the exposure of the subjects to the noise not considered in the study. Lack of predictive model(s).

Table A1 (Continued): Previous Work on Effect of Noise on Hearing Threshold

Author	Work	Factors Considered	Method	Result	Limitation
Amedofu (2002)	Hearing – impairment among workers in a surface Gold mining company in Ghana.	Age, noise level, years of exposure and hearing loss.	Audiometry, sound level meter, SPSS statistical analysis.	The range of hearing loss was stated among the miners in terms of age, exposure and noise level. Canvassed for noise control in the mining company	Lack of predictive model.
Vardhan *et al*. (2004)	Assessment of machine generated noise in open cast mines and development of suitable maintenance guidelines for its attenuation	Noise level produced by the machine	Understudying the machine maintenance system, measurement of the noise level from the machine with sound level meter.	Adequate maintenance of machine will lower the noise produced by the machine.	Impact of noise on workers' age, and exposure not considered. No model predicted.
Pandey and Thote (2005)	Dumper operators exposure to noise - some investigations	Noise level produced by the dumper, years of exposure of the operators.	Sound level meter, years of exposure. Statistical analysis.	Dumpers operator is exposed to occupational noise levels beyond PEL. Dumper operators having spent 9 years in the operation are mostly with higher hearing threshold.	Only years of exposure and noise level considered. Age was not considered. Lack of predictive model.
Phillips *et al*. (2007)	Rock drills used in South African mines: A comparative study of noise and vibration levels	Noise level on human health. Intermittent noise and continuous noise.	Questionnaires, statistical analysis.	Sensitivity of noise varied among the workers.	Age, years of exposure and frequency not mentioned. No predictive model from any factor(s).

Table A1 (Continued): Previous Work on Effect of Noise on Hearing Threshold

Author	Work	Factors Considered	Method	Result	Limitation
Onder *et al.* (2012)	Determination of noise induced hearing loss in mining: an application of hierarchical log linear modelling.	Age, noise levels, years of exposure and NIHL.	Sound level meter, Statistical analysis and audiometry.	Workers with 4-11 years of experience in crushing and screening plants possess higher hearing threshold.	The cognate result was not based on all workers in the mine. Only some workers' years of exposure was targeted. No predictive model from the factors considered.
Kerketta *et al.* (2012a)	Hearing threshold, loss, noise levels, and worker's profiles of an open cast chromite mines in Odisha, India.	Age, workstation, length of employment at the mine, hearing threshold.	Audiometry, sound level meter and ANOVA.	Heavy earth moving machinery (HEMM) operators exposed to noise levels greater than 95dBA. Hearing loss increases as age, workstation and work experiences increase at 4, 6 and 8kHz frequencies. Older and more experienced workers having higher incidence of hearing loss.	Only high frequency 4, 6 and 8kHz were considered.
Kerketta *et al.* (2012b)	Determination of the test frequency causing significant hearing loss of the mine workers of an open cast chromite mine	Age, work experience, workstations, noise level and frequency causing hearing loss.	Audiometry, sound level meter, SPSS 16.0. Generalised Linear Model ANOVA	Frequency 4kHz and 6kHz are the most influential frequency that caused hearing loss by age and workstation; for year of exposure is 4kHz at 1% level of significance. .	Only high frequencies (4, 6 and 8kHz) were observed. No predictive model was developed for hearing threshold by using the factors considered.

Table A1 (Continued): Previous Work on Effect of Noise on Hearing Threshold

Author	Work	Factors Considered	Method	Result	Limitation
Nanda (2012)	Noise impact assessment and prediction in mines using soft computing techniques	Noise level produced by the machinery in the mines, NIHL frequency exposure.	Sound level meter, Adaptive Neuro Fuzzy Inference System (ANFIS), Multilayer perception (MLP), Radical Basis Function Network (RBFN), Fuzzy Inference system for the development of frequency noise prediction model.	ANFIS gave better accuracy as compared to other soft-computing techniques. Models were developed.	Age and years of exposure were not considered in the modeling.
Ismail *et al.*, (2013)	Noise – Induced hearing loss among quarry workers in a North-Eastern state of Malaysia: A study on knowledge, attitude and practice.	Age, years of exposure, noise level, hearing Loss.	Logistic regressions, measurement of noise exposure, audiometry.	Noise is one of the occupational hazards and environmental pollutants in quarries causing NIHL among workers. Workers not engage in using personal protective equipment.	Not given the precise level of NIHL on the factors. No predictive model from the factors considered.

Table A1 (Continued): Previous Work on Effect of Noise on Hearing Threshold

Author	Work	Factors Considered	Method	Result	Limitation
Kerketta *et al.*, (2016)	Assessment of noise induced hearing loss of the mine workers of Chromite mines at Sukinda, Odisha, India.	Age, years of exposure and workstations.	Audiometry, SPSS 16.0 package, Generalized Linear Model ANOVA.	Subjects will develop NIHL after 25years of starting work at noisy work zone in the open cast chromite mines. Workstation is the primary influential factor for the NIHL.	Noise level and frequency was not considered. Specific age bracket for the workers that can justify the 25 years of exposure not highlighted. There was no predictive model for the hearing threshold prediction from the factors considered.
Akanbi and Oriolowo (2016)	Modelling the prevention of transformation of pressbycussis to noise induced hearing loss.	Age, years of exposure	Noise exposure measurement, Audiometry, Statistical analysis of one factor at a time	Age of the workers was the major contributory factor.	No interacting effects were explored.
Gyanfi *et al.*, (2016)	Noise Exposure and hearing capabilities of quarry workers in Ghana: A cross-sectionals study.	Age, duration of exposure, ear plug usage.	Sound level meter, structured questionnaires, audiometry, Logistic regression.	Machine used at the quarry sites produced noise beyond permissible exposure limit, usage of the PPE reduced the development of NIHL	Effect of noise level on age not considered.

Table A1 (Continued): Previous Work on Effect of Noise on Hearing Threshold

Author	Work	Factors Considered	Method	Result	Limitation
Tripathy and Rao (2017)	Assessment of Noise Induced Hearing Loss (NIHL) of mine workers in a Bauxite mine using fuzzy logic.	Age, exposure, noise level and frequency.	Digital audiometer, SPSS statistical design.	2.3% of the miners (38-55 years of age) were NIHL affected.	Lack of modelling equation for prediction at a particular frequency with the factors considered.
Akanbi *et al*. (2021).	Models for estimating the hearing threshold of quarry workers at high frequencies	Age, years of exposure, noise level, main factors effects and factors interactions effects.	Age, years of exposure, noise level measurement, audiometry, SPSS statistical design, ANOVA. Considered only 3, 4, 6 and 8kHz frequency.	Predicted that noise levels have highest contribution and age has the least prediction ability in hearing threshold of workers. Age, years of exposure and noise level independently predicted the hearing threshold at frequency 4 and 6kHz; years of exposure, noise level independently predicted the hearing threshold at frequency 3kHz; and only noise level independently predicted hearing threshold at frequency 6kHz. No interactive factors predictors at the high frequencies considered. All predicted models were in linear form.	Not specified the age, or years at which factors interaction influences the hearing threshold.

APPENDIX B

CONSENT AND VOLUNTARY PARTICIPATION FORM

INTRODUCTION

I--have been invited to participate in this research study which has been explained to me by Oriolowo Kolawole Taofik. This research is being conducted by Engr. Oriolowo Kolawole Taofik to fulfil the requirements for a Ph.D. thesis in Industrial and Production Engineering Department in the University of Ibadan.

PURPOSE: The purpose of this study is to conduct research on my occupation with regards to my hearing capabilities

PROCEDURES: (1) Practical consultation of quarry workers, (2) medical investigation on hearing capabilities (Audiogram) and (3) a questionnaire asking about my work history.

RISKS AND DISCOMFORTS: The procedure involved in conducting research will not create any risk or discomfort to me during and after the research other than the situation occurrence during a normal day's work.

CONTACT PERSON: Oriolowo Kolawole Taofik on 08027347109, or his supervisor, Prof. O.G. Akanbi on 08023387396, can be contacted for more information regarding my rights as a subject.

CONFIDENTIALITY: Any information about me obtained when participating in this research will be kept as secret and confidential. Also my research records may be subpoenaed by court order or be inspected by federal regulatory authorities. In case of any publication that results from this research, none of my personal identification information will be published without my consent.

VOLUNTARY PARTICIPATION: I am participating in this study voluntarily. My consent can be withdrawn at any time if I wish. I understand that it is not compulsory for me to answer all questions in the questionnaire if I do not wish to do so, which attract no penalty. I had asked question about the research, which had been answered adequately concerning areas which I did not understand before signing this form. I voluntarily participated in this research.

Subject’s Name ………………………. Signature ……………… Time ………

Investigator’s Name ………………... Signature ……………. Time …

APPENDIX C

QUESTIONNAIRE ON HEARING THRESHOLD FOR THE QUARRY WORKERS

UNIVERSITY OF IBADAN

FACULTY OF TECHNOLOGY

INDUSTRIAL & PRODUCTION ENGINEERING DEPARTMENT

Research Questionnaire

Subject Number **___________**

The following questions request you to provide information about yourself. Your responses to these questions will be kept confidential. Your honest response is needed as possible throughout. The information provided is only for research purpose.

1) Age:

2) Gender (Circle one): Male Female

3) Years of experience

4) Job position:

5) Do you operate machine? yes ( ) No ( )

6) If yes type of machine

7) Have you ever sustained any injury which resulted to the hearing problem? Yes / No

a) If "Yes," please describe the injury and estimate the approximate injury period.

8) Please circle any of the following specific illnesses or conditions, either if you presently have, or if you had the illness/condition in the past.

(a) Tuberculosis (b) Ulcer (c) Diabetes (d) Hearing problems (e) Sight problems (f) Hypertension (g) Specify Others. …………………………………………..

APPENDIX D

2018 EXPERIMENT

Table D1: Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

	Factors			Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
1.	52	26	115	36	48	55	58	60	84	73	74
2.	56	33	115	33	48	65	68	70	94	76	72
3.	56	26	115	30	45	48	59	70	90	69	71
4.	50	19	115	27	35	40	42	48	60	55	58
5.	42	21	116.9	30	32	35	39	45	50	45	53
6	55	27	116.9	32	47	50	61	72	89	67	73
7.	63	35	116.9	33	50	55	60	69	89	71	82
8.	49	22	116.9	32	33	35	37	40	60	50	57
9.	51	18	116.9	29	33	35	40	45	60	45	55
10.	52	13	113.5	31	33	34	37	40	64	42	60
11.	47	20	113.5	28	30	34	38	42	53	47	51
12.	35	13	113.5	25	26	29	31	35	36	37	32
13.	58	25	113.5	25	34	40	48	51	60	48	59
14	26	07	96	17	20	22	25	26	27	20	29
15	45	19	96	23	27	30	34	36	50	34	43

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
16	34	14	96	26	31	35	35	37	52	34	37
17	49	21	96	26	27	36	37	40	55	35	40
18	25	03	96	16	21	23	26	27	28	29	30
19	40	19	94.4	25	30	36	40	43	55	39	44
20	30	10	94.4	24	27	29	30	30	31	25	30
21	43	20	94.4	25	30	38	40	45	55	33	44
22	27	06	94.4	17	21	23	26	28	31	24	30
23	39	14	94.4	20	24	27	27	30	53	36	50
24	43	21	94.4	23	26	34	38	40	58	36	39
25	38	19	94.4	22	29	29	35	39	53	38	40
26	32	11	93.1	23	25	34	35	36	50	28	30
27	36	25	93.1	23	28	30	37	40	45	40	44
28	44	24	93.1	28	33	34	36	45	50	39	41
29	41	19	93.1	27	27	30	35	39	58	44	53
30	42	20	93.1	27	29	30	35	38	58	47	59
31	54	23	93.1	34	37	45	50	65	90	70	81
32	48	20	93.1	29	31	35	43	50	66	44	59
33	24	06	93.0	14	19	22	25	29	28	23	26
34	37	14	93.0	23	25	26	30	31	35	29	31

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
35	37	18	93.0	23	25	27	30	31	37	29	33
36	54	29	88.3	29	31	38	41	50	90	71	62
37	45	20	88.3	29	38	40	42	48	62	55	60
38	60	35	97.3	33	36	43	45	53	91	89	71
39	21	03	45	20	22	22	23	23	24	20	21
40	21	04	45	21	24	25	25	25	27	21	23
41	25	07	112.3	21	24	26	27	28	29	26	30
42.	36	13	112.3	21	23	28	32	34	36	28	33
43.	30	08	112.3	22	24	26	27	28	33	25	28
44.	31	13	112.3	22	23	25	27	29	33	31	32
45.	47	25	112.3	30	32	35	40	42	50	38	45
46.	51	26	112.3	26	30	38	42	45	70	63	65
47.	53	30	112.3	27	30	35	39	43	85	56	61
48.	35	13	108.3	22	25	31	38	41	44	37	40
49.	21	03	108.3	18	21	23	26	28	28	24	29
50.	27	06	108.3	21	23	26	28	28	30	24	29
51.	51	24	94.5	32	35	40	45	50	89	50	60
52.	48	23	94.5	26	30	35	41	47	65	41	49
53.	43	19	94.5	29	30	41	43	50	62	42	51

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
54.	41	20	94.5	23	25	30	43	47	61	44	46
55.	24	06	94.5	21	22	23	24	25	27	24	26
56.	35	12	91.1	22	24	25	28	32	35	27	29
57.	29	07	91.1	23	24	25	26	28	29	26	28
58.	30	12	91.1	23	24	27	28	30	31	30	31
59.	34	14	91.1	25	29	30	35	35	39	33	30
60.	28	10	91.1	17	20	22	24	27	28	25	27
61.	52	29	91.1	30	32	40	48	50	77	46	68
62.	34	13	91.5	20	22	25	25	27	30	24	29
63.	20	02	91.5	16	18	22	23	25	27	23	24
64.	34	13	91.5	22	23	23	25	27	29	24	27
65.	50	24	91.5	30	33	40	41	51	65	45	60
66.	47	26	91.5	28	30	39	43	48	75	55	65
67.	52	29	91.5	30	33	35	42	47	81	69	74
68	48	22	91.5	35	37	43	48	55	66	47	59
69	40	20	97.2	23	37	40	50	53	60	51	58
70	45	19	97.2	28	35	43	45	50	65	43	61
71	34	12	97.2	21	24	26	29	30	32	25	30
72	50	28	97.2	29	30	38	49	65	70	63	69

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
73	48	21	87.3	25	30	31	40	50	73	61	69
74	40	14	87.3	22	25	29	30	39	45	42	44
75	29	06	87.3	20	22	27	28	30	31	25	31
76	51	28	87.3	30	35	45	49	69	80	70	72
77	52	33	93.2	32	38	40	50	55	88	63	78
78	33	12	93.2	20	20	26	28	30	32	29	33
79	35	14	93.2	20	23	26	28	30	34	30	32
80	38	13	30.2	21	22	24	25	27	30	25	28
81	41	11	37.8	22	23	24	34	36	40	26	38
82	37	12	44.3	20	21	23	25	27	31	26	29
83	37	15	49.3	20	25	26	28	32	33	25	28
84	34	18	28.4	24	27	28	30	31	35	33	29
85	35	10	38.4	20	21	22	23	25	30	26	28
86	29	10	50.0	20	21	23	25	30	32	28	30
87	34	15	114.3	25	25	27	28	30	32	28	30
88	35	12	114.3	21	23	27	28	30	31	27	30
89	53	21	114.3	32	39	47	51	55	61	37	59
90	32	06	114.3	21	23	25	27	29	30	23	28
91	38	19	114.3	21	25	28	30	31	30	30	34

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
92	51	22	114.3	30	43	53	55	60	65	52	64
93	38	07	114.9	21	22	23	24	26	28	23	28
94	59	23	114.9	29	36	43	54	59	68	43	56
95	18	03	114.9	20	22	24	26	29	30	24	26
96	44	12	114.9	25	28	28	26	28	35	28	33
97	39	14	114.9	27	30	32	36	38	42	39	41
98	41	19	113	20	22	40	43	51	65	43	61
99	36	17	113	20	24	27	27	28	29	24	28
100	34	19	113	22	26	28	30	32	31	26	29
101	44	20	113	27	30	32	33	35	47	27	36
102	39	14	113	27	32	33	36	35	37	29	33
103	41	21	113	26	30	32	35	37	41	35	37
104	51	24	113	28	30	33	39	50	65	43	55
105	27	09	113	20	22	23	27	28	35	27	29
106	36	19	92.8	26	28	30	35	40	44	41	40
107	59	34	92.8	27	31	30	35	44	72	48	63
108	55	34	92.8	31	33	37	47	50	62	49	58
109	31	13	92.8	20	22	24	27	30	31	28	31
110	46	23	92.8	20	25	33	39	50	65	49	60

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
111	47	22	92.8	30	32	39	45	51	60	49	44
112	45	25	92.8	25	29	30	35	42	68	43	58
113	37	15	92.8	20	21	23	24	26	33	25	31
114	47	22	92.8	35	37	41	45	60	65	45	52
115	46	27	92.8	28	31	36	42	50	60	51	54
116	36	18	92.3	30	33	37	39	40	50	38	40
117	58	33	92.3	30	36	40	50	51	65	45	60
118	68	37	92.3	35	42	49	57	59	72	54	69
119	32	13	92.3	21	24	26	29	30	35	25	30
120	29	07	92.3	20	21	23	25	27	30	25	26
121	43	22	92.3	28	34	39	46	53	59	30	48
122	46	22	92.3	30	35	39	43	54	58	35	47
123	36	12	92.3	25	25	27	35	37	39	20	29
124	34	11	92.3	20	22	24	25	28	35	22	27
125	39	10	92.3	23	25	27	30	32	37	24	30
126	42	13	92.3	25	28	31	33	35	37	30	33
127	49	20	92.8	31	36	40	49	55	64	41	55
128	55	12	92.3	26	38	47	50	58	67	30	59
129	44	25	92.8	34	35	40	49	50	64	42	47

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
130	49	20	92.8	33	36	40	48	52	70	45	58
131	45	20	92.8	30	35	38	43	50	60	34	41
132	44	19	92.8	29	33	40	48	51	63	40	52
133	47	16	92.8	30	34	40	51	53	68	40	53
134	37	17	92.8	23	27	33	41	50	60	32	43
135	41	22	92.8	26	30	40	43	50	66	28	49
136	38	17	97.0	20	22	23	30	33	45	28	39
137	35	15	97.0	25	27	29	31	33	45	33	42
138	39	10	97.0	23	25	27	30	32	37	24	30
139	52	29	97.0	29	31	35	41	52	72	54	69
140	51	33	97.0	30	33	37	40	50	75	49	70
141	39	16	97.0	28	32	34	41	45	65	49	61
142	40	15	59.0	26	28	30	35	40	52	35	43
143	48	24	60.4	27	31	35	41	49	66	41	51
144	50	29	40.6	26	31	34	40	48	67	30	53
145	35	13	114.5	23	24	24	25	29	31	21	22
146	51	31	114.5	24	30	38	47	52	63	39	55
147	49	20	114.5	27	31	35	40	49	61	43	45
148	39	10	114.5	24	25	27	30	35	37	24	34

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
149	40	17	112.2	23	29	36	40	49	57	31	52
150	52	27	112.2	27	30	39	42	**50**	87	47	62
151	53	32	112.2	29	32	39	44	56	73	52	69
152	34	13	112.2	22	23	25	26	28	30	28	27
153	30	14	112.2	20	22	23	25	30	35	28	28
154	39	18	101.7	25	27	30	33	35	45	31	38
155	42	20	101..7	27	32	35	39	43	70	33	45
156	38	16	101.7	20	25	27	30	32	45	28	30
157	48	16	101.7	28	32	39	44	51	63	43	52
158	29	10	101.7	23	25	27	30	32	37	29	30
159	46	21	96.5	27	30	33	39	42	56	35	53
160	30	11	96.5	19	22	25	29	30	32	27	29
161	51	31	96.5	30	38	45	51	59	69	40	59
162	35	13	96.5	20	23	25	27	30	38	30	25
163	29	07	96.5	20	23	23	26	27	29	24	27
164	41	17	96.5	25	28	30	39	43	71	39	. 62
165	55	33	96.5	30	39	44	50	57	82	59	73
166	56	36	98.1	31	36	43	50	56	72	40	58
167	20	01	98.1	19	22	24	27	28	30	25	23

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
168	43	22	98.1	24	29	33	42	51	56	34	43
169	35	18	98.1	20	22	23	25	26	30	24	27
170	49	21	98.1	21	24	27	30	35	57	43	47
171	45	20	98.1	23	25	34	39	44	59	30	41
172	39	08	92.3	23	25	27	30	32	37	24	30
173	33	12	93.3	22	24	26	27	28	30	23	28
174	49	23	93.3	29	38	37	41	53	78	38	50
175	60	37	93.3	30	35	41	46	50	74	47	65
176	50	26	93.3	26	32	37	42	51	64	37	56
177	39	10	93.3	23	25	27	30	32	37	24	30
178	38	19	90.2	23	25	29	30	32	34	28	30
179	43	22	90.2	25	28	36	42	49	61	38	59
180	39	11	88.2	21	23	26	28	29	30	25	29
181	36	15	88.2	20	23	26	28	30	36	27	28
182	46	19	88.2	24	29	35	39	43	61	37	50
183	30	11	88.2	22	25	28	30	31	32	26	29
184	40	19	95.4	26	31	35	40	45	55	31	35
185	50	22	95.4	25	31	35	40	47	68	37	59
186	54	31	95.4	35	44	49	52	55	79	44	59

Table D1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2018

		Factors		Hearing threshold							
NO	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
187	49	22	58.4	25	30	32	35	40	50	29	39
188	34	13	49.5	18	24	26	27	28	34	29	27
189	39	10	92.3	23	25	27	30	32	37	24	30
190	26	05	80.0	18	22	23	27	29	30	24	25
191	36	14	55.0	21	24	25	26	28	30	28	29
192	58	29	90	28	32	36	40	45	64	47	58
193	35	17	56.0	20	21	24	25	28	32	27	27
194	59	20	93.3	32	37	42	49	57	75	39	64
195	61	35	93.3	34	41	45	50	58	79	46	69
196	53	26	93.3	30	39	41	49	52	67	43	62
197	44	15	90.2	28	33	39	47	54	65	56	55
198	45	20	90.2	27	33	34	37	45	65	46	55
199	46	21	90.2	26	29	30	32	48	64	46	60
200	37	10	88.2	21	22	27	27	27	35	24	30
201	35	15	88.2	22	25	27	29	29	34	23	32
202	28	08	88.2	21	23	25	27	27	29	20	26
203	32	09	88.2	23	24	26	27	28	30	21	22
204	43	16	88.2	27	29	33	38	40	48	34	39

AG = Age (years); YE = Years of exposure (years); NL = Noise level (dB)

DAILY EQUIVALENT NOISE LEVEL OF MACHINE AT THE QUARRIES

Table D2: Noise level of machine at the quarry 1 [Q1]

Day 1	**9am-10am**	**10am-11am**	**11am-12noon**	**12noon-1pm**	**1pm-2pm**	**2pm-3pm**	**3pm-4pm**	**4pm-5pm**
				Noise Level (dBA)				
Generator	96	96	96	96	96	96	96	96
Primary Crusher	115	115	116	117	117	117	117	117
Secondary Crusher	118	118	117	116	117	117	118	118
Dumper	96	96	96	96	96	96	96	96
Compressor	112	112	114	114	114			
Wagon Drilling	95	95	95	94	94			
Pay loader	93	94	95	95	95	95	95	95
Drilling Machine	89.4	89.4	89.5	89.5	89.6	89.2	89.4	89.4
Lathe Machine	87.6	87.4	87.5	87.4	87.5	87.6	87.4	87.4
Excavator	97.1	97.1	97.1	97.5	97.5	97.5	97.6	97.5
Leq	120.5	120.5	120.6	120.7	121.0	120.1	120.1	120.1
Day 2								
Generator	95	95	95	95	95	95	95	95
Primary Crusher	115	115	116	116	117	117	116	117
Secondary Crusher	118	118	117	117	116	117	117	118
Compressor	112	112	113	114	114	114	114	114
Wagon Drilling	95	95	95	94	94	95	95	95
Pay loader	92	93	93	93	94	95	95	95
Drilling Machine	97.0	97.0	97.0	97.3	97.3	97.2	97.2	97.2
Lathe Machine	88.1	88.0	88.1	88.5	88.5	88.5	88.6	88.5

Excavator Machine	97.0	97.0	97.1	97.2	97.2	97.5	97.4	97.5
Leq	120.5	120.5	120.5	120.6	120.7	121.0	121.0	121.5

Table D2 (Continued): Noise level of machine at the quarry 1 [Q1]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 3	**Noise Level (dBA)**							
Generator	94	94	94	95	95	95	95	95
Primary Crusher	114	114	115	115	115	115	115	115
Secondary Crusher	117	117	117	117	117	118	118	118
Dumper	96	96	96	96	96	96	96	96
Compressor	113	113	114	114	114	114	114	114
Wagon Drilling	94	94	94	94	94	94	94	94
Pay loader	92	93	93	93	94	95	95	95
Drilling Machine	96.9	96.9	96.9	97.0	97.0	97.0	97.1	97.2
Lathe Machine	87.5	87.5	87.5	87.6	87.6	87.7	87.7	87.7
Excavator	97.1	97.1	97.1	97.5	97.5	97.5	97.6	97.6
Leq	119.8	119.8	120.3	120.3	120.3	120.8	120.8	120.8
Day 4								
Generator	92	93	93	93	94	94	94	94
Primary Crusher	114	114	113	114	115	115	115	115
Secondary Crusher	116	116	117	116	117	117	117	117
Dumper	94	95	95	95	94	95	95	95

Compressor	113	113	114	114	114	114		
Wagon Drilling	95	95	95	95	95	95		
Pay loader	91	91	91	92	93	93	94	94
Drilling Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Lathe Machine	87.5	87.6	87.6	87.7	87.7	87.7	87.7	87.7
Excavator	97.2	97.3	97.3	97.3	97.5	97.5	97.5	97.5
Leq	119.3	119.3	119.8	119.6	120.3	120.3	119.2	119.2

Table D2 (Continued): Noise level of machine at the quarry 1 [Q1]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 5				**Noise Level (dBA)**				
Generator	91	92	93	93	93	93	93	93
Primary Crusher	113	111	112	113	114	114	114	114
Secondary Crusher	115	115	115	116	116	117	117	117
Dumper	95	95	95	95	95	95	95	95
Compressor	114	113	114	113			114	114
Wagon Drilling	94	93	94	94			94	94
Pay loader	90	90	89	91	91	91		93
Drilling Machine	97.0	97.0	97.0	97.1	97.2	97.2	97.2	97.2
Lathe Machine	87.1	87.1	87.2	87.2	87.3	87.3	87.3	87.3
Excavator	97.2	97.2	97.3	97.3	97.3	97.3	97.3	97.3
Leq	118.9	118.1	118.7	119.1	118.2	118.2	118.2	120.1

Table D3: Noise level of machine at the quarry 2 [Q2]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 1				**Noise Level (dBA)**				
Generator	95	95	96	96	99	98	99	93
Primary Crusher	108	108	111	111	112	113	113	113
Secondary Crusher	105	105	106	107	107	108	108	108
Dumper	94	94	94	95	95	96	95	96
Compressor	108	109	108		108		109	108
Wagon Drilling	90	90	93		92		93	93
Pay loader	89	89	91	93	93	93	93	93
Drilling Machine	97.1	97.1	97.1	97.3	97.3	97.3	97.3	97.3
Lathe Machine	86.5	86.5	87.1	87.4	87.4	87.5	87.5	87.5
Excavator	96.5	96.5	97.1	97.2	97.2	97.2	97.2	97.2
Leq	112.2	112.2	113.8	112.7	114.6	114.4	115.5	115.3
Day 2								
Generator	96	96	97	97	97	98	99	99
Primary Crusher	108	107	109	109	111	110	112	112
Secondary Crusher	106	106	107	108	108	109	109	109
Dumper	94	94	94	95	95	95	95	95
Compressor	108	108	108	108	108	108	109	109
Wagon Drilling	90	89	91	92	92	93	93	94

Pay loader	89	89	91	93	92	93	93	93
Drilling Machine	96.0	96.2	96.5	97.0	97.0	97.0	97.0	97.0
Lathe Machine	87.4	87.4	87.5	87.5	87.5	87.5	87.5	87.5
Excavator Machine	96.8	96.7	96.8	97.1	97.1	97.1	97.1	97.1
Leq	112.4	112.2	113.8	112.7	114.6	114.4	115.5	115.3

Table D3 (Continued): Noise level of machine at the quarry 2 [Q2]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 3				**Noise Level (dBA)**				
Generator	98	98	98	97	97	97	98	98
Primary Crusher	112	112	112	112	113	113	113	113
Secondary Crusher	107	108	108	109	110	110	111	111
Dumper	94	94	93	94	93	95	96	95
Compressor	108	108		108	109		108	109
Wagon Drilling	90	91		90	91		92	93
Pay loader	90	90	90	93	93	92	93	92
Drilling Machine	97.0	97.2	97.2	97.2	97.2	97.2	97.2	97.2
Lathe Machine	87.0	87.2	87.2	87.2	87.2	87.2	87.2	87.2
Excavator Machine	95.9	95.9	95.9	95.9	95.9	96.0	96.0	96.0
Leq	114.5	114.7	113.6	114.9	115.9	114.9	116.0	116.2
Day 4								
Generator	98	98	98	97	97	97	98	98
Primary Crusher	113	113	114	115	115	115	115	115
Secondary Crusher	109	108	108	110	109	110	110	110
Dumper	93	93	93	94	95	95	95	95
Compressor	107	108	108	108	109	109		
Wagon Drilling	90	90	89	90	91	92		

Pay loader	91	90	90	90	92	93	93	92
Drilling Machine	89.4	89.4	89.5	90.0	90.0	90.0	90.0	90.0
Lathe Machine	87.0	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Excavator Machine	97.0	97.1	97.1	97.1	97.1	97.1	97.1	97.1
Leq	115.3	115.2	115.9	116.9	116.9	117.1	116.3	116.3

Table D3 (Continued): Noise level of machine at the quarry 2 [Q2]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 5	**Noise Level (dBA)**							
Generator	97	96	97	97	96	97	97	96
Primary Crusher	112	113	113	114	114	115	115	114
Secondary Crusher	109	108	108	110	111	112	113	113
Dumper	94	94	95	94	94	95	95	95
Compressor	108	108	108	109	109	109	109	109
Wagon Drilling	90	91	89	91	90	91	91	91
Pay loader	89	88	90	92	92	92	92	92
Drilling Machine	96.8	97.1	97.0	97.0	97.1	97.1	97.0	97.0
Lathe Machine	87.0	87.1	87.0	87.0	87.0	87.0	87.0	87.0
Excavator	94.5	94.5	94.5	95.0	95.0	95.2	95.4	95.6
Leq	114.9	115.2	115.3	116.4	116.7	117.5	117.8	117.3

Table D4: Noise level of machine at the quarry 3 [Q3]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 1				**Noise Level (dBA)**				
Generator	91	91	92	93	93	93	92	93
Primary Crusher	112	112	111	112	112	114	114	114
Secondary Crusher	114	115	114	115	114	115	115	115
Dumper	93	93	93	95	95	95	94	95
Compressor	112	113	112	113	112	113	113	113
Wagon Drilling	93	93	92	93	93	93	93	93
Pay loader	89	91	91	92	92	92	92	93
Drilling Machine	97.8	97.8	97.8	98.0	98.0	98.0	98.0	98.0
Lathe Machine	89.0	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Excavator	98.0	98.0	98.0	98.0	98.0	98.0	98.0	98.0
Leq	117.6	118.3	117.3	118.3	117.6	118.9	118.9	118.9
Day 2								
Generator	90	91	91	92	93	92	93	93
Primary Crusher	111	111	111	111	113	113	114	114
Secondary Crusher	115	115	115	115	115	115	115	115
Dumper	92	92	93	94	95	95	95	95
Compressor	112	112	112	113	113	113	114	113
Wagon Drilling	92	92	92	92	93	93	93	93

Pay loader	90	92	93	93	93	93	93	93
Drilling Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Lathe Machine	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0
Excavator Machine	97.3	97.3	97.3	97.5	97.5	97.5	97.5	97.5
Leq	117.8	117.8	117.8	118.1	118.6	118.6	119.2	119.2

Table D4 (Continued): Noise level of machine at the quarry 3 [Q3]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 3				**Noise Level (dBA)**				
Generator	96	96	97	97	97	98	99	99
Primary Crusher	114	114	115	115	115	115	115	115
Secondary Crusher	116	116	116	114	114	115	115	115
Dumper	93	93	93	95	95	95	95	95
Compressor	113	113	113	114	114	114	114	114
Wagon Drilling	92	92	92	92	92	93	93	93
Pay loader	90	93	94	94	95	95	95	95
Drilling Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Lathe Machine	88.0	88.0	88.2	88.2	88.5	88.5	88.5	88.5
Excavator Machine	97.1	97.1	97.1	97.1	97.1	97.1	97.1	97.1
Leq	119.3	119.3	119.6	119.2	119.2	119.5	119.5	119.5
Day 4								
Generator	92	92	92	94	95	95	96	96
Primary Crusher	114	114	115	116	116	116	116	116
Secondary Crusher	115	115	115	115	115	115	115	115
Dumper	92	92	93	93	94	93	93	93
Compressor	112	112	112	113	114	113	113	114
Wagon Drilling	90	92	93	92	93	93	93	93

Pay loader	90	90	90	94	95	95	95	95
Drilling Machine	97.0	97.1	97.1	97.1	97.1	97.1	97.1	97.1
Lathe Machine	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Excavator Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Leq	118.6	118.6	119.0	119.6	119.9	119.7	119.7	119.7

Table D4 (Continued): Noise level of machine at the quarry 3 [Q3]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 5				**Noise Level (dBA)**				
Generator	90	93	95	95	96	96	97	98
Primary Crusher	116	116	116	117	117	117	117	117
Secondary Crusher	115	114	115	115	115	115	115	115
Dumper	94	94	94	94	95	95	95	94
Compressor	110	112	113	112	114	114	115	115
Wagon Drilling	90	92	93	92	90	91	92	91
Pay loader	90	90	94	94	94	94	95	95
Drilling Machine	97.0	97.0	97.0	97.0	97.1	97.1	97.1	97.1
Lathe Machine	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Excavator	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Leq	119.1	119.1	119.7	119.9	120.3	120.3	120.6	120.6

Table D5: Noise level of machine at the quarry 4 [Q4]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 1	**Noise Level (dBA)**							
Generator	97	99	100	102	101	102	103	103
Primary Crusher	113	114	114	115	115	115	116	115
Secondary Crusher	110	112	112	113	114	113	112	113
Dumper	97	97	97	97	97	97	97	97
Compressor	100	100	102	102	103	103	102	102
Wagon Drilling	88	89	99	98	99	100	100	101
Pay loader	90	92	92	93	94	94	96	99
Drilling Machine	90.1	90.2	90.2	90.2	90.2	90.2	90.2	90.2
Lathe Machine	87.4	87.4	87.4	87.4	87.4	87.4	87.4	87.4
Excavator	95.0	95.2	95.2	95.2	95.2	95.2	95.2	95.2
Leq	115.1	116.4	116.5	117.5	117.9	117.6	17.9	117.6
Day 2								
Generator	98	100	100	101	103	103	102	103
Primary Crusher	114	115	114	116	115	116	114	115
Secondary Crusher	110	112	112	113	112	113	112	113
Dumper	96	96	97	97	96	96	97	97
Compressor	99	100	102	102	103	102	102	102
Wagon Drilling	87	99	98	99	100	99	100	99

Pay loader	89	90	94	96	98	94	96	99
Drilling Machine	90.2	90.2	90.2	90.2	90.2	90.2	90.2	90.2
Lathe Machine	87.5	87.5	87.5	87.5	87.5	87.6	87.6	87.6
Excavator Machine	95.0	95.2	95.2	95.2	95.2	95.2	95.2	95.2
Leq	115.7	117.7	116.5	118.1	117.3	118.1	116.6	117.6

Table D5 (Continued): Noise level of machine at the quarry 4 [Q4]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 3				Noise Level (dBA)				
Generator	98	100	100	101	102	102	101	101
Primary Crusher	113	113	113	114	115	116	113	113
Secondary Crusher	111	111	111	111	112	113	114	114
Dumper	95	96	96	96	96	96	96	97
Compressor	101	101	101	101	102	102	101	102
Wagon Drilling	88	98	98	99	100	102	102	102
Pay loader	90	92	92	92	93	93	94	94
Drilling Machine	90.2	90.2	90.2	90.2	90.2	90.2	90.2	90.2
Lathe Machine	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Excavator Machine	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Leq	115.4	115.6	115.6	116.2	117.2	118.1	117.0	117.0
Day 4								
Generator	98	100	101	102	104	104	103	102
Primary Crusher	112	112	114	115	115	114	115	114
Secondary Crusher	110	110	112	113	114	115	112	113
Dumper	96	96	96	96	97	96	97	96
Compressor	100	99	101	101	103	103	103	103
Wagon Drilling	87	98	98	98	100	102	101	102

Pay loader	90	91	89	94	90	88	94	94
Drilling Machine	89.2	89.2	90.1	90.2	90.2	90.2	90.2	90.2
Lathe Machine	88.0	88.0	88.1	88.1	88.1	88.1	88.1	88.2
Excavator Machine	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Leq	114.5	114.6	116.5	117.5	118.0	118.0	117.3	117.1

Table D5 (Continued): Noise level of machine at the quarry 4 [Q4]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 5	**Noise Level (dBA)**							
Generator	99	100	101	101	104	104	103	103
Primary Crusher	114	115	116	115	116	116	114	115
Secondary Crusher	111	111	112	112	113	113	112	112
Dumper	97	97	97	97	97	96	96	96
Compressor	99	100	102	103	103	103	103	103
Wagon Drilling	88	99	99	100	102	101	104	99
Pay loader	89	91	94	96	97	94	96	99
Drilling Machine	89	89	89	90	90	90	90	90
Lathe Machine	88.5	88.5	88.5	88.5	88.5	88.5	86.0	86.0
Excavator	97.1	97.1	97.1	97.1	97.5	97.5	97.5	97.5
Leq	116.0	116.8	117.8	117.2	118.3	118.2	116.8	117.3

SUMMARY OF THE AVERAGE NOISE LEVEL IN THE QUARRIES

Table D6: Summary of the Average Noise Level in Q1

Days	**L_{eq} (dB)**
1	120.3
2	120.8
3	120.4
4	119.6
5	118.9
Average L_{eq}	120.0

Table D7: Summary of the Average Noise Level in Q2

Days	**L_{eq} (dB)**
1	113.8
2	113.7
3	115.1
4	116.2
5	116.4
Average L_{eq}	115.0

Table D8: Summary of the Average Noise Level in Q3

Days	**L_{eq} (dB)**
1	118.2
2	118.4
3	119.4
4	119.4
5	120.0
Average L_{eq}	119.1

Table D9: Summary of the Average Noise Level in Q4

Days	**L_{eq} (dB)**
1	117.1
2	117.2
3	116.5
4	116.7
5	117.3
Average L_{eq}	117.0

APPENDIX E

2019 EXPERIMENT

Table E1: Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2019.

	FACTORS			HEARING THRESHOLD (dB)							
No	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
1.	53	27	115	38	49	57	60	64	86	75	77
2.	57	34	115	36	51	69	70	71	95	79	77
3.	57	27	115	35	49	50	64	77	94	75	79
4.	51	20	115	29	42	43	44	50	68	51	65
5.	43	22	116.6	34	36	37	41	50	57	47	60
***6.**											
7.	64	36	116.9	36	57	60	69	74	95	71	82
8.	50	23	116.6	30	34	35	38	47	69	53	67
9.	52	19	116.9	31	38	39	45	48	65	50	60
10.	53	14	113.5	33	35	35	38	42	68	46	65
11.	48	21	113.5	31	32	39	43	44	55	57	62
12.	36	14	113.5	26	26	29	31	37	38	39	42
13.	59	26	113.5	29	36	43	53	61	69	50	64
14	27	08	96	19	21	22	25	27	28	25	30
15	46	20	96	25	30	34	35	36	57	39	45
16	35	16	96	26	31	35	35	38	54	36	39
17	50	23	96	28	27	36	39	42	59	40	43
***18**											
19	41	21	94.4	27	31	39	44	46	60	44	48
20	31	12	94.4	24	27	29	30	31	32	27	34
***21**											
22	28	07	94.4	17	21	23	29	31	32	26	31
23	40	15	94.4	23	25	29	29	33	59	36	38
24	44	22	94.4	26	29	39	42	44	60	37	41
25	39	20	94.4	24	31	33	37	44	54	40	43
26	33	12	93.1	25	28	34	35	37	56	31	35

Table E1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2019.

	FACTORS			HEARING THRESHOLD (dB)							
No	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
27	37	26	93.1	25	31	36	37	45	57	61	56
28	45	25	93.1	28	33	34	38	51	53	40	45
29	42	20	93.1	29	29	35	39	42	63	47	64
***30**											
31	55	24	93.1	37	39	48	53	67	96	77	86
32	49	21	93.1	33	34	37	43	57	70	49	64
33	25	07	93.0	19	22	25	27	29	29	26	30
34	38	15	93.0	23	25	26	31	33	37	32	33
***35**											
36	55	30	88.3	32	38	42	48	59	98	79	67
37	46	20	88.3	33	41	42	46	53	69	59	65
38	61	36	97.3	36	39	45	47	55	94	84	77
39	22	04	45	25	22	22	23	23	25	22	23
***40**											
41	26	08	112.3	24	25	26	27	29	30	28	31
42.	37	14	112.3	21	23	28	32	36	39	36	36
43.	31	09	112.3	23	25	26	27	28	39	28	31
44.	32	14	112.3	24	25	29	29	30	35	33	32
45.	48	26	112.3	35	36	40	45	49	68	68	40
46.	52	27	112.3	28	34	43	49	59	77	72	66
47.	54	31	112.3	28	33	44	47	53	95	61	64
48.	36	14	108.3	22	26	34	43	45	46	41	42
49.	22	04	108.3	18	21	23	26	28	30	24	29
***50.**											
51.	52	25	94.5	34	38	43	48	58	92	58	64
52.	49	24	94.5	28	36	40	47	51	70	45	51
53.	44	20	94.5	34	33	57	47	59	67	48	53
54.	42	21	94.5	28	29	35	47	51	71	54	49
55.	25	07	94.5	21	22	23	24	27	29	26	29

Table E1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2019.

	FACTORS			HEARING THRESHOLD (dB)							
No	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
56.	36	13	91.1	24	26	27	31	36	54	39	30
57.	30	08	91.1	23	24	25	26	28	29	26	28
58.	31	13	91.1	23	24	27	29	31	31	30	31
59.	35	15	91.1	29	32	34	39	37	41	35	31
60.	29	11	91.1	20	23	25	26	28	29	27	28
61.	53	30	91.1	32	34	44	50	54	80	51	73
62.	35	14	91.5	23	24	26	26	28	31	28	31
63.	21	03	91.5	18	20	22	23	26	29	25	27
64.	35	14	91.5	22	23	23	27	29	31	28	32
65.	51	25	91.5	36	37	44	45	57	70	49	64
66.	48	27	91.5	30	32	40	45	53	79	59	75
67.	53	30	91.5	34	37	39	50	57	88	71	76
68	49	23	91.5	36	37	43	51	59	68	57	61
69	41	21	97.2	24	41	45	52	57	67	56	60
70	46	20	97.2	30	38	41	48	59	71	48	66
71	35	13	97.2	23	25	28	30	31	33	27	31
72	51	29	97.2	31	37	43	56	70	75	65	72
73	49	22	87.3	28	33	38	45	57	79	65	73
74	41	15	87.3	27	30	34	37	43	58	52	56
75	30	07	87.3	24	26	27	28	35	36	28	33
76	52	29	87.3	37	41	45	51	70	90	77	82
77	53	34	93.2	38	44	49	55	60	98	67	83
78	34	13	93.2	22	24	26	29	30	33	31	34
79	36	15	93.2	21	25	29	30	31	36	34	35
80	39	14	30.2	22	23	26	28	29	31	27	30
81	42	12	37.8	24	23	24	36	37	42	28	40
82	38	13	44.3	22	23	25	27	28	32	28	31
83	38	16	49.3	23	25	26	28	34	35	27	31

Table E1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2019.

	FACTORS			HEARING THRESHOLD (dB)							
No	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
84	35	19	28.4	24	27	29	32	33	38	33	32
85	36	11	38.4	22	23	24	26	29	32	28	30
86	30	11	50.0	24	23	27	29	34	36	32	33
87	35	16	114.3	27	27	28	29	33	34	30	32
88	36	13	114.3	24	26	27	28	32	33	30	33
***89**											
90	33	07	114.3	23	24	25	27	29	31	27	30
91	39	20	114.3	22	25	32	32	33	37	30	34
92	52	23	114.3	39	45	49	57	63	87	62	84
93	39	08	114.9	22	23	25	26	27	28	25	29
***94**											
95	19	04	114.9	20	22	24	26	30	33	29	31
96	45	13	114.9	26	29	29	27	29	34	30	35
97	40	15	114.9	27	33	35	38	40	46	44	49
98	42	20	113	24	27	46	48	60	71	48	66
99	37	18	113	20	24	27	27	31	30	29	32
***100**											
101	45	21	113	29	33	35	35	36	40	32	38
102	40	15	113	28	32	33	36	37	40	39	43
103	42	22	113	29	33	35	37	38	42	38	40
104	52	25	113	30	32	36	43	55	68	46	59
105	28	10	113	20	22	25	28	29	37	33	34
106	37	20	92.8	28	32	38	43	43	48	45	43
107	60	35	92.8	29	33	34	41	48	81	58	73
108	56	35	92.8	34	37	43	51	53	72	58	68
109	32	14	92.8	22	24	26	28	30	33	30	32
110	47	24	92.8	22	30	36	45	59	73	56	70
111	48	23	92.8	31	37	42	50	57	69	58	64

Table E1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2019.

	FACTORS			HEARING THRESHOLD (dB)							
No	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
112	46	26	92.8	30	34	40	45	52	70	50	68
113	38	16	92.8	21	21	23	24	26	37	28	34
114	48	23	92.8	38	40	47	53	67	72	50	62
115	47	28	92.8	32	36	39	48	57	67	60	64
116	37	19	92.3	31	33	37	40	46	54	42	49
117	59	34	92.3	36	41	46	53	59	69	51	70
***118**											
119	33	14	92.3	24	27	28	29	30	39	28	32
120	30	08	92.3	22	24	25	27	28	32	28	29
121	44	23	92.3	29	36	41	48	58	61	43	58
122	47	23	92.3	32	41	42	47	55	60	43	55
123	37	13	92.3	25	25	27	35	38	41	29	33
124	35	12	92.3	24	25	25	27	31	37	24	29
125	40	11	92.3	23	25	27	33	33	39	27	37
***126**											
127	50	21	92.8	34	38	44	51	57	69	50	60
***128**											
129	45	26	92.8	36	40	44	59	60	73	46	57
130	50	21	92.8	35	39	49	54	62	73	50	60
131	46	21	92.8	33	39	41	51	57	63	44	48
132	45	20	92.8	34	35	45	50	58	66	49	55
133	48	17	92.8	35	40	43	54	59	72	45	56
134	38	18	92.8	24	29	37	46	55	65	35	47
135	42	23	92.8	29	35	42	49	59	67	40	51
136	39	18	97.0	24	26	29	32	37	47	33	44
137	36	16	97.0	28	29	30	34	36	48	39	45
***138**											
139	53	30	88.0	33	36	40	48	57	82	64	80
140	52	34	97.0	34	37	40	47	55	85	61	80

Table E1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the yearr 2019.

	FACTORS			HEARING THRESHOLD (dB)							
No	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
141	40	17	97.0	30	34	36	44	53	71	57	78
142	41	16	59.0	28	30	34	40	46	58	45	53
143	49	25	60.4	29	33	40	47	57	70	51	64
144	51	30	40.6	29	33	39	48	53	76	40	73
145	36	14	114.5	24	27	29	30	31	41	28	39
146	52	32	114.5	27	39	48	50	56	73	47	71
147	50	21	114.5	28	34	39	43	59	71	53	61
***148**											
149	41	18	112.2	23	29	36	45	54	69	41	55
150	53	28	112.2	30	40	47	52	**60**	93	57	72
151	54	33	112.2	34	42	49	52	64	85	61	69
152	35	14	112.2	22	23	25	26	29	34	32	37
153	31	15	112.2	22	24	24	26	34	40	36	35
154	40	19	101.7	26	30	33	36	40	53	41	47
155	43	21	101..7	29	37	45	49	49	78	40	54
156	39	17	101.7	25	27	29	31	33	40	35	37
157	49	17	101.7	35	39	43	48	59	72	51	61
***158**											
159	47	22	96.5	33	38	42	46	56	63	44	69
160	31	12	96.5	22	24	27	30	32	40	34	33
161	52	32	96.5	35	40	47	53	62	79	47	73
162	36	14	96.5	21	23	25	27	30	40	34	35
163	30	08	96.5	20	23	23	26	27	30	28	29
164	42	18	96.5	29	30	37	46	54	77	50	. 70
165	56	34	96.5	35	48	53	54	68	99	68	84
166	57	37	98.1	39	47	52	57	58	80	50	72
167	21	02	98.1	23	25	26	28	29	30	27	29
168	44	23	98.1	27	35	40	44	55	67	43	52
169	36	19	98.1	24	24	25	26	28	35	27	30

Table E1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers in the year 2019.

FACTORS				HEARING THRESHOLD (dB)							
No	**AG**	**YE**	**NL**	**250Hz**	**500Hz**	**1kHz**	**2kHz**	**3kHz**	**4kHz**	**6kHz**	**8kHz**
170	50	22	98.1	21	24	27	30	39	64	53	57
171	46	21	98.1	25	26	38	40	50	66	37	50
***172**											
173	34	13	93.3	22	24	26	27	28	37	25	33
174	50	24	93.3	36	40	42	49	61	89	49	60
175	61	38	93.3	33	40	44	50	59	80	59	75
176	51	27	93.3	31	39	41	48	63	69	48	67
***177**											
178	39	20	90.2	25	27	29	30	32	39	32	35
179	44	23	90.2	27	32	40	48	59	70	50	62
180	40	12	88.2	23	25	27	28	29	33	28	33
181	37	16	88.2	23	25	27	29	33	39	30	36
182	47	20	88.2	28	32	38	40	45	72	49	68
183	31	12	88.2	24	27	28	30	31	33	28	31
184	41	20	95.4	29	34	36	44	57	63	36	42

AG = Age (years)

YE = Years of exposure (years)

NL = Noise level (dB)

Subject Numbers 6, 18, 21, 30, 35, 40, 50, 89, 94, 100, 118, 126, 128, 138, 148, 158, 172, 177 and 189 that partake during 2018 Experiment, were not available during 2019 experiment..

DAILY EQUIVALENT NOISE LEVEL OF MACHINE AT THE QUARRIES

Table E2: Noise level of machine at the quarry 1 [Q1]

	9am- 10am	10am- 11am	11am-12noon	12noon- 1pm	1pm- 2pm	2pm- 3pm	3pm- 4pm	4pm- 5pm
Day 1	**Noise Level (dBA)**							
Generator	96	96	96	96	96	96	96	96
Primary Crusher	115	115	116	117	117	117	117	117
Secondary Crusher	118	118	117	116	117	117	118	118
Dumper	96	96	96	96	96	96	96	96
Compressor	112	112	114	114	114			
Wagon Drilling	95	95	95	94	94			
Pay loader	93	94	95	95	95	95	95	95
Drilling Machine	89.4	89.4	89.5	89.5	89.6	89.2	89.4	89.4
Lathe Machine	87.6	87.4	87.5	87.4	87.5	87.6	87.4	87.4
Excavator	97.1	97.1	97.1	97.5	97.5	97.5	97.6	97.5
Leq	120.5	120.5	120.6	120.7	121.0	120.1	120.1	120.1

Table E2 (Continued): Noise level of machine at the quarry 1 [Q1]

	9am- 10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 2	**Noise Level (dBA)**							
Generator	95	95	95	95	95	95	95	95
Primary Crusher	115	115	116	116	117	117	116	117
Secondary Crusher	118	118	117	117	116	117	117	118
Dumper	96	96	96	96	96	96	96	96
Compressor	112	112	113	114	114	114	114	114
Wagon Drilling	95	95	95	94	94	95	95	95
Pay loader	92	93	93	93	94	95	95	95
Drilling Machine	97.0	97.0	97.0	97.3	97.3	97.2	97.2	97.2
Lathe Machine	88.1	88.0	88.1	88.5	88.5	88.5	88.6	88.5
Excavator Machine	97.0	97.0	97.1	97.2	97.2	97.5	97.4	97.5
Leq	120.5	120.5	120.5	120.6	120.7	121.0	121.0	121.5

Day 3								
Generator	94	94	94	95	95	95	95	95
Primary Crusher	114	114	115	115	115	115	115	115
Secondary Crusher	117	117	117	117	117	118	118	118
Dumper	96	96	96	96	96	96	96	96
Compressor	113	113	114	114	114	114	114	114
Wagon Drilling	94	94	94	94	94	94	94	94
Pay loader	92	93	93	93	94	95	95	95
Drilling Machine	96.9	96.9	96.9	97.0	97.0	97.0	97.1	97.2
Lathe Machine	87.5	87.5	87.5	87.6	87.6	87.7	87.7	87.7
Excavator	97.1	97.1	97.1	97.5	97.5	97.5	97.6	97.6
Leq	119.8	119.8	120.3	120.3	120.3	120.8	120.8	120.8

Table E2 (Continued): Noise level of machine at the quarry 1 [Q1]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 4	**Noise Level (dBA)**							
Generator	92	93	93	93	94	94	94	94
Primary Crusher	114	114	113	114	115	115	115	115
Secondary Crusher	116	116	117	116	117	117	117	117
Dumper	94	95	95	95	94	95	95	95
Compressor	113	113	114	114	114	114		
Wagon Drilling	95	95	95	95	95	95		
Pay loader	91	91	91	92	93	93	94	94
Drilling Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Lathe Machine	87.5	87.6	87.6	87.7	87.7	87.7	87.7	87.7
Excavator	97.2	97.3	97.3	97.3	97.5	97.5	97.5	97.5
Leq	119.3	119.3	119.8	119.6	120.3	120.3	119.2	119.2

Day 5

Generator	90	91	92	93	93	93	93	93
Primary Crusher	113	111	112	113	114	114	114	114
Secondary Crusher	115	115	115	116	116	117	117	117
Dumper	95	95	95	95	95	95	95	95
Compressor	114	113	114	113			114	114
Wagon Drilling	94	93	94	94			94	94
Pay loader	90	90	89	91	91	91		93
Drilling Machine	97.0	97.0	97.0	97.1	97.2	97.2	97.2	97.2
Lathe Machine	87.1	87.1	87.2	87.2	87.3	87.3	87.3	87.3
Excavator	97.2	97.2	97.3	97.3	97.3	97.3	97.3	97.3
Leq	118.9	118.1	118.7	119.1	118.2	118.2	118.2	120.1

Table E3: Noise level of machine at the quarry 2 [Q2]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 1	**Noise Level (dBA)**							
Generator	95	95	96	96	99	98	99	93
Primary Crusher	108	108	111	111	112	113	113	113
Secondary Crusher	105	105	106	107	107	108	108	108
Dumper	94	94	94	95	95	96	95	96
Compressor	108	109	108		108		109	108
Wagon Drilling	90	90	93		92		93	93
Pay loader	89	89	91	93	93	93	93	93
Drilling Machine	97.1	97.1	97.1	97.3	97.3	97.3	97.3	97.3
Lathe Machine	86.5	86.5	87.1	87.4	87.4	87.5	87.5	87.5
Excavator	96.5	96.5	97.1	97.2	97.2	97.2	97.2	97.2
Leq	112.2	112.2	113.8	112.7	114.6	114.4	115.5	115.3

Day 2

Generator	96	96	97	97	97	98	99	99
Primary Crusher	108	107	109	109	111	110	112	112
Secondary Crusher	106	106	107	108	108	109	109	109
Dumper	94	94	94	95	95	95	95	95
Compressor	108	108	108	108	108	108	109	109
Wagon Drilling	90	89	91	92	92	93	93	94
Pay loader	89	89	91	93	92	93	93	93
Drilling Machine	96.0	96.2	96.5	97.0	97.0	97.0		97.0
Lathe Machine	87.4	87.4	87.5	87.5	87.5	87.5	97.0	87.5
Excavator Machine	96.8	96.7	96.8	97.1	97.1	97.1	87.5	97.1
Leq	112.4	112.2	113.8	112.7	114.6	114.4	97.1	115.3

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
	Noise Level (dBA)							
Day 3								
Generator	98	98	98	97	97	97	98	98
Primary Crusher	112	112	112	112	113	113	113	113
Secondary Crusher	107	108	108	109	110	110	111	111
Dumper	94	94	93	94	93	95	96	95
Compressor	108	108		108	109		108	109
Wagon Drilling	90	91		90	91		92	93
Pay loader	90	90	90	93	93	92	93	92
Drilling Machine	97.0	97.2	97.2	97.2	97.2	97.2	97.2	97.2
Lathe Machine	87.0	87.2	87.2	87.2	87.2	87.2	87.2	87.2
Excavator Machine	95.9	95.9	95.9	95.9	95.9	96.0	96.0	96.0
Leq	114.5	114.7	113.6	114.9	115.9	114.9	116.0	116.2

Table E3 (Continued): Noise level of machine at the quarry 2 [Q2]

Day 4

Generator	98	97	97	97	97	98	99	99
Primary Crusher	113	113	114	115	115	115	115	115
Secondary Crusher	109	108	108	110	109	110	110	110
Dumper	93	93	93	94	95	95	95	95
Compressor	107	108	108	108	109	109		
Wagon Drilling	90	90	89	90	91	92		
Pay loader	91	90	90	90	92	93	93	92
Drilling Machine	89.4	89.4	89.5	90.0	90.0	90.0	90.0	90.0
Lathe Machine	87.0	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Excavator Machine	97.0	97.1	97.1	97.1	97.1	97.1	97.1	97.1
Leq	115.3	115.2	115.9	116.9	116.9	117.1	116.3	116.3

Table E3 (Continued): Noise level of machine at the quarry 2 [Q2]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
				Noise Level (dBA)				
Day 5								
Generator	97	96	97	97	96	97	97	96
Primary Crusher	112	113	113	114	114	115	115	114
Secondary Crusher	109	108	108	110	111	112	113	113
Dumper	94	94	95	94	94	95	95	95
Compressor	108	108	108	109	109	109	109	109
Wagon Drilling	90	91	89	91	90	91	91	91
Pay loader	89	88	90	92	92	92	92	92
Drilling Machine	96.8	97.1	97.0	97.0	97.1	97.1	97.0	97.0
Lathe Machine	87.0	87.1	87.0	87.0	87.0	87.0	87.0	87.0
Excavator Machine	94.5	94.5	94.5	95.0	95.0	95.2	95.4	95.6
Leq	114.9	115.2	115.3	116.4	116.7	117.5	117.8	117.3

Table E4: Noise level of machine at the quarry 3 [Q3]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
	Noise Level (dBA)							
Day 1								
Generator	91	91	92	93	93	92	93	93
Primary Crusher	112	112	111	112	112	114	114	114
Secondary Crusher	114	115	114	115	114	115	115	115
Dumper	93	93	93	95	95	95	94	95
Compressor	112	113	112	113	112	113	113	113
Wagon Drilling	93	93	92	93	93	93	93	93
Pay loader	89	91	91	92	92	92	92	93
Drilling Machine	97.8	97.8	97.8	98.0	98.0	98.0	98.0	98.0
Lathe Machine	89.0	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Excavator Machine	98.0	98.0	98.0	98.0	98.0	98.0	98.0	98.0
Leq	117.6	118.3	117.3	118.3	117.6	118.9	118.9	118.9
Day 2								
Generator	90	91	91	92	93	92	93	93
Primary Crusher	111	111	111	111	113	113	114	114
Secondary Crusher	115	115	115	115	115	115	115	115
Dumper	92	92	93	94	95	95	95	95
Compressor	112	112	112	113	113	113	114	113
Wagon Drilling	92	92	92	92	93	93	93	93
Pay loader	90	92	93	93	93	93	93	93
Drilling Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Lathe Machine	88.0	88.0	88.0	88.0	88.0	88.0	88.0	88.0
Excavator Machine	97.3	97.3	97.3	97.5	97.5	97.5	97.5	97.5
Leq	117.8	117.8	117.8	118.1	118.6	118.6	119.2	119.2

Table E4: Noise level of machine at the quarry 3 [Q3]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
Day 3				**Noise Level (dBA)**				
Generator	92	93	93	95	95	95	96	96
Primary Crusher	114	114	115	115	115	115	115	115
Secondary Crusher	116	116	116	114	114	115	115	115
Dumper	93	93	93	95	95	95	95	95
Compressor	113	113	113	114	114	114	114	114
Wagon Drilling	92	92	92	92	92	93	93	93
Pay loader	90	93	94	94	95	95	95	95
Drilling Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Lathe Machine	88.0	88.0	88.2	88.2	88.5	88.5	88.5	88.5
Excavator Machine	97.1	97.1	97.1	97.1	97.1	97.1	97.1	97.1
Leq	119.3	119.3	119.6	119.2	119.2	119.5	119.5	119.5
Day 4								
Generator	92	92	92	94	95	95	96	96
Primary Crusher	114	114	115	116	116	116	116	116
Secondary Crusher	115	115	115	115	115	115	115	115
Dumper	92	92	93	93	94	93	93	93
Compressor	112	112	112	113	114	113	113	114
Wagon Drilling	90	92	93	92	93	93	93	93
Pay loader	90	90	90	94	95	95	95	95
Drilling Machine	97.0	97.1	97.1	97.1	97.1	97.1	97.1	97.1
Lathe Machine	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Excavator Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Leq	118.6	118.6	119.0	119.6	119.9	119.7	119.7	119.7

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm

Day 5 **Noise Level (dBA)**

Table E4: Noise level of machine at the quarry 3 [Q3]

Generator	90	93	95	95	96	96	97	98
Primary Crusher	116	116	116	117	117	117	117	117
Secondary Crusher	115	114	115	115	115	115	115	115
Dumper	94	94	94	94	95	95	95	94
Compressor	110	112	113	112	114	114	115	115
Wagon Drilling	90	92	93	92	90	91	92	91
Pay loader	90	90	94	94	94	94	95	95
Drilling Machine	97.0	97.0	97.0	97.0	97.1	97.1	97.1	97.1
Lathe Machine	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Excavator Machine	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0
Leq	119.1	119.1	119.7	119.9	120.3	120.3	120.6	120.6

Table E5: Noise level of machine at the quarry 4 [Q4]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
	Noise Level (dBA)							
Day 1								
Generator	97	99	100	102	101	102	103	103
Primary Crusher	113	114	114	115	115	115	116	115
Secondary Crusher	110	112	112	113	114	113	112	113
Dumper	97	97	97	97	97	97	97	97
Compressor	100	100	102	102	103	103	102	102
Wagon Drilling	88	89	99	98	99	100	100	101
Pay loader	90	92	92	93	94	94	96	99
Drilling Machine	90.1	90.2	90.2	90.2	90.2	90.2	90.2	90.2
Lathe Machine	87.4	87.4	87.4	87.4	87.4	87.4	87.4	87.4
Excavator Machine	95.0	95.2	95.2	95.2	95.2	95.2	95.2	95.2
Leq	115.1	116.4	116.5	117.5	117.9	117.6	117.9	117.6

Table E5 (Continued): Noise level of machine at the quarry 4 [Q4]

	9am-10am	10am-11am	11am-12noon	12noon-1pm	1pm-2pm	2pm-3pm	3pm-4pm	4pm-5pm
	Noise Level (dBA)							
Day 2								
Generator	98	100	100	101	103	103	102	103
Primary Crusher	114	115	114	116	115	116	114	115
Secondary Crusher	110	112	112	113	112	113	112	113
Dumper	96	96	97	97	96	96	97	97
Compressor	99	100	102	102	103	102	102	102
Wagon Drilling	87	99	98	99	100	99	100	99
Pay loader	89	90	94	96	98	94	96	99
Drilling Machine	90.2	90.2	90.2	90.2	90.2	90.2	90.2	90.2
Lathe Machine	87.5	87.5	87.5	87.5	87.5	87.6	87.6	87.6
Excavator Machine	95.0	95.2	95.2	95.2	95.2	95.2	95.2	95.2
Leq	115.7	117.7	116.5	118.1	117.3	118.1	116.6	117.6

Day 3

Generator	98	100	100	101	102	102	102	101
Primary Crusher	113	113	113	114	115	116	113	113
Secondary Crusher	111	111	111	111	112	113	114	114
Dumper	95	96	96	96	96	96	96	97
Compressor	101	101	101	101	102	102	101	102
Wagon Drilling	88	98	98	99	100	102	102	102
Pay loader	90	92	92	92	93	93	94	94
Drilling Machine	90.2	90.2	90.2	90.2	90.2	90.2	90.2	90.2
Lathe Machine	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Excavator Machine	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Leq	115.4	115.6	115.6	116.2	117.2	118.1	117.0	117.0

Day 4

Generator	98	100	101	102	104	104	103	102
Primary Crusher	112	112	114	115	115	114	115	114
Secondary Crusher	110	110	112	113	114	115	112	113
Dumper	96	96	96	96	97	96	97	96
Compressor	100	99	101	101	103	103	103	103
Wagon Drilling	87	98	98	98	100	102	101	102
Pay loader	90	91	89	94	90	88	94	94
Drilling Machine	89.2	89.2	90.1	90.2	90.2	90.2	90.2	90.2
Lathe Machine	88.0	88.0	88.1	88.1	88.1	88.1	88.1	88.2
Excavator	95.0	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Machine	114.5	114.6	116.5	117.5	118.0	118.0	117.3	117.1

Table E5: Noise level of machine at the quarry 4 [Q4]

Day 5

Generator	99	100	101	101	104	104	103	103
Primary Crusher	114	115	116	115	116	116	114	115
Secondary Crusher	111	111	112	112	113	113	112	112
Dumper	97	97	97	97	97	96	96	96
Compressor	99	100	102	103	103	103	103	103
Wagon Drilling	88	99	99	100	102	101	104	99
Pay loader	89	91	94	96	97	94	96	99
Drilling Machine	89	89	89	90	90	90	90	90
Lathe Machine	88.5	88.5	88.5	88.5	88.5	88.5	86.0	86.0
Excavator Machine	97.1	97.1	97.1	97.1	97.5	97.5	97.5	97.5
Leq	116.0	116.8	117.8	117.2	118.3	118.2	116.8	117.3

SUMMARY OF THE AVERAGE NOISE LEVEL IN THE QUARRIES

Table E6: Summary of the Average Noise Level in Q1

Days	**L_{eq} (dB)**
1	120.3
2	120.8
3	120.4
4	119.6
5	118.9
Average L_{eq}	120.0

Table E7: Summary of the Average Noise Level in Q2

Days	**L_{eq} (dB)**
1	113.8
2	113.7
3	115.1
4	116.2
5	116.4
Average L_{eq}	115.0

Table E8: Summary of the Average Noise Level in Q3

Days	**L_{eq} (dB)**
1	118.2
2	118.4
3	119.4
4	119.4
5	120.0
Average L_{eq}	119.1

Table E9: Summary of the Average Noise Level in Q4

Days	**L_{eq} (dB)**
1	117.1
2	117.2
3	116.5
4	116.7
5	117.3
Average L_{eq}	117.0

Table E11: Respondent in production section and non production section between the year 2018 and 2019.

	2018		2019	
Quarry	**Production section**	**Non-production section**	**Production section**	**Non-production section**
1	45	07	45	05
2	49	10	49	09
3	61	11	42	10
4	49	07	49	6
TOTAL	204	35	185	30

APPENDIX F

POPULATION SAMPLE

Generally the larger the population, the larger the sampling ratio needed for representativeness. For populations under 1000, a minimum ratio of 30% (300 individuals) is advisable to ensure representativeness of the sample. For larger populations, such as a population of 10000, a comparatively small minimum ratio of 10% (1000) is required for representativeness.

Quarry	No of quarry workers	2018 Sample	2019 Sample
Q1	62	45 (72.58%)	41(66.13%)
Q2	67	49 (73.13%)	46(68.66%)
Q3	79	61 (77.22%)	58(73.42%)
Q4	65	49 (77.78%)	40(77.78%)
Total	271	204 (75.27%)	185(68.27%)

Of a total of 271 of quarry workers in the four sites 204 were sampled, representing 75.27% of the population of the quarry workers in the year 2018 and 185 out of the same 204 in the year 2018, were sampled in the year 2019, which is sufficient, (Suskie, 1996; Nardi, 2003; Neuman, 2007) recommended 30% for a population below 10000. Each site was represented a cluster of quarry workers which exhibited the characteristics of input variables. Within each cluster, a simple probabilistic sampling technique of casting lots was used to select the quarry workers used for the study.

APPENDIX G

Results of F Test of Variance Equality of Hearing Threshold of Baseline Year and a Subsequent Year at Different Frequencies

Frequency	F value	p-value	Hearing Threshold Variance 1 (Year 2018)	Hearing Threshold Variance 2 (Year 2019)	Variance Ratio	Confidence Interval	
250Hz	0.78235	0.08791	14.56627	18.61857	0.782352	0.5889462	1.0372038
500Hz	0.77075	0.07027	24.28018	31.50188	0.7707535	0.580215	1.021827
1kHz	0.97523	0.86	41.51171	42.56598	0.9752321	0.734144	1.2929148
2kHz	1.1535	0.3237	65.98964	57.20787	1.153506	0.8683471	1.5292619
3kHz	1.1377	0.3728	95.86349	84.26381	1.137659	0.8564176	1.5082526
4kHz	1.234	0.1463	233.5254	189.2402	1.234016	0.928954	1.635998
6kHz	0.89301	0.4307	141.7866	158.7743	0.8930076	0.6722465	1.1839056
8kHz	0.94078	0.6701	134.6766	143.1541	0.940781	0.7082098	1.2472412

F test of variance equality is an inferential statistical indicator to show whether there is significant difference in variances between two datasets. The test is a means of showing whether two datasets come from the same population even though a measurement from the population differs in time, such as in years, because it is expected that a measurement (a measurement of a variable) on a normal distribution should have approximately the same variance irrespective of the time the measurement is taken as long the experiment conditions are still valid. In the case of hearing threshold measurements for the base year (the first year) and second year, there are significant differences in hearing threshold values at experimental frequencies; because the measurements came from the hearing threshold of the same population of quarry workers, their variances should be approximately equal. F value is the variance ratio value.

The F values of variance equality at frequency 250 Hz, 500 Hz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz and 8 kHz are not significant at the respective p-values as each of them is greater than alpha values of 0.05, thus suggest the acceptance of null hypothesis that the true variance ratio of hearing threshold at each frequency is equal to 1. The variance ratio is only equal to 1, when both variances of hearing threshold values of workers for two datasets are roughly equal. Each variance ratio is approximately 1. Conclusively, the datasets on hearing threshold came from the same population of quarry workers.

The confidence interval of 95% is a statistic that shows confidence in the estimate obtained. 95% confidence interval is the probability that out of 100 samples drawn from the population of quarry workers, there is confidence that 95% of those samples will contain the population’s true variance ratio within the stated interval. Apparently, the variance ratio interval for each of hearing threshold is compact, as the upper and lower limits are closer to 1 than not.

APPENDIX H

Experimental Design

Table H: Experimental Design and its Response for the Hearing Threshold of the Quarry Workers.

FACTORS				RESPONSES							
Std	AG	YE	NL 250Hz Response 1		500Hz Response 2	1kHz Response 3	2kHz Response 4	3kHz Response 5	4kHz Response 6	6kHz Response 7	8kHz Response 8
181	53	27	115	37.562	49.034	57	60.002	64.024	86.123	74.897	77.302
49	57	34	115	36.211	50.928	69	69.123	70.754	95.032	79	76.678
10	57	27	115	35	48.879	50	63.896	77.032	94.003	74.945	78.932
55	51	20	115	29	42.126	43	44	49.878	67.995	51.143	65.321
34	43	22	116.6	34	36.016	37	41	50.023	57.351	46.981	60.002
36	64	36	116.9	36.036	57.344	60	68.763	73.562	94.999	70.9416	83.987
30	50	23	116.6	30.013	33.893	35.023	38.003	46.923	69.321	53	67
1	52	19	116.9	31	38.041	38.913	45.321	48.023	65.023	50.004	60.001
62	53	14	113.5	33	34.997	34.926	38.325	42.001	67.945	46.123	65
7	48	21	113.5	31	32	39.028	42.765	44.086	55.043	57.012	62
63	36	14	113.5	25.928	26	29	30.876	37.326	38	38.683	42.223
72	59	26	113.5	28.956	36	43	53.134	60.765	69	50.004	64.128
17	27	08	96	19.012	20.979	22.032	25.043	27.012	28	25.004	30.006
81	46	20	96	25	30.046	34.236	35.233	35.666	57.001	39.023	44.861
54	35	16	96	25.993	31.024	34.921	34.563	38.043	53.991	34.768	39.213
47	50	23	96	27.565	26.593	36.001	38.871	41.999	59.301	40.005	43.005
14	41	21	94.4	27.033	30.999	39	44.002	46.124	60	44.342	47.994
56	31	12	94.4	23.891	27.032	29	30.023	31.032	32.023	27	33.786
173	28	07	94.4	16.895	21.002	23.014	29.021	30.856	32.011	26.5131	31.218
111	40	15	94.4	23.246	25	28.732	29.2	33.444	59	36	38
92	44	22	94.4	26.0124	29.076	39.346	41.918	44	60.3	37.432	40.321
132	39	20	94.4	24.320	31.032	33.004	37673	43.993	54.342	39.543	43
117	33	12	93.1	25	27.59	34.006	35.02	37.631	56.6	30.5	35
51	37	26	93.1	25	31.007	35.976	37.003	44.796	57.432	60.95	56.543
142	45	25	93.1	27.005	33	34.041	38.234	51.022	53.161	40.230	45.118
137	42	20	93.1	28.925	29.095	35.005	39.052	41.654	63.002	47.1	64
31	55	24	93.1	37.005	39.002	47.761	53.118	67.450	96.035	77.098	86.23
133	49	21	93.1	33.303	34.005	36.954	43.032	57	70	49.054	64.765
152	25	07	93.0	18.963	22.124	25.304	27.775	29.8	29.432	25.62	30.043
185	38	15	93.0	23	25	26.554	31	33.015	37.271	32.842	33.717
163	55	30	88.3	32	38.004	42.043	48.003	59.674	98.063	79.582	67.210
70	46	20	88.3	33.003	41.006	42.757	45.161	53.502	68.321	59.231	64.321
5	61	36	97.3	35.986	39	45.138	47.5	55	94	83,654	76.032

139	22	04	45	25.777	22	22.271	23.4	23	25.052	22.321	23
99	26	08	112.3	24	24.987	26	27.985	28.903	30.965	28.964	31.765
159	37	14	112.3	21.453	23.677	27.963	31.453	36.654	39.764	36.375	36.094
95	31	09	112.3	23.231	25.055	26	27.547	28.432	39.889	28.021	30.965
107	32	14	112.3	24.642	25.137	29.325	29	30.069	34.234	33	32.874
23	48	26	112.3	35.531	36.78	40.903	45.328	49	68.765	68.975	40.653
168	52	27	112.3	28.847	33.976	43	48.943	59	77.054	72.007	66.532
68	54	31	112.3	28.784	33.696	44.324	47.012	53.001	94.324	61	64.236
120	36	14	108.3	22.206	26.345	34	43.643	45.275	46.654	41.065	41.654
128	22	04	108.3	18.456	21	23.987	26.001	27.128	29.345	24.765	29.005
91	52	25	94.5	34.719	38	43.643	47.385	58	92.023	58.067	64.076
130	49	24	94.5	27.563	35.853	40.998	47	51.564	70.326	45.765	50.671
106	44	20	94.5	34	33.855	57.354	47	59.087	67.987	48.643	53.8
141	42	21	94.5	28.986	29.076	35.759	47	50.986	71	53.042	49.3
86	25	07	94.5	20.543	22.859	23.543	24.394	26,852	29	26.653	29.065
156	36	13	91.1	24.895	26.743	27.408	31.001	36	54.875	38.532	30.120
82	30	08	91.1	23.026	24.987	25.453	26.478	28.067	29	26.654	27.5.09
158	31	13	91.1	23.317	24.821	27	29.543	31.084	31.074	29,054	31.107
21	35	15	91.1	29.095	32.042	34.341	39.006	37.701	41.054	35.321	31.982
60	29	11	91.1	21.562	23.876	25.976	26.324	28.678	29	27	28.876
165	53	30	91.1	32.654	34.567	44.065	50.876	54.097	80.532	51.654	73.987
41	35	14	91.5	23.987	24.975	26.342	26.964	28.1	31.098	28.987	31.654
102	21	03	91.5	18.876	20.909	22.876	22.654	26.763	29.202	25.3	27.984
27	35	14	91.5	22.548	23	23.764	27.054	28.986	31.345	28.876	32.098
100	51	25	91.5	36.007	37.965	44	45.5	57.965	70.980	49.987	64.999
76	48	27	91.5	30.123	32,968	40.327	45.732	53.542	78.329	59.001	75.587
145	53	30	91.5	34.998	37.6	39.096	50.868	57.006	88.765	71.945	76.776
169	49	23	91.5	36.987	37	43.234	51.065	59.320	68.654	57.432	61.543
114	41	21	97.2	24.654	41.675	45.876	52.001	57.5	67.432	56.976	61
25	46	20	97.2	30	38.765	41.532	48.762	58.543	71.092	48.654	67.984
8	35	13	97.2	23	25.01	28.065	30	31.987	33.112	27.968	39.654
75	51	29	97.2	31.987	37.43	43.006	56.033	70.321	75.654	65.438	72.568
143	49	22	87.3	28.435	33.654	38.843	45	57.654	79	65.349	73
154	41	15	87.3	27	30.04	34.764	37.654	43.23	58.023	52.654	56.432
53	30	07	87.3	24.965	26	26.976	28	35.3	36	28.659	34.075
172	52	29	87.3	37.975	41.654	45.123	51.987	70.997	90	77.3	82.275
183	53	34	93.2	38	44.013	48.975	55.654	60.034	98.007	67.634	83.001
97	34	13	93.2	22.1	24.876	26.877	29.543	30.543	33.496	31.549	34.956
180	36	15	93.2	21.849	24.866	29.654	30.543	31	36.654	33.764	35.987
129	39	14	30.2	22.854	23.543	26.879	28.764	29.9	31	27.890	29.999
36	42	12	37.8	24.453	23.875	24.098	36.548	37.872	42.836	28.099	40.543
2	38	13	44.3	22.761	23.438	25.765	27.02	28.438	32.556	28.126	31.007
164	38	16	49.3	23.432	25.980	26.087	28.075	33.965	35.009	27.682	31.879
19	35	19	28.4	24.765	27.799	29.543	32.987	33.117	38.765	33.432	32.259
147	36	11	38.4	22	23.432	24.543	26.3	29.088	32.665	28.608	29.764

177	30	11	50.0	24.854	23.334	27	29.004	34.237	36.896	32.956	33.326
80	35	16	114.3	27.543	27.654	28.6	29.653	33.432	34.453	30.118	32.754
90	36	13	114.3	24.701	26.865	27.4	28.601	31.554	33.987	29.874	33.760
48	33	07	114.3	23.987	24.7	25.762	27.07	29.536	31	27.638	29.176
166	39	20	114.3	22.083	25.873	32	32.098	33.385	37.432	30.549	34.964
157	52	23	114.3	39.6	45.769	49.754	57.958	63.549	87	62.376	84.749
109	39	08	114.9	22.065	23.658	25.098	26.076	27.001	28.547	25.773	29.064
3	19	04	114.9	20.105	22.743	23.864	26.665	30.988	33.658	29.911	31.237
46	45	13	114.9	26.001	29.055	29	27.902	29.342	34.036	30.457	35.471
122	40	15	114.9	27.986	33.345	35.4	38.432	40.654	46	44.551	49.091
101	42	20	113	24.986	27	46.864	48.875	60.987	71.984	48	66.765
89	37	18	113	20.862	24.874	27.543	27.985	31.506	30.675	29.849	32.990
20	45	21	113	28.531	33	35.969	35.987	36.987	40.598	32.984	38.665
64	40	15	113	28.845	32	33.987	36.765	37.654	40.867	39.432	43.887
105	42	22	113	28.654	33	35	37.765	38.986	42.569	38.908	40.897
136	52	25	113	29.674	31.986	36.765	43.598	55.765	68.398	46.653	59.445
170	28	10	113	20.674	22.875	25.974	28.349	29.657	37.654	33	34.827
6	37	20	92.8	27.976	32.190	38.986	43.543	43.797	48.397	45.987	43.865
171	60	35	92.8	29.730	33	34.690	41.654	48.598	81.965	58.657	73
39	56	35	92.8	34.383	36.439	43.986	51.980	53.271	72.654	58	68.654
162	32	14	92.8	22.597	24.670	26.658	28.976	30.374	33.654	30.768	32.666
108	47	24	92.8	22.965	30.418	36.976	45.569	59	73	56.988	70.756
175	48	23	92.8	31.714	37.717	42	50.598	57.654	69.543	58.977	64.987
30	46	26	92.8	30.054	34	40.654	45.943	52.101	70	50	68.954
184	38	16	92.8	21.999	21.984	23.875	24	26.768	37.865	28.966	34.624
126	48	23	92.8	38.887	40.997	47.876	53.876	67	72.513	50.606	62.954
112	47	28	92.8	32.986	36.096	39.654	48	57.765	67.985	60.374	64.597
135	37	19	92.3	31.486	33	37.763	40.543	46.896	54.876	42	49.640
104	59	34	92.3	36.964	41.876	46	53.765	59.985	69.654	51.970	70.543
98	33	14	92.3	24	27	28.654	29.387	30.886	39.768	28.329	31.866
125	30	08	92.3	22	24.982	25.876	27.176	27.986	32.987	28.965	29
131	44	23	92.3	29.653	36	41.785	48.407	58.648	61.765	43.419	58
40	47	23	92.3	32.734	41.438	42.674	47.781	55.765	60.342	43.765	55.765
61	37	13	92.3	25.965	25.965	27	35.964	37.559	41.848	29.876	34.987
65	35	12	92.3	24.543	25.326	25.027	27.489	31.765	37.865	24.654	29.542
178	40	11	92.3	23.654	25.964	27.098	33.827	33.698	39.654	27.397	37.980
138	50	21	92.8	34	38.745	44.365	51.656	57.987	69.359	50.493	60.654
59	45	26	92.8	36.543	40.543	44.654	59.271	60.547	73.987	45.983	57.964
52	50	21	92.8	35.985	39.988	49.986	54.659	62.984	73.659	50.328	60.386
174	46	21	92.8	33.436	39.943	41	51	57.786	63.973	43.643	48.342
37	45	20	92.8	34.765	35.643	45.653	50.644	58.524	66.248	49	55.965
88	48	17	92.8	34.876	40.487	42.876	53.976	59.863	72	45.438	56
176	38	18	92.8	24.754	29.974	37.295	45.548	55.432	65.543	35	47.879
140	42	23	92.8	29.651	35.985	42	49.597	59.653	67.430	40.111	51.887
4	39	18	97.0	24.439	26.377	29.934	32	37.098	47.321	33.532	44.774

146	36	16	97.0	28	29.543	30.853	34.728	36.543	48.875	39.877	45.435
179	53	30	88.0	33.266	36	40.228	48.674	57.654	82.595	64.074	79.654
153	52	34	97.0	33.964	37.853	40.214	47.193	55.384	85.923	61.998	80.923
73	40	17	97.0	30.781	34.876	36.193	44.653	53.736	71.656	57.432	78.576
110	41	16	59.0	28.643	30.096	34.387	40	46.392	58.183	45.418	53.717
11	49	25	60.4	28.364	33.507	40.530	47	57.977	70.386	51.629	63.765
84	51	30	40.6	29.142	33.654	39	48.607	53	76.636	40.507	73.418
150	36	14	114.5	24.762	27.447	29.754	30.927	34.008	41.210	28.923	39.532
161	52	32	114.5	27.543	39	48.209	50.523	56	73.392	47.507	71.654
151	50	21	114.5	28	34.965	39.932	43.764	59	71.141	53.521	61.654
79	41	18	112.2	23.954	29.876	36.210	45.154	54.362	69.653	41.543	55.876
155	53	28	112.2	30.864	40.507	47	52	60.354	93.876	57.965	72.765
182	54	33	112.2	34.005	42.876	49.015	52.321	64	85.927	61.764	69
66	35	14	112.2	22	23.003	25.239	26.054	29.832	34.965	32.098	37.543
58	31	15	112.2	22	24	24.762	26.085	34.503	40.654	36	35.543
9	40	19	101.7	26	30.297	33.653	36.543	40.605	53.543	41	47.976
26	43	21	101.7	29.784	37.735	45	48.432	49.891	78.439	40.985	54.798
22	39	17	101.7	25.141	27.760	29.001	31	33.548	40.764	35.456	37.964
29	49	17	101.7	35.445	39.328	43.097	48	59.476	72.42	50.475	61.654
12	47	22	96.5	33993	38.714	42.432	46.765	56.538	63.543	44.643	69.965
57	31	12	96.5	22.106	24.751	26.986	30.432	32.997	40.865	34.976	33.865
85	52	32	96.5	35.058	40.471	47.543	53.643	34.621	79.543	46,854	73.548
28	36	14	96.5	21.318	23.093	25.654	27.587	30.432	40.065	34.654	35.876
160	30	08	96.5	20.537	23.086	23.214	26.054	27.64	30.654	27,628	29.654
149	42	18	96.5	29.038	30	37.543	46.543	54.828	77.978	50.985	. 70.587
116	56	34	96.5	35.197	48	53.632	54.065	68.991	99.374	69.978	84.543
124	57	37	98.1	39.458	47	52.435	57.638	58.5	80.432	50.976	72.654
87	21	02	98.1	23.765	25.654	25.435	28.9	29.537	30.962	27.659	29.865
96	44	23	98.1	27.985	35.543	40.256	44.872	55.406	67.753	43.852	52.008
167	36	19	98.1	24.549	24.654	25.543	26.765	28.783	35.835	27.785	30.654
127	50	22	98.1	21.997	24.932	27.846	30.432	39.337	63.864	53.979	57.587.7
134	46	21	98.1	25.765	26	38.648	40.951	50.132	65.438	37.967	50.987
13	34	13	93.3	22.006	24	26.5	27.876	28	37.736	25.956	33.654
24	50	24	93.3	36.765	40.223	42	49.826	61.824	89.765	49.642	60
15	61	38	93.3	33	40	44.5	49.543	59.883	80.743	59.876	75.569
42	51	27	93.3	31.8	39784	41.4	48	63.438	69.985	48.436	67.953
148	39	20	90.2	25.764	27.764	29.9	30	32.365	39.777	32.658	35.783
118	44	23	90.2	27.654	32.843	40.3	48.865	59.9	70.547	50.541	62.629
144	40	12	88.2	23.654	25.385	27.5	28.763	29.653	33.558	28.854	33.432
67	37	16	88.2	23.876	25.695	27.7	29.865	33.62	39.749	30.65	36.743
71	47	20	88.2	28	32.843	38.6	40.674	45.4	71.997	49.762	68.865
16	31	12	88.2	24.654	27.432	28.4	30.639	31.619	33.984	28	31.725
94	41	20	95.4	29.864	34.654	36.9	44	57.538	63.548	36.43	42.387
123	51	23	95.4	33.765	39	48.5	55.58	58.7	79.634	48.39	65.815
93	55	32	95.4	39.964	49	51.6	54.962	60	88.839	54.964	69.926

78	50	23	58.4	28.987	33.988	35.9	40.643	44.612	57.564	41.654	45.965
43	35	14	49.5	20.775	24.765	26.4	27.659	28.7	37.954	34.592	30.763
77	27	10	80.0	20.760	2.098	23.9	27.547	29.734	31.695	28.776	29.957
83	37	15	55.0	23.975	24.854	25.9	26.985	28	35.985	30.978	32.754
113	59	30	90	33.987	36	38.9	43.769	47.6	72.542	54.652	69.438
119	36	18	56.0	22	23.868	25.6	27	30.924	35.954	31.434	33.748
121	60	21	93.3	38.696	47.876	52	59.859	67.974	93.976	51.747	73.176
45	62	36	93.3	37.654	46.953	49.9	50.654	68.983	85.654	54.87	80.809
115	54	27	93.3	33.904	42.975	45.7	52.876	60	82.963	60.654	74.876
103	45	16	90.2	30.976	38.631	44.7	50.754	63.947	70.954	59.454	65.520
44	46	21	90.2	30	34.7	35.6	40.658	60	72.658	52.765	68.738
50	47	22	90.2	30.549	31.537	32	33.543	60.396	73.987	56.645	69.967
34	38	11	88.2	23.375	24.432	27.6	27.677	27.828	37	30.764	33.865
38	36	16	88.2	24.643	27.564	28	29.653	30.5	37.543	28.886	35.444
32	29	09	88.2	22.391	23.052	25.6	27.763	28	30.438	29.982	30.986
69	33	10	88.2	24.653	25.437	26.3	28	29.784	32.7	28.658	29.654
33	45	17	88.2	30	32.453	34.7	38.609	41.484	50.657	47.655	49.761

APPENDIX I

Hearing Threshold levels among the Respondents in the Quarry.

Table I1: Mean Hearing Threshold level in the quarry

Category of workers	Mean HTL (dBA)	HTL ≤ 25 dBA N (%)	HTL > 25 dBA N (%)	
Q1	40.48	14(31.1)	31(68.9)	
Q2	46.75	15(30.6)	34(69.4)	t = 8.486
Q3	47.92	17(40.5)	25(59.5)	F= 49.513
Q4	47.51	14(28.6)	35(71.4)	

Mean hearing threshold = 45.6dB

Table I2: Ranges of Noise level, Hearing Threshold level of Respondent, Age and Years of exposure in each of the four quarries

	Q1	Q2	Q3	Q4
Noise level (dBA)	38-116.7	28.4-108.3	40.6-114.9	49.0-114.5
Hearing threshold level (dBA)	09-91	11-78	11-78	15-79
Age(years)	21-65	19-52	18-58	19-60
Years of exposure	05-37	02-32	02-33	01-37

Table I3: Number of respondent in the quarries and their mean hearing threshold

Quarry	N	Mean
Q1	45	40.48
Q2	49	46.75
Q3	42	47.92
Q4	49	47.51
Total	185	

One way ANOVA Test

Table I4: Differences between the Mean values of Hearing Threshold Level of the Respondents of the Four Quarries.

	Sum of Squares	df	Mean Square	F	Brown-Forsythe Sig.
Between Groups	184.278	3	61.426	1.068	0.364*
Within Groups	11500.180	184	57.501		
Total	11684.458	187			

*Significant at $p < 0.05$

According to one-way ANOVA test, the differences between the mean values of hearing threshold level of the respondent of the four quarries are not significant (F=1.068, p = 0.364). This indicates that the differences between the values are close zero; the hearing threshold values are more or less the same. Thus, the respondents at all the quarries were subjected to about the same working conditions and environmental noise. The Brown-Forsythe significant value is generated for data that fails normal distribution test (Karagoz and Saracbasi, 2016).

APPENDIX J

2018 EXPERIMENT (CONTROL SUBJECTS)

Table J1: Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers (Control Subjects) in the year 2018

	FACTORS			HEARING THRESHOLD							
NO	**AG**	**YE**	**NL**	**250 Hz**	**500Hz**	**1 kHz**	**2 kHz**	**3 kHz**	**4 kHz**	**6 kHz**	**8 kHz**
1.	42	20	30	20	22	22	23	25	29	23	28
2.	49	13	30	25	28	30	32	33	37	34	36
3.	50	29	30	26	29	30	32	35	36	30	41
4.	27	09	30	23	25	27	27	28	30	26	38
5.	40	11	39	25	27	30	33	35	37	28	39
6	45	17	39	32	36	38	40	41	47	37	50
7.	59	25	39	33	36	38	40	42	48	36	51
8.	49	23	29	28	30	31	33	37	42	35	44
9.	41	17	25	27	30	33	35	38	43	38	45
10.	49	23	35	31	32	34	37	40	44	35	46
11.	35	12	45	27	29	31	34	37	39	32	41
12.	24	05	40	25	26	29	31	35	36	37	32
13.	47	15	35	25	27	31	33	35	39	32	41
14	39	09	38	17	20	22	25	26	27	20	29
15	44	09	36	23	27	30	31	33	35	32	38
16	37	15	36	25	27	29	31	33	37	31	40

Table J1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers (Control Subjects) in the year 2018

	FACTORS			HEARING THRESHOLD							
NO	AG	YE	NL	250 Hz	500Hz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
17	41	19	36	25	26	28	30	32	37	34	39
18	35	08	38	16	21	23	26	26	28	29	30
19	39	10	24	24	27	29	31	41	47	39	48
20	35	10	23	24	26	28	30	30	35	25	30
21	49	15	24	24	29	37	39	44	48	35	49
22	30	09	39	17	21	23	26	28	31	24	30
23	28	04	39	20	24	27	27	30	35	30	38
24	47	22	38	22	25	33	37	39	41	35	38
25	47	18	34	22	25	26	28	30	33	25	38
26	42	18	28	23	25	29	30	32	36	24	39
27	33	05	47	23	25	28	30	32	40	34	44
28	54	26	40	28	33	34	36	45	49	39	41
29	43	20	32	27	27	30	32	34	39	32	41
30	32	19	32	25	27	29	31	34	38	34	40
31	46	26	37	24	27	30	33	35	39	25	39
32	40	18	37	29	31	34	36	38	43	33	46
33	32	08	38	14	19	23	26	30	35	23	38

Table J1 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers (Control Subjects) in the year 2018

FACTORS				HEARING THRESHOLD							
NO	**AG**	**YE**	**NL**	**250 Hz**	**500Hz**	**1 kHz**	**2 kHz**	**3 kHz**	**4 kHz**	**6 kHz**	**8 kHz**
34	34	12	36	23	25	26	30	31	35	29	31
35	37	09	40	23	25	27	30	31	37	29	33

2019 EXPERIMENT (CONTROL SUBJECTS)

Table J2: Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers (Control Subjects) in the year 2019

	FACTORS			**HEARING THRESHOLD**							
NO	**AG**	**YE**	**NL**	**250 Hz**	**500Hz**	**1 kHz**	**2 kHz**	**3 kHz**	**4 kHz**	**6 kHz**	**8 kHz**
1.	43	21	30	20	21	22	23	26	28	22	30
2.	50	14	30	26	28	30	32	33	37	35	38
3.	51	30	30	26	29	30	32	38	39	33	45
4.	28	10	30	23	26	27	28	29	33	27	40
5.	41	12	39	25	27	30	33	37	38	28	39
6	46	18	39	31	35	37	40	43	48	39	50
7.	60	26	39	35	38	42	43	45	48	38	50
8*.											
9.	42	18	25	28	31	33	36	40	44	38	47
10.	50	24	35	31	32	34	38	40	45	35	48
11.	36	13	45	27	29	32	34	38	40	32	42
12.	25	06	40	25	27	29	31	35	39	37	32
13*.											
14	40	10	38	17	21	22	26	26	28	20	30
15	45	10	36	24	28	30	32	33	37	31	39

Table J2 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers (Control

Subjects) in the year 2019

	FACTORS			HEARING THRESHOLD							
NO	**AG**	**YE**	**NL**	**250 Hz**	**500Hz**	**1 kHz**	**2 kHz**	**3 kHz**	**4 kHz**	**6 kHz**	**8 kHz**
16	38	16	36	26	27	30	32	33	39	33	41
17	42	20	36	26	27	28	31	32	39	34	42
18	36	09	38	16	21	23	26	27	29	28	30
19*											
20	36	11	23	25	26	29	30	31	36	26	31
21	50	16	24	25	30	39	40	44	50	37	51
22	31	10	39	18	22	23	27	28	33	25	33
23	29	05	39	20	24	27	27	30	36	30	39
24	48	23	38	23	25	34	37	40	43	35	39
25	48	19	34	23	26	27	28	30	33	25	39
26	43	20	28	24	25	30	31	32	37	24	39
27	34	06	47	23	25	28	30	32	41	35	46
28	55	27	40	28	34	35	37	45	50	39	41
29*											
30	33	20	32	27	29	30	31	35	41	35	43
31	47	27	37	25	28	30	35	36	40	27	40
32	41	19	37	30	32	34	36	39	45	34	47

Table J2 (Continued): Age, Years of Exposure, Noise level and Hearing Threshold of the Quarry Workers (Control

Subjects) in the year 2019

	FACTORS			HEARING THRESHOLD							
NO	**AG**	**YE**	**NL**	**250 Hz**	**500Hz**	**1 kHz**	**2 kHz**	**3 kHz**	**4 kHz**	**6 kHz**	**8 kHz**
33	33	09	38	16	19	23	27	32	36	24	39
34	35	13	36	24	26	27	30	31	36	29	33
35*											

***Absent Subjects in 2019 experiment.**

Group Statistics of Hearing Threshold of Experimental and Control Groups

Table J3 displays the mean, standard deviation and standard error mean. The mean values of hearing threshold of experimental group at the varying frequencies which are quite higher than the mean values of the threshold of the control group.

Table J3: Group Statistics of Hearing Threshold of Experimental and Control Groups

Hearing Threshold Frequency	Group	N	Mean	Std. Deviation	Std. Error Mean
250 Hz	Experiment	185	27.60	5.304	0.390
	Control	30	24.57	4.415	0.806
500 Hz	Experiment	185	31.43	7.362	0.541
	Control	30	27.27	4.331	0.791
1 kHz	Experiment	185	35.30	8.975	0.660
	Control	30	29.83	4.843	0.884
2 kHz	Experiment	185	39.38	10.634	0.782
	Control	30	32.10	4.759	0.869
3 kHz	Experiment	185	44.93	13.547	0.996
	Control	30	34.67	5.561	1.015
4 kHz	Experiment	185	56.82	20.504	1.507
	Control	30	38.93	5.948	1.086
6 kHz	Experiment	185	43.08	13.857	1.019
	Control	30	31.17	5.434	0.992
8 kHz	Experiment	185	50.28	17.416	1.280
	Control	30	40.10	6.205	1.133

The significance of F for equality of variances of experimental group with control group are all less than 0.05. Thus, the null hypotheses that they are equal are rejected. For this reason, the t tests for non-assumption of variance equality were carried out and the results are as shown in the table J4.

Table J4: Levene's Test for Equality of Variances

Hearing Threshold	F	Significance
250Hz	5.455	0 .020
500Hz	14.301	0 .000
1 kHz	17.951	0.000
2 kHz	34.245	0.000
3 kHz	49.463	0.000
4 kHz	60.333	0.000
6 kHz	24.941	0.000
8 kHz	60.670	0.000

Table J5: T Test of Difference between Hearing Threshold of Experimental and Control Groups for Unequal Variances

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Frequency							
250 Hz	3.387	43.783	.002	3.033	.895	1.228	4.8383
500 Hz	4.348	60.461	.000	4.166	.958	1.2283	6.0821
1 kHz	4.953	67.019	.000	5.464	1.103	3.2619	7.6660
2 kHz	6.232	86.090	.000	7.284	1.169	4.9603	9.6072
3 kHz	7.216	97.461	.000	10.263	1.422	7.4405	13.0856
4 kHz	9.626	156.735	.000	17.883	1.858	14.2132	21.5525
6 kHz	8.375	104.173	.000	11.909	1.422	9.0892	14.7288
8 kHz	5.955	119.636	.000	10.181	1.710	6.7959	13.5662

For each frequency in the table above the t value is significant at 0.05 alpha level. Therefore, the null hypotheses that the hearing thresholds of experimental group subjects are not different from the hearing thresholds of the control group subjects are rejected. The differences observed are as a result of relatively higher hearing thresholds of experimental group subjects ascribable to their exposure to noise.

```
T-TEST GROUPS=grouping_var(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=Fre_250Hz Fre_500Hz Fre_1KHz Fre_2KHz Fre_3KHz Fre_4KHz Fre_6KHz Fre_8KHz
  /CRITERIA=CI(.95).
```

T-Test

Notes

Output Created		13-MAR-2023 12:30:34
Comments		
Input	Data	C:\Users\user\Desktop\GIANT\orry JOHNSON\Data_2023.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	215
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 GROUPS=grouping_var(1 2) /MISSING=ANALYSIS /VARIABLES=Fre_250Hz Fre_500Hz Fre_1KHz Fre_2KHz Fre_3KHz Fre_4KHz Fre_6KHz Fre_8KHz /CRITERIA=CI(.95).
Resources	Processor Time	00:00:00.00
	Elapsed Time	00:00:00.03

Group Statistics

	grouping_var	N	Mean	Std. Deviation	Std. Error Mean
Fre_250Hz	1	185	27.60	5.304	.390
	2	30	24.57	4.415	.806
Fre_500Hz	1	185	31.43	7.362	.541
	2	30	27.27	4.331	.791
Fre_1KHz	1	185	35.30	8.975	.660
	2	30	29.83	4.843	.884
Fre_2KHz	1	185	39.38	10.634	.782
	2	30	32.10	4.759	.869
Fre_3KHz	1	185	44.93	13.547	.996
	2	30	34.67	5.561	1.015
Fre_4KHz	1	185	56.82	20.504	1.507
	2	30	38.93	5.948	1.086
Fre_6KHz	1	185	43.08	13.857	1.019
	2	30	31.17	5.434	.992
Fre_8KHz	1	185	50.28	17.416	1.280
	2	30	40.10	6.205	1.133

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df					
Fre_250Hz	Equal variances assumed	5.455	.020	2.968	213					
	Equal variances not assumed			3.387	43.783					
Fre_500Hz	Equal variances assumed	14.301	.000	3.012	213					
	Equal variances not assumed			4.348	60.461					
Fre_1KHz	Equal variances assumed	17.951	.000	3.254	213					
	Equal variances not assumed			4.953	67.019					
Fre_2KHz	Equal variances assumed	34.245	.000	3.686	213					
	Equal variances not assumed			6.232	86.090					

Fre_3 KHz	Equal variances assumed	49.463	.000	4.087	213					
	Equal variances not assumed			7.216	97.461					
Fre_4 KHz	Equal variances assumed	60.333	.000	4.736	213					
	Equal variances not assumed			9.626	156.735					
Fre_6 KHz	Equal variances assumed	24.941	.000	4.642	213					
	Equal variances not assumed			8.375	104.173					
Fre_8 KHz	Equal variances assumed	60.670	.000	3.164	213					
	Equal variances not assumed			5.955	119.636					

Independent Samples Test

		t-test for Equality of Means				
					95% Confidence Interval of the Difference	
		Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	
Fre_250Hz	Equal variances assumed	.003	3.033	1.022	1.019	

	Equal variances not assumed	.002	3.033	.895	1.228	
Fre_500Hz	Equal variances assumed	.003	4.166	1.383	1.440	
	Equal variances not assumed	.000	4.166	.958	2.249	
Fre_1KHz	Equal variances assumed	.001	5.464	1.679	2.154	
	Equal variances not assumed	.000	5.464	1.103	3.262	
Fre_2KHz	Equal variances assumed	.000	7.284	1.976	3.389	
	Equal variances not assumed	.000	7.284	1.169	4.960	
Fre_3KHz	Equal variances assumed	.000	10.263	2.511	5.314	
	Equal variances not assumed	.000	10.263	1.422	7.441	
Fre_4KHz	Equal variances assumed	.000	17.883	3.776	10.441	
	Equal variances not assumed	.000	17.883	1.858	14.213	
Fre_6KHz	Equal variances assumed	.000	11.909	2.565	6.852	
	Equal variances not assumed	.000	11.909	1.422	9.089	
Fre_8KHz	Equal variances assumed	.002	10.181	3.218	3.839	
	Equal variances not assumed	.000	10.181	1.710	6.796	

Independent Samples Test

	t-test for Equality of Means

		95% Confidence Interval of the Difference
		Upper
Fre_250Hz	Equal variances assumed	5.048
	Equal variances not assumed	4.838
Fre_500Hz	Equal variances assumed	6.892
	Equal variances not assumed	6.082
Fre_1KHz	Equal variances assumed	8.774
	Equal variances not assumed	7.666
Fre_2KHz	Equal variances assumed	11.178
	Equal variances not assumed	9.607
Fre_3KHz	Equal variances assumed	15.212
	Equal variances not assumed	13.086
Fre_4KHz	Equal variances assumed	25.325
	Equal variances not assumed	21.553
Fre_6KHz	Equal variances assumed	16.966
	Equal variances not assumed	14.729
Fre_8KHz	Equal variances assumed	16.524
	Equal variances not assumed	13.566

APPENDIX J Continued

Control Experiment Data Analysis

Response 1: Hearing Threshold at 250Hz

In Table J6, the Model F-value of 99.79 implies the model is significant. In this case A, B, C, AB, AC, BC, A^2, B^2, C^2 are significant model terms.

Table J6: ANOVA for Quadratic model for the Hearing Threshold at 250 Hz

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	48.59	9	5.40	99.79	<0.0001	significant
A-Age	2.88	1	2.88	53.23	<0.0001	
B-Exposure	10.74	1	10.74	198.58	<0.0001	
C-Noise Level	1.15	1	1.15	21.18	<0.0001	
AB	1.52	1	1.52	28.06	<0.0001	
AC	8.03	1	8.03	148.38	<0.0001	
BC	4.99	1	4.99	92.29	<0.0001	
A^2	6.87	1	6.87	126.95	<0.0001	
B^2	0.2300	1	0.2300	4.25	0.0474	
C^2	3.22	1	3.22	59.50	<0.0001	
Residual	1.73	32	0.0541			
Cor Total	50.32	41				

Table J7: Model Estimation for 250Hz Threshold

Std. Dev.	0.2326	**R^2**	0.9656
Mean	22.82	Adjusted R^2	0.9559
C.V. %	1.02	Predicted R^2	0.8762
		Adeq Precision	36.8155

Response 2: Hearing Threshold at 500 Hz

Table J8 shows that the Model F-value of 81.48 implies the model is significant. In this case A, B, C are significant model terms.

Table J8: ANOVA for Quadratic model of Hearing Threshold at 500 Hz.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	53.28	9	5.92	81.48	<0.0001	significant
A-Age	3.84	1	3.84	52.91	<0.0001	
B-Exposure	1.55	1	1.55	21.35	<0.0001	
C-Noise Level	0.9363	1	0.9363	12.89	0.0011	
AB	0.0595	1	0.0595	0.8194	0.3721	
AC	0.0386	1	0.0386	0.5312	0.4714	
BC	0.1320	1	0.1320	1.82	0.1871	
A^2	0.0684	1	0.0684	0.9413	0.3392	
B^2	0.0920	1	0.0920	1.27	0.2688	
C^2	0.0276	1	0.0276	0.3796	0.5422	
Residual	2.32	32	0.0727			
Cor Total	55.60	41				

Table J9: Model Estimation

Std. Dev.	0.2695	**R^2**	0.9582
Mean	24.90	**Adjusted R^2**	0.9464
C.V. %	1.08	**Predicted R^2**	0.9109
		Adeq Precision	37.2605

Response 3: Hearing Threshold at 1 kHz

In Table J10, the Model F-value of 30.96 implies that the model is significant. In this case A, B, C, AB, AC, BC, A^2, C^2 are significant model terms.

Table J10: ANOVA for Quadratic model of Hearing Threshold at 1 kHz

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	130.98	9	14.55	30.96	<0.0001	significant
A-Age	29.58	1	29.58	62.93	<0.0001	
B-Exposure	8.56	1	8.56	18.22	0.0002	
C-Noise Level	17.33	1	17.33	36.86	<0.0001	
AB	6.41	1	6.41	13.64	0.0008	
AC	3.85	1	3.85	8.20	0.0073	
BC	10.27	1	10.27	21.84	<0.0001	
A^2	6.58	1	6.58	14.00	0.0007	
B^2	1.65	1	1.65	3.51	0.0700	
C^2	12.06	1	12.06	25.65	<0.0001	
Residual	15.04	32	0.4701			
Cor Total	146.02	41				

Table J11: Model Evaluation Result

Std. Dev.	0.6856	**R^2**	0.8970
Mean	27.00	**Adjusted R^2**	0.8680
C.V. %	2.54	**Predicted R^2**	0.8246
		Adeq Precision	33.0392

Response 4: Hearing Threshold at 2 kHz.

In Table J12, the Model F-value of 30.61 implies the model is significant. In this case A, AC are significant model terms.

Table J12: ANOVA for Quadratic model of Hearing Threshold at 2 kHz

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	140.83	9	15.65	30.61	<0.0001	significant
A-Age	42.50	1	42.50	83.13	<0.0001	
B-Exposure	0.0699	1	0.0699	0.1367	0.7140	
C-Noise Level	0.9988	1	0.9988	1.95	0.1718	
AB	0.0470	1	0.0470	0.0919	0.7637	
AC	8.20	1	8.20	16.04	0.0003	
BC	0.1466	1	0.1466	0.2868	0.5960	
A^2	0.7368	1	0.7368	1.44	0.2387	
B^2	0.0496	1	0.0496	0.0971	0.7574	
C^2	0.4618	1	0.4618	0.9034	0.3490	
Residual	16.36	32	0.5112			
Cor Total	157.19	41				

Table J13: Model Estimation Result

Std. Dev.	0.7150	R^2	0.8959
Mean	29.22	Adjusted R^2	0.8667
C.V. %	2.45	Predicted R^2	0.8021
		Adeq Precision	34.2971

Response 5: Hearing Threshold at 3 kHz

Table J14 shows the Model F-value of 126.08, which implies that the model is significant. In this case A, C, AB, AC, BC, B^2, C^2 are significant model terms.

Table J14: ANOVA for Quadratic Model of Hearing Threshold at 3 kHz

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	272.11	9	30.23	126.08	<0.0001	Significant
A-Age	83.23	1	83.23	347.06	<0.0001	
B-Exposure	0.5165	1	0.5165	2.15	0.1520	
C-Noise Level	2.81	1	2.81	11.73	0.0017	
AB	1.53	1	1.53	6.37	0.0167	
AC	16.48	1	16.48	68.71	< 0.0001	
BC	1.39	1	1.39	5.79	0.0221	
A^2	0.2758	1	0.2758	1.15	0.2915	
B^2	2.21	1	2.21	9.20	0.0048	
C^2	1.97	1	1.97	8.23	0.0072	
Residual	7.67	32	0.2398			
Cor Total	279.79	41				

Table J15: Model Estimation Result

Std. Dev.	0.4897	**R^2**	0.9726
Mean	31.34	**Adjusted R^2**	0.9649
C.V. %	1.56	**Predicted R^2**	0.9492
		Adeq Precision	66.0469

Response 6: Hearing Threshold at 4 kHz

Table J16 gives the Model F-value of 69.16, which implies that the model is significant. In this case A, C, A^2 are significant model terms.

Table J16: ANOVA for Quadratic Model of 4 kHz Threshold

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	490.21	9	54.47	69.16	<0.0001	significant
A-Age	65.10	1	65.10	82.66	<0.0001	
B-Exposure	0.5132	1	0.5132	0.6516	0.4255	
C-Noise Level	3.28	1	3.28	4.17	0.0495	
AB	2.39	1	2.39	3.04	0.0910	
AC	2.43	1	2.43	3.08	0.0886	
BC	1.42	1	1.42	1.80	0.1888	
A^2	3.51	1	3.51	4.46	0.0427	
B^2	0.0204	1	0.0204	0.0260	0.8730	
C^2	0.0236	1	0.0236	0.0300	0.8635	
Residual	25.20	32	0.7876			
Cor Total	515.41	41				

Table J17: Model Estimation Result

Std. Dev.	0.8875	R^2	0.9511
Mean	34.56	Adjusted R^2	0.9373
C.V. %	2.57	Predicted R^2	0.8470
		Adeq Precision	35.8885

Response 7: Hearing Threshold at 6 kHz

Table J18 shows that Model F-value of 36.93 implies that the model is significant. In this case A, C, A^2 are significant model terms.

Table J18: ANOVA for Quadratic Model for 6 kHz Threshold

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	105.64	9	11.74	36.93	<0.0001	significant
A-Age	17.19	1	17.19	54.07	<0.0001	
B-Exposure	0.6211	1	0.6211	1.95	0.1718	
C-Noise Level	2.38	1	2.38	7.50	0.0100	
AB	0.4299	1	0.4299	1.35	0.2534	
AC	0.9165	1	0.9165	2.88	0.0992	
BC	0.1977	1	0.1977	0.6221	0.4361	
A^2	1.54	1	1.54	4.86	0.0349	
B^2	0.1006	1	0.1006	0.3164	0.5777	
C^2	0.6142	1	0.6142	1.93	0.1741	
Residual	10.17	32	0.3178			
Cor Total	115.81	41				

Table J19: Model Estimation Result

Std. Dev.	0.5638	**R^2**	0.9122
Mean	27.85	**Adjusted R^2**	0.8875
C.V. %	2.02	**Predicted R^2**	0.8239
		Adeq Precision	27.2190

Response 8: Hearing Threshold at 8 kHz

Table J20 shows that Model F-value of 33.41 implies that the model is significant. In this case A, A^2 are significant model terms.

Table J20: ANOVA for Quadratic model

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	305.26	9	33.92	33.41	<0.0001	significant
A-Age	31.96	1	31.96	31.48	<0.0001	
B-Exposure	0.0182	1	0.0182	0.0179	0.8944	
C-Noise Level	3.25	1	3.25	3.20	0.0833	
AB	0.0063	1	0.0063	0.0062	0.9378	
AC	1.40	1	1.40	1.38	0.2491	
BC	0.0362	1	0.0362	0.0356	0.8514	
A^2	9.22	1	9.22	9.08	0.0050	
B^2	3.28	1	3.28	3.23	0.0819	
C^2	0.6751	1	0.6751	0.6650	0.4208	
Residual	32.49	32	1.02			
Cor Total	337.75	41				

Table J21: Model Estimation Result

Std. Dev.	1.01	**R^2**	0.9038
Mean	30.87	**Adjusted R^2**	0.8768
C.V. %	3.26	**Predicted R^2**	0.8015
		Adeq Precision	25.6861

APPENDIX K

Table K1: Developed Models' Performance, Actual Versus Predicted Values (Internal Validation)

250Hz		500Hz		1kHz		2kHz		3 kHz		4kHz		6kHz		8kHz	
Actual Value	**Predicted Value**	**Actual Value**	**Predicted Value**	**Actual Value**	**Predicted Value**	**Actual Value**	**Predicted Value**	**Actual Value**	**Predicted Value**	**Actual Value**	**Predicted Value**	**Actual Value**	**Predicted Value**	**Actual Value**	**Predicted Value**
31.00	31.02	38.04	37.99	38.91	38.96	45.32	45.39	48.02	47.95	65.02	65.08	50.04	50.10	60.00	59.97
22.76	22.69	23.44	23.39	25.77	25.92	27.02	27.06	28.44	28.46	32.56	32.49	28.13	28.15	31.01	30.99
20.11	20.08	22.74	22.79	23.86	23.92	26.67	26.75	30.99	31.12	33.66	33.69	29.91	29.76	31.24	31.19
24.44	24.36	26.38	26.21	29.93	29.99	32.00	32.05	37.10	37.46	47.32	47.39	33.53	32.46	44.77	44.78
36.00	36.04	39.00	38.98	45.14	45.06	47.50	47.48	55.00	54.65	94.00	93.97	83.65	83.68	76.03	75.97
28.00	27.91	32.19	31.68	39.00	38.74	43.54	43.49	43.80	42.94	48.40	47.95	46.00	46.00	43.87	42.75
31.00	30.03	32.00	32.04	39.03	38.07	42.77	42.97	44.09	44.11	55.04	54.43	57.01	57.07	62.00	61.07
23.00	22.42	25.01	25.06	28.07	29.01	30.00	29.83	31.99	32.01	33.11	33.18	27.97	27.07	39.65	39.49
26.00	25.96	30.30	30.42	33.65	33.19	36.54	36.48	40.61	40.59	53.54	54.00	41.00	40.75	47.98	47.78
35.00	35.04	48.88	48.97	50.00	49.97	63.90	63.76	77.03	76.76	94.00	93.87	74.95	75.01	78.93	79.04
28.36	28.45	33.51	33.45	40.53	40.58	47.00	46.88	57.98	58.08	70.39	71.05	51.63	52.04	63.77	63.96
33.99	33.88	38.71	37.77	42.43	41.85	46.77	46.62	56.54	56.61	63.54	63.75	44.64	43.55	69.97	70.02
22.00	21.09	24.00	23.99	26.50	26.53	27.88	26.73	28.00	28.07	37.74	37.85	25.96	26.02	33.65	34.03
27.03	26.56	31.00	30.93	39.00	38.97	44.00	44.08	46.12	46.95	60.00	59.74	44.34	44.63	47.99	50.04
33.00	33.74	40.00	40.04	44.50	44.49	49.54	49.88	59.88	60.01	80.74	81.04	59.88	59.63	75.57	76.02
24.65	24.66	27.43	27.47	28.40	28.70	30.64	30.59	31.62	31.66	33.99	33.90	28.00	27.95	31.73	32.00
19.01	18.91	20.98	21.01	22.03	21.98	25.04	25.44	27.01	27.05	28.00	27.98	25.00	25.05	30.01	30.04
30.01	29.75	33.89	34.01	35.02	34.66	38.00	37.86	46.92	47.01	69.32	68.76	53.00	53.04	67.00	66.74
24.77	24.79	27.80	28.04	29.54	30.06	32.99	33.01	33.12	32.85	38.77	39.04	33.43	32.70	32.26	31.97
28.53	28.45	33.00	32.57	35.97	35.66	35.99	36.23	36.99	37.03	40.60	40.56	32.98	33.43	38.67	39.01

29.10	28.86	32.04	31.94	34.34	34.03	39.01	38.95	37.70	37.89	41.05	40.74	35.32	34.67	31.98	32.04
25.14	24.88	27.76	27.99	29.00	28.67	31.00	31.64	33.55	33.75	40.76	41.02	35.46	35.39	37.96	38.04
35.53	35.58	36.78	37.02	40.90	41.02	45.33	44.98	49.00	49.25	68.77	68.79	68.98	69.35	40.65	41.00
36.77	36.87	40.22	39.93	42.00	42.03	49.83	50.02	61.82	62.03	89.77	89.57	49.64	50.04	60.00	59.78
30.00	29.98	38.77	38.63	41.53	41.48	48.76	49.05	58.54	58.46	71.09	71.01	48.65	49.02	67.98	67.90
29.78	29.75	37.74	38.00	45.00	45.23	48.43	47.96	49.89	49.54	78.44	77.96	40.99	41.43	54.80	55.07
22.53	22.76	23.00	22.93	23.76	24.34	27.05	26.65	28.99	29.01	31.35	30.93	28.88	28.73	32.10	31.67
21.32	21.04	23.09	22.76	25.65	25.99	27.59	28.01	30.43	29.67	40.07	40.09	34.65	35.00	35.88	36.02
34.45	34.42	39.33	39.33	43.10	42.98	48.00	47.95	59.48	59.04	72.42	71.87	50.48	50.51	61.65	62.34
30.05	29.85	34.00	33.88	40.65	41.03	45.94	46.40	52.10	52.09	70.00	70.85	50.00	49.97	68.95	69.14
37.01	37.04	39.00	38.87	47.76	48.02	53.12	52.99	67.45	67.92	96.04	96.14	77.10	77.92	86.23	85.76
22.39	22.11	23.05	23.08	25.60	25.50	27.76	27.82	28.00	27.86	30.44	30.01	29.98	30.01	30.99	31.02
30.00	29.56	32.45	32.47	34.70	35.03	38.61	39.01	41.48	41.45	50.66	51.03	47.65	48.03	49.76	49.89
23.38	21.98	24.43	24.35	27.60	27.59	27.68	28.01	27.83	28.05	37.00	37.04	30.76	31.02	33.87	34.00
36.04	35.96	57.34	57.02	60.00	60.01	68.76	69.01	73.56	74.04	95.00	94.69	70.94	71.04	83.99	83.75
24.45	24.49	23.88	24.01	24.10	23.87	36.55	36.32	37.87	37.93	42.84	42.65	28.10	27.47	40.54	40.45
34.77	34.69	35.64	35.98	45.65	46.32	50.64	50.55	58.52	58.47	66.25	66.11	49.00	48.95	55.97	56.02
24.64	24.90	27.56	28.54	28.00	27.94	29.65	29.73	30.50	30.53	37.54	37.57	28.89	29.01	35.44	36.03
34.38	33.73	36.44	35.98	43.99	44.02	51.98	60.05	53.27	52.75	72.65	72.54	58.00	57.75	68.65	69.00
32.73	32.69	41.44	40.98	42.68	42.41	47.78	47.77	55.75	55.63	60.34	60.42	43.77	43.56	55.77	56.07
23.99	23.54	24.98	25.33	26.34	26.13	26.96	26.70	28.10	28.19	31.10	31.07	28.99	28.88	31.65	32.03
31.80	31.78	39.78	40.09	41.40	41.61	48.00	48.05	63.44	64.41	69.99	69.98	48.44	47.86	67.95	68.43
20.78	20.74	24.77	24.63	26.40	26.57	27.66	27.93	28.70	28.93	37.95	38.02	34.59	35.11	30.76	30.55
30.00	29.65	34.70	35.40	35.60	36.03	40.66	40.94	60.00	60.09	72.66	73.04	52.77	53.01	68.74	68.53
37.65	37.71	46.95	47.01	49.90	50.02	50.65	51.05	68.98	68.98	85.65	86.22	54.87	55.13	80.81	81.08
26.00	25.87	29.06	29.08	29.00	28.76	27.90	28.08	29.34	28.86	34.04	33.97	30.46	30.23	35.47	34.92
27.57	28.01	26.59	27.05	36.00	35.52	38.87	39.03	42.00	42.38	59.30	59.39	40.01	39.92	43.01	43.06
23.99	23.88	24.70	25.09	25.76	26.05	27.07	26.94	29.54	30.04	31.00	31.02	27.64	27.61	29.18	28.96
36.21	36.33	50.93	50.97	69.00	69.24	69.12	69.27	70.75	71.00	95.03	95.04	79.00	79.03	76.68	76.94

30.55	30.34	31.54	32.07	32.00	31.87	33.54	32.65	60.40	59.99	73.99	74.02	56.65	56.73	69.97	69.99
25.00	24.87	31.01	31.04	35.98	36.05	37.00	36.84	44.77	44.92	57.43	57.96	60.95	61.03	56.54	57.00
35.99	36.00	39.99	40.01	49.99	50.22	54.66	55.06	62.98	62.99	73.66	73.92	50.33	50.27	60.39	59.90
24.97	25.00	26.00	26.02	26.98	27.09	28.00	28.08	35.30	34.96	36.00	36.02	28.66	29.02	34.08	33.99
25.99	26.00	31.02	31.00	34.92	35.05	34.56	35.00	38.04	37.96	53.99	54.01	34.77	35.04	39.21	39.53
29.00	29.03	42.13	42.23	43.00	42.98	44.00	44.06	49.88	50.01	68.00	68.03	51.14	50.96	65.32	65.18
23.89	23.54	27.03	26.67	29.00	28.65	30.02	30.00	31.03	31.05	32.02	31.96	27.00	27.87	33.79	34.82
22.11	21.98	24.75	25.01	26.99	27.08	30.43	30.49	33.00	32.98	40.87	40.83	34.98	34.92	33.87	34.00
22.00	21.78	24.00	24.06	24.76	25.01	26.09	26.12	34.50	35.08	40.65	40.64	36.00	35.96	35.54	35.76
36.54	37.00	40.54	40.58	44.65	44.72	59.27	59.02	60.55	61.00	73.99	74.03	45.98	46.02	57.96	58.00
21.56	22.00	23.88	24.00	25.98	26.02	26.32	25.97	28.68	29.03	29.00	29.02	27.00	26.66	28.88	29.07
25.97	25.50	25.97	25.87	27.00	27.07	35.96	36.03	37.56	38.00	41.85	42.06	29.88	30.02	34.99	35.07
33.00	32.95	35.00	35.06	34.93	35.07	38.33	37.98	42.00	41.97	67.95	68.01	46.12	45.76	65.00	64.96
25.93	25.86	26.00	26.34	29.00	29.06	30.88	31.02	37.33	37.63	38.00	38.06	38.68	38.56	42.22	42.27
28.85	28.65	32.00	31.99	33.99	34.01	36.77	37.01	37.65	38.02	40.88	41.04	39.43	38.95	43.89	44.02
24.54	24.45	25.33	25.03	25.03	24.99	27.49	26.60	31.77	32.00	37.87	38.03	24.65	25.04	29.54	30.04
22.00	22.07	23.00	23.08	25.24	25.33	26.05	26.12	29.83	29.67	34.97	34.92	32.10	32.03	37.54	38.24
23.88	24.06	25.70	26.01	27.70	26.68	29.87	30.01	33.62	33.83	39.75	40.07	30.65	30.54	36.74	37.03
28.78	28.37	33.70	34.05	44.32	43.98	47.01	47.00	53.00	53.14	94.32	93.96	61.00	60.57	64.24	63.86
24.65	25.00	25.44	26.00	26.30	26.38	28.00	28.03	29.78	30.05	32.70	33.06	28.66	28.76	29.65	30.08
33.00	32.85	41.00	40.96	42.76	42.85	45.16	45.04	53.50	53.86	68.32	68.53	59.23	59.59	64.32	64.51
28.00	27.95	32.84	33.01	38.60	39.04	40.67	40.23	45.40	46.03	72.00	71.81	49.76	50.15	68.87	69.05
28.97	29.07	36.00	36.07	43.00	42.97	53.13	52.87	60.77	61.07	69.00	68.89	50.00	49.96	64.13	64.00
30.78	30.23	34.88	35.04	36.19	36.54	44.65	45.07	53.74	54.00	71.66	72.00	57.43	57.33	78.58	79.01
34.00	33.87	36.02	35.6	37.00	37.02	41.00	41.06	50.02	49.76	57.35	56.99	46.98	46.50	60.00	59.99
31.99	31.87	37.43	36.8	43.00	42.87	56.03	55.97	70.32	70.54	75.65	75.76	65.44	64.50	72.57	72.97
30.12	30.01	32.97	32.99	40.33	39.76	45.73	46.21	53.54	54.07	78.33	77.95	59.00	59.21	75.59	76.01
20.76	20.83	20.98	20.76	23.90	24.00	27.55	28.12	29.73	29.50	31.70	32.00	28.78	28.95	29.96	30.03
28.99	29.00	33.99	34.02	35.90	36.09	40.64	40.76	44.61	44.72	57.56	58.00	41.65	42.01	45.97	46.01

24.00	23.65	29.88	29.99	36.21	35.97	45.14	44.87	54.36	53.96	69.65	70.02	41.54	42.20	55.88	55.76
27.54	28.01	27.65	28.05	28.60	28.89	29.65	29.99	33.43	33.05	34.45	34.42	30.12	30.00	32.75	32.87
25.00	24.98	30.05	30.00	34.24	34.16	35.23	34.65	35.67	35.76	57.00	56.58	39.02	38.54	44.86	45.00
23.03	22.97	24.99	25.00	25.45	25.47	26.48	26.72	28.07	27.89	29.00	28.85	26.65	27.01	27.51	26.69
23.96	24.06	24.85	24.99	25.90	25.80	26.99	26.79	28.00	27.95	35.99	36.02	30.98	31.08	32.76	33.01
29.14	28.65	33.65	34.08	39.00	39.07	48.61	49.00	53.00	54.86	76.64	77.00	40.51	40.53	73.42	72.97
38.06	38.08	40.47	40.03	47.54	48.07	53.64	54.03	34.62	35.01	79.54	80.02	46.85	47.01	73.55	74.01
20.54	20.99	22.86	23.03	23.54	24.02	24.39	23.87	26.85	25.65	29.00	29.03	26.65	27.01	29.07	29.01
23.77	24.01	25.65	25.51	25.44	24.99	28.90	28.52	29.54	29.94	30.96	31.00	27.66	28.03	29.87	29.72
34.88	35.01	40.49	40.73	42.88	42.96	53.98	53.76	59.86	60.02	72.00	72.03	45.44	44.98	56.00	56.12
20.86	21.12	24.87	24.93	27.54	27.49	27.99	28.02	31.51	31.55	30.68	30.67	29.85	30.41	32.99	32.54
24.70	25.01	26.87	26.69	27.40	26.78	28.60	29.02	31.55	32.01	33.99	34.01	29.87	30.01	33.76	34.06
34.72	35.03	38.00	37.68	43.64	43.76	47.39	46.65	58.00	57.88	92.02	92.01	58.07	58.02	64.08	63.98
26.01	25.87	29.08	28.98	39.35	38.65	41.92	42.03	44.00	43.96	60.30	60.20	37.43	36.76	40.32	40.65
39.97	40.01	49.00	48.87	51.60	51.61	54.96	55.02	60.00	60.09	88.84	89.01	54.96	55.71	69.93	41.01
29.86	28.75	34.65	35.01	36.90	37.03	44.00	43.96	57.54	57.74	63.55	64.02	36.43	37.86	42.39	41.88
23.23	23.04	25.06	24.65	26.00	25.98	27.55	27.54	28.43	28.76	39.89	40.01	28.02	27.86	30.97	31.12
27.99	27.56	35.54	35.65	40.26	39.99	44.87	45.02	55.41	55.24	67.75	67.53	43.85	44.09	52.01	52.02
22.10	21.75	24.88	25.54	26.88	27.01	29.54	29.57	30.54	30.99	33.50	33.40	31.55	31.88	34.96	34.86
22.00	22.12	24.98	24.87	25.88	26.05	27.18	27.03	27.99	28.09	32.99	33.01	28.97	29.04	29.00	28.92
24.00	23.87	24.99	25.02	26.00	26.02	27.99	28.02	28.90	29.00	30.97	30.69	28.96	29.21	31.77	32.04
36.01	35.98	37.97	38.01	44.00	43.97	45.50	44.98	57.97	58.25	70.98	71.01	49.99	50.02	65.00	64.83
24.99	25.33	27.00	27.02	46.86	47.00	48.88	48.96	60.99	61.06	71.98	71.95	48.00	47.87	66.77	67.03
18.88	18.99	20.91	21.08	22.88	22.56	22.65	22.85	26.76	27.03	29.20	29.77	25.30	25.34	27.98	28.02
30.98	31.03	38.63	39.04	44.70	44.68	50.75	51.05	63.95	64.06	70.95	71.01	59.45	59.42	65.52	66.03
36.96	37.01	41.88	42.01	46.00	45.87	53.77	53.89	59.99	60.01	69.65	70.01	51.97	52.01	70.54	70.77
28.65	29.01	33.00	33.01	35.00	34.98	37.77	37.98	38.99	39.00	42.60	42.66	38.91	38.65	40.90	41.02
34.00	33.98	33.86	33.96	57.35	57.35	47.00	46.98	59.09	59.04	67.99	68.06	48.64	49.00	53.80	54.01
24.64	24.56	25.14	24.99	29.33	29.43	29.00	28.99	30.07	30.02	34.23	34.32	33.00	33.01	32.87	33.72

22.97	23.00	30.42	30.44	36.98	37.02	45.57	46.02	59.00	59.01	73.00	72.99	56.99	56.87	70.76	71.00
22.07	22.10	23.66	23.98	25.10	24.99	26.08	25.98	27.00	29.87	28.55	29.03	25.77	25.99	29.06	28.86
28.64	29.03	30.10	30.03	34.39	34.19	40.00	39.98	46.39	46.03	58.18	57.65	45.42	44.98	53.72	54.09
23.25	23.23	25.00	24.98	28.73	29.05	29.20	28.96	33.44	33.01	59.00	59.01	36.00	35.94	38.00	37.02
32.99	32.54	36.10	35.99	39.65	40.01	48.00	48.02	57.77	58.65	67.99	68.01	60.37	59.98	64.60	63.98
33.99	34.01	36.00	35.87	38.90	38.91	43.77	44.04	47.60	47.62	72.54	72.58	54.65	55.04	69.44	68.96
24.65	25.01	41.68	41.79	45.88	45.98	52.00	51.67	57.50	57.78	67.43	66.79	56.98	57.08	61.00	60.96
33.90	34.01	42.98	42.99	45.70	46.04	52.88	53.02	60.00	59.66	82.96	83.02	60.65	61.07	74.88	75.01
35.20	34.87	48.00	47.87	53.63	53.54	54.07	53.97	68.99	69.01	99.37	99.01	69.98	70.04	84.54	84.45
25.00	24.95	27.59	28.09	34.01	33.94	35.02	34.97	37.63	37.53	56.60	57.01	30.50	31.00	35.00	34.74
27.65	28.00	32.84	32.56	40.30	39.98	48.87	49.01	59.90	60.12	70.55	71.03	50.54	51.04	62.63	62.69
22.00	21.55	23.87	24.01	25.60	26.10	27.00	26.89	30.92	31.01	35.95	36.00	31.43	31.34	33.75	34.03
22.21	22.03	26.35	26.49	34.00	34.10	43.64	43.58	42.28	42.02	46.65	47.01	41.07	40.65	41.65	41.98
38.70	38.96	47.88	47.97	52.00	51.65	59.86	59.99	67.97	68.32	93.98	94.10	51.75	51.85	73.18	72.99
27.99	28.04	33.35	32.75	35.40	35.03	38.43	38.97	40.65	41.43	46.00	45.97	44.55	45.00	49.09	48.97
33.77	34.03	39.00	38.96	48.50	48.65	55.58	55.55	58.70	59.09	79.63	79.54	48.39	48.06	65.82	66.01
39.46	40.01	47.00	46.87	52.44	52.05	57.64	58.54	58.50	58.79	80.43	80.44	50.98	51.00	72.65	73.00
22.00	21.98	24.98	25.02	25.88	26.02	27.18	26.79	27.99	28.09	32.99	33.06	28.97	29.52	29.00	28.97
38.89	39.02	41.00	40.95	47.88	48.04	53.88	54.04	67.00	67.07	72.51	73.18	50.61	51.08	62.95	63.00
22.00	22.01	24.93	25.03	27.85	28.01	30.43	30.09	39.34	38.92	63.86	64.03	53.98	54.00	57.59	58.03
18.46	19.00	21.00	20.76	23.99	23.64	26.00	25.99	27.13	27.02	29.35	29.96	24.77	25.15	29.01	28.89
22.85	22.90	23.54	24.00	26.88	27.20	28.76	28.52	29.90	29.67	31.00	30.87	27.89	28.05	30.00	29.87
27.56	28.00	35.85	35.95	41.00	40.59	47.00	46.69	51.56	51.45	70.33	69.98	45.77	46.02	50.67	51.11
29.65	29.87	36.00	35.65	41.79	42.01	48.41	48.04	58.65	58.45	61.77	62.01	43.42	42.99	58.00	57.86
24.32	23.98	31.03	30.98	33.00	32.86	37.67	38.43	43.99	44.07	54.32	54.33	39.54	40.42	43.00	42.78
33.03	32.98	34.01	33.65	36.95	37.26	43.03	42.87	57.00	56.58	70.00	69.97	49.05	49.10	64.77	65.00
25.77	25.78	26.00	25.69	38.65	39.00	40.95	41.06	50.13	49.95	65.44	64.98	37.97	36.87	50.99	51.07
31.49	31.54	33.00	32.64	37.76	38.02	40.54	41.65	46.90	47.04	54.88	55.25	42.00	41.87	49.64	49.95
29.67	29.50	31.99	32.06	36.77	37.76	43.60	42.02	55.77	58.00	68.40	67.74	46.65	47.01	59.45	49.98

28.93	29.09	29.10	28.85	35.01	34.97	39.05	39.01	41.65	42.04	63.00	63.08	47.10	46.93	64.00	63.56
34.00	33.96	38.75	38.69	44.37	44.85	51.66	52.01	57.99	58.44	69.36	69.02	50.49	50.57	60.65	61.00
21.78	21.62	22.00	21.59	22.27	22.74	23.40	23.87	23.00	22.78	25.05	24.96	22.32	22.34	23.00	22.90
29.65	29.64	35.99	35.94	42.00	41.67	49.60	50.02	59.65	60.01	67.43	67.04	40.11	39.58	51.89	52.07
28.99	29.00	29.08	28.98	35.76	36.00	47.00	47.03	50.99	50.98	71.00	71.05	53.04	52.87	49.30	48.97
27.01	27.00	33.00	32.56	34.04	34.00	38.23	38.03	51.02	50.98	53.16	52.76	40.23	40.02	45.12	44.76
28.44	28.24	33.66	34.03	38.84	39.01	45.00	45.10	57.65	58.02	79.00	78.59	65.35	64.86	73.00	72.94
23.65	23.97	25.39	25.26	27.50	27.77	28.76	28.92	29.65	30.02	33.56	33.60	28.85	29.01	33.43	33.40
35.00	34.99	37.60	37.59	39.10	39.04	50.87	50.76	57.01	56.95	88.77	89.02	71.95	72.00	76.78	77.02
28.00	27.75	29.54	30.04	30.85	31.02	34.73	35.01	36.54	36.73	48.88	48.93	39.88	40.01	45.44	45.46
22.00	21.78	23.43	23.41	24.54	25.00	26.30	25.59	29.09	28.99	32.67	33.07	28.61	28.52	29.76	30.04
25.76	25.77	27.76	27.89	29.90	30.08	30.00	30.03	32.37	32.11	39.78	40.03	32.66	32.65	35.78	36.00
29.04	29.00	30.00	29.76	37.54	37.89	46.54	46.59	54.83	55.01	77.98	78.07	50.99	51.07	70.59	71.00
24.76	25.07	27.45	28.09	29.75	28.98	30.93	31.06	34.01	33.98	41.21	40.76	28.92	29.08	39.53	40.01
28.00	27.90	34.97	34.99	39.93	40.02	43.76	44.13	59.00	58.88	71.14	71.06	53.52	54.00	61.65	62.07
18.96	19.04	22.12	22.08	25.30	24.98	27.78	28.02	29.80	29.81	29.43	29.42	25.62	26.06	30.04	29.98
33.96	34.04	37.85	38.23	40.21	39.99	47.19	47.03	55.38	55.02	85.92	86.01	62.00	62.02	80.92	81.43
27.00	26.68	30.04	29.95	34.76	35.01	37.65	38.03	43.23	42.76	58.02	58.02	52.65	53.06	56.43	56.23
30.86	30.80	40.51	41.04	47.00	46.87	52.00	52.00	60.35	59.98	93.88	94.04	57.97	60.00	72.77	73.05
24.90	25.01	26.74	27.06	27.41	27.75	31.00	31.07	36.00	35.98	54.88	55.01	38.53	39.76	30.12	30.00
39.60	39.62	45.77	46.58	49.75	50.02	57.96	58.00	63.55	64.02	87.00	86.98	62.38	63.06	84.75	85.01
23.32	23.30	24.82	25.00	27.00	27.02	29.54	30.05	31.08	31.03	31.07	30.65	29.05	29.09	31.11	30.65
21.45	21.59	23.68	24.06	27.96	28.68	31.45	31.07	36.65	36.76	39.76	40.03	36.38	35.98	36.09	35.98
20.54	20.84	23.09	22.87	23.21	22.96	26.05	25.71	27.64	27.68	30.65	31.02	27.63	27.99	29.65	29.51
27.54	28.06	39.00	38.76	48.21	47.77	50.52	50.52	56.00	55.98	73.39	72.76	47.51	48.04	71.65	72.00
22.60	22.50	24.67	24.70	26.66	26.68	28.98	29.03	30.37	30.21	33.65	33.55	30.77	30.56	32.67	32.96
32.00	31.99	38.00	38.01	42.04	41.87	48.00	47.76	59.67	60.01	98.06	99.10	79.58	79.95	67.21	66.69
23.43	23.24	25.98	25.89	26.09	26.00	28.08	27.98	33.97	34.00	35.01	34.99	27.68	28.01	31.88	31.99
32.65	32.67	34.57	35.00	44.07	43.92	50.88	50.54	54.10	54.06	80.53	80.53	51.65	51.70	73.99	74.00

22.08	21.96	25.87	26.01	32.00	32.10	32.10	31.96	33.39	33.10	37.43	37.53	30.55	30.57	34.96	35.00
24.55	24.97	24.65	25.00	25.54	25.51	26.76	27.00	28.78	28.58	35.83	35.99	27.79	27.80	30.65	30.69
28.85	29.02	33.98	34.04	43.00	42.89	48.94	49.01	59.00	58.87	77.05	77.03	77.01	76.99	66.53	66.59
36.99	37.04	37.00	37.06	43.23	42.65	51.07	50.98	59.32	59.06	68.65	69.00	57.43	57.33	61.54	61.75
20.67	20.98	22.88	22.97	25.97	25.99	28.35	28.30	29.66	29.97	37.65	37.45	33.00	32.97	34.83	35.00
29.73	30.02	33.00	33.05	34.69	35.01	41.65	41.85	48.60	48.50	81.97	82.00	58.66	58.69	73.00	72.76
37.98	38.03	41.65	41.63	45.12	44.79	51.99	52.02	71.00	70.99	90.00	90.01	77.30	77.35	82.28	82.25
16.90	16.78	21.00	20.99	23.01	22.96	29.02	29.00	30.86	30.88	32.01	32.00	26.51	26.59	31.22	31.05
33.44	33.03	39.94	40.01	41.00	41.02	51.00	51.05	57.79	58.00	63.97	63.58	43.64	43.60	48.34	48.32
31.71	31.78	37.72	37.81	42.00	41.99	50.60	50.55	57.65	57.67	69.54	70.00	58.98	59.00	64.99	65.01
24.75	24.66	29.97	30.08	37.30	37.25	45.55	46.01	55.43	55.40	65.54	65.99	35.00	34.50	47.88	47.89
24.85	24.67	23.33	23.32	27.00	27.02	29.00	29.02	34.24	34.33	36.90	37.00	33.00	33.02	33.33	33.25
23.65	24.00	25.96	26.01	27.10	27.04	33.83	33.99	33.70	33.80	39.65	40.00	27.40	27.43	38.00	38.38
33.27	33.20	36.00	36.04	40.23	40.29	48.67	48.77	57.65	57.67	82.60	82.62	64.07	64.03	79.65	79.90
21.85	21.89	24.87	24.99	29.65	29.67	30.54	30.55	31.00	31.02	36.65	36.72	33.76	34.01	35.99	36.00
37.56	37.59	49.03	48.99	57.00	56.89	60.00	59.98	64.02	63.87	86.12	86.08	74.90	75.03	77.30	77.35
34.01	33.98	42.88	42.99	49.02	48.99	52.32	53.32	64.00	63.99	85.93	85.98	61.77	61.99	69.00	68.99
38.00	37.99	44.01	44.05	48.98	48.89	55.65	55.74	60.03	59.99	98.01	97.99	67.63	67.71	83.00	82.99
22.00	21.99	21.98	21.99	23.88	23.99	24.00	23.99	26.77	26.97	37.87	37.87	28.97	29.03	34.62	34.63
23.00	23.02	25.00	24.99	26.55	26.97	31.00	30.99	33.02	32.87	37.27	37.26	32.84	32.96	33.72	33.76

APPENDIX L
Developed Models: External Validation Analysis

Table L1: External Validation Analysis, Actual Values vs Predicted Values for the Hearing Threshold

250Hz		500Hz		1kHz		2kHz		3 kHz		4kHz		6kHz		8kHz	
Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value	Observed Value	Predicted Value
24.97	25.02	26.00	26.03	26.98	27.00	28.00	27.98	35.30	35.32	36.00	36.01	28.66	28.91	34.08	34.19
25.99	26.01	31.02	31.09	34.92	35.02	34.56	34.59	38.04	38.06	53.99	54.90	34.77	35.02	39.21	39.21
36.54	37.72	40.54	40.65	44.65	43.93	59.27	59.43	60.55	60.89	73.99	74.30	45.98	46.26	57.96	57.86
21.56	21.69	23.88	24.00	25.98	26.00	26.32	26.20	28.68	28.70	29.00	30.20	27.00	27.09	28.88	29.01
35.00	34.85	37.60	37.58	39.10	39.25	50.87	50.90	57.01	56.76	88.77	88.76	71.95	72.01	76.78	76.99
25.76	25.78	27.76	27.99	29.90	30.00	30.00	30.01	32.37	31.97	39.78	40.02	32.66	33.21	35.78	36.02
29.04	28.67	30.00	30.02	37.54	38.01	46.54	47.01	54.83	55.01	77.98	77.67	50.99	50.89	70.59	71.06
24.76	25.00	27.45	27.65	29.75	29.99	30.93	31.04	34.01	33.89	41.21	40.76	28.92	29.09	39.53	40.02
28.00	27.94	34.97	35.04	39.93	39.74	43.76	44.84	59.00	59.43	71.14	70.80	53.52	53.99	61.65	62.27
18.96	19.70	22.12	21.87	25.30	26.01	27.78	28.03	29.80	30.09	29.43	29.98	25.62	26.02	30.04	29.98
33.96	34.03	37.85	37.99	40.21	39.98	47.19	46.98	55.38	54.65	85.92	86.02	62.00	61.56	80.92	80.75
27.00	27.04	30.04	29.86	34.76	35.00	37.65	37.98	43.23	42.35	58.02	57.96	52.65	52.73	56.43	55.98
30.86	31.08	40.51	41.22	47.00	46.58	52.00	51.79	60.35	59.67	93.88	94.02	57.97	58.01	72.77	73.02
24.90	25.06	26.74	27.04	27.41	27.03	31.00	30.65	36.00	35.98	54.88	54.99	38.53	39.02	30.12	29.75
36.00	35.92	39.00	38.87	45.14	44.78	47.50	47.49	55.00	54.67	94.00	93.97	83.65	84.01	76.03	75.89
28.00	27.89	32.19	32.01	39.00	39.04	43.54	44.03	43.80	43.95	48.40	47.89	46.00	46.02	43.87	44.02
19.01	20.02	20.98	21.33	22.03	21.98	25.04	24.95	27.01	26.78	28.00	28.05	25.00	24.99	30.01	29.87
30.01	29.97	33.89	34.03	35.02	34.76	38.00	37.94	46.92	47.03	69.32	68.78	53.00	52.96	67.00	66.53
28.53	28.56	33.00	33.07	35.97	35.87	35.99	36.07	36.99	37.00	40.60	41.04	32.98	32.87	38.67	38.53
35.53	36.02	36.78	36.98	40.90	41.07	45.33	44.87	49.00	48.87	68.77	69.01	68.98	68.76	40.65	40.78

APPENDIX M

Details of Explanation of the Feasibility of the Optimal Age and Years of Exposure at the Responses of Frequency 250 Hz – 8 kHz.

$HT_{250\ Hz} = 44.14 + 0.6AG - 0.2NL - 0.01AG^2$

$= 44.14 + 0.6(57) - 0.2(93.2) - 0.01(57)^2$

$= 27.21$ dB < 30 dB (Feasible).

If the worker starts work at age (57 -18) years; with 37 years of exposure to the noise in the quarry, by then, the age will be (57 - 18) + 37 years = 76 years > 52 years which is not feasible.

It is better for the worker in this category of age to have exposed to the noise exposure for the maximum of 13 years, when the age would have reached 52 years, after which he must be working at less noisy work zone.

$HT_{500\ Hz} = 337.4 - 2.6AG - 0.01AG*NL - 0.03AG^2 - 0.01NL^2$

$= 337.4 - 2.6(49) - 0.01(49)(96.7) - 0.03(49)^2 - 0.01(96.7)^2$

$= 90.59$ dB > 30 dB (Not Feasible).

If the worker starts work at age (49 -18) years; with 33 years of exposure to the noise in the quarry, by then, the age will be (49 - 18) + 33 years = 64 years > 52 years which is not feasible.

It is better for the worker in this category of age to have maximum of 21 years of noise exposure, when the age would have reached 52 years, after which he must be working at less noisy work zone.

$HT_{1\ kHz} = 48.12 - 1.6AG + 0.6YE + 0.02AG^2$

$= 48.12 - 1.6(43) + 0.6(13) + 0.02(43)^2$

$= 24.3$ dB < 30 dB (Feasible).

If the worker starts work at age (43 -18) years; with 13 years of exposure to the noise in the quarry, by then, the age will be (43 - 18) + 13 years = 38 years < 52 years which is feasible.

The worker in this category of age can still work in production section for up to 17 years of noise exposure, when the age would have reached 52 years, after which he must be working at less noisy work zone.

$HT_{2\ kHz} = 196.76 - 3.03AG + 1.5YE + 0.03AG^2 - 0.01NL^2$

$= 196.7 - 3.03(42) + 1.5(3) + 0.03(42)^2 - 0.01(94.8)^2$

$= 37.05$ dB > 30 dB (Not Feasible).

If the worker starts work at age (42 -18) years; with 3 years of exposure to the noise in the quarry, by then, the age will be (42 - 18) + 3 years = 27 years < 52 years, which is feasible.

The worker in this category can still be fitted into the production section for the maximum time of 25 years of noise exposure, when the age would have reached 52 years, after which he must be working at less noisy work zone.

$HT_{3\ kHz} = 60.9 - 1.16AG + 0.02AG^2 - 0.04YE^2$

$= 60.9 - 1.16(52) + 0.02(52)^2 - 0.04(2)^2$

$= 50.304$ dB > 30 dB (Not Feasible)

If the worker starts work at age (52 -18) years; with 2 years of exposure to the noise in the quarry, by then, the age will be (52 - 18) + 2 years = 36 years < 52 years, which is feasible.

The workers in this category have the opportunity of maximum of 18 years of noise exposure, when the age would have reached 52 years, after which he must be working at less noisy work zone.

$HT_{4\,kHz} = 104.3 - 0.35AG – 0.08AG*YE$

$= 104.3 – 0.35(60) – 0.08(60)(3)$

$= 68.9$ dB >30 dB (Not Feasible).

If the worker starts work at age (60 -18) years; with 3 years of exposure to the noise in the quarry, by then, the age will be (60 - 18) + 3 years = 45 years < 52 years, which is feasible.

There is maximum opportunity of 7 years for the worker in this category to work in the production section, when the age would have reached 52 years, after which he must be working at less noisy work zone.

$HT_{6\,kHz} = 35.08 – 0.16AG$

$= 35.08 – 0.16 (55)$

$=26.28$ dB < 30 dB (Feasible).

If the worker starts work at age (55 -18) years; with 1 year of exposure to the noise in the quarry, by then, the age will be (55 - 18) + 1 year = 38 years < 52 years which is feasible.

The worker in this category still safe to work in noisy working area for the maximum period of 15 years, when the age would have reached 52 years, after which he must be working at less noisy work zone.

$HT_{8\,kHz} = 87.26 – 1.53AG$

$=87.26 – 1.53(38)$

$= 29.12$ dB < 30 dB (Feasible).

If the worker starts work at age (38 -18) years; with 32 years of exposure to the noise in the quarry, by then, the age will be (38 - 18) + 32 years = 52 years which is feasible. The worker in this category can only work for 32 years or less in production section safely. After 32 years, the worker must be placed on less noise working zone.

The only feasible optimisation value of age is from 8 kHz frequency as 38 years or less and years of exposure as 32 years or less. Conclusively, this work predicts that the age of workers that works in the production or the noisy area in the quarry should not be more than 52 years with 32 years or less of noise exposure.

Thus, this expression : $(X - 18) + Y \leq 52$ can be used to explain the relationship between the present age of the worker in the quarry and the optimal year of exposure to the noise, where X represent the present age of the workers and Y represent the optimal years of exposure to the noise.

APPENDIX N

Paired Sample Pearson Correlation, Coefficient of Mean Difference and Paired sample t- test

```
FILTER OFF.

USE 1 thru 185.

EXECUTE.

T-TEST PAIRS=NHTL@250 Hz NHTL@500 Hz NHTL@1 kHz NHTL@2KHz NHTL@3 kHz NHTL@4 kHz NHTL@6 kHz NHTL@8 kHz WITH HTL@250 Hz HTL@500 Hz HTL@1kHz HTL@2 kHz HTL@3 kHz HTL@4 kHz HTL@6 kHz HTL@8 kHz (PAIRED)

  /CRITERIA=CI(.9500)

  /MISSING=ANALYSIS.
```

T-Test

Notes

Output Created		29-OCT-2019 01:31:04
Comments		
Input	Data	D:\orry JOHNSON\Ori_Post_Sem1.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	185
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=NHTL@250Hz NHTL@500 Hz NHTL@1 kHz NHTL@2 kHz NHTL@3 kHz NHTL@4 kHz NHTL@6 kHz NHTL@8 kHz WITH HTL@250 Hz HTL@500 Hz HTL@1 kHz HTL@2 kHz HTL@3 kHz HTL@4 kHz HTL@6 kHz HTL@8 kHz (PAIRED) /CRITERIA=CI(.9500) /MISSING=ANALYSIS.
Resources	Processor Time	00:00:00.08
	Elapsed Time	00:00:00.16

[DataSet1] D:\orry JOHNSON\Ori_Post_Sem1.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	
Pair 1	Hearing_Threshold_250 Hz after 1yr	27.59	185	4.381	
	Hearing_Threshold_250 Hz	24.23	185	7.870	
Pair 2	Hearing_Threshold_500 Hz after 1yr	31.79	185	5.662	
	Hearing_Threshold_500 Hz	27.09	185	5.051	
Pair 3	Hearing_Threshold_1 kHz after 1yr	36.93	185	6.559	
	Hearing_Threshold_1 kHz	30.32	185	6.587	
Pair 4	Hearing_Threshold_2 kHz after 1yr	42.71	185	7.564	
	Hearing_Threshold_2 kHz	33.64	185	8.307	
Pair 5	Hearing_Threshold_3 kHz after 1yr	50.07	185	9.222	
	Hearing_Threshold_3 kHz	37.66	185	9.973	
Pair 6	Hearing_Threshold_4 kHz after 1yr	65.02	185	13.979	
	Hearing_Threshold_4 kHz	46.49	185	15.544	
Pair 7	Hearing_Threshold_6 kHz after 1yr	45.94	185	12.610	
	Hearing_Threshold_6 kHz	36.59	185	12.157	
Pair 8	Hearing_Threshold_8 kHz after 1yr	48.72	185	12.139	
	Hearing_Threshold_8 kHz	39.23	185	11.839	

Paired Samples Statistics

		Std. Error Mean
Pair 1	Hearing_Threshold_250 Hz after 1yr	0.317
	Hearing_Threshold_250 Hz	0.569
Pair 2	Hearing_Threshold_500 Hz after 1yr	0.410
	Hearing_Threshold_500 Hz	0.365
Pair 3	Hearing_Threshold_1 kHz after 1yr	0.475
	Hearing_Threshold_1 kHz	0.477
Pair 4	Hearing_Threshold_2 kHz after 1yr	0.547
	Hearing_Threshold_2 kHz	0.601
Pair 5	Hearing_Threshold_3 kHz after 1yr	0.667
	Hearing_Threshold_3 kHz	0.722
Pair 6	Hearing_Threshold_4 kHz after 1yr	1.012
	Hearing_Threshold_4 kHz	1.125
Pair 7	Hearing_Threshold_6 kHz after 1yr	0.912
	Hearing_Threshold_6 kHz	0.880
Pair 8	Hearing_Threshold_8 kHz after 1yr	0.878
	Hearing_Threshold_8 kHz	0.857

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Hearing_Threshold_250 Hz after 1yr & Hearing_Threshold_250 Hz	185	0.436	0.000
Pair 2	Hearing_Threshold_500 Hz after 1yr & Hearing_Threshold_500 Hz	185	0.821	0.000
Pair 3	Hearing_Threshold_1 kHz after 1yr & Hearing_Threshold_1 kHz	185	0.770	0.000
Pair 4	Hearing_Threshold_2 kHz after 1yr & Hearing_Threshold_2 kHz	185	0.742	0.000
Pair 5	Hearing_Threshold_3 kHz after 1yr & Hearing_Threshold_3 kHz	185	0.705	0.000
Pair 6	Hearing_Threshold_4 kHz after 1yr & Hearing_Threshold_4 kHz	185	0.795	0.000
Pair 7	Hearing_Threshold_6 kHz after 1yr & Hearing_Threshold_6 kHz	185	0.166	0.022
Pair 8	Hearing_Threshold_8 kHz after 1yr & Hearing_Threshold_8 kHz	185	0.664	0.000

Paired Samples Test

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean					
Pair 1	Hearing_Threshold_250 Hz after 1yr - Hearing_Threshold_250 Hz	3.361	7.147	0.517					
Pair 2	Hearing_Threshold_500 Hz after 1yr - Hearing_Threshold_500 Hz	4.696	3.256	0.236					
Pair 3	Hearing_Threshold_1 kHz after 1yr - Hearing_Threshold_1 kHz	6.613	4.458	0.323					
Pair 4	Hearing_Threshold_2 kHz after 1yr - Hearing_Threshold_2 kHz	9.063	5.738	0.415					
Pair 5	Hearing_Threshold_3 kHz after 1yr - Hearing_Threshold_3 kHz	12.403	7.409	0.536					
Pair 6	Hearing_Threshold_4 kHz after 1yr - Hearing_Threshold_4 kHz	18.524	9.575	0.693					
Pair 7	Hearing_Threshold_6 kHz after 1yr - Hearing_Threshold_6 kHz	9.351	15.996	1.157					

Pair 8	Hearing_Threshold_8 kHz after 1yr - Hearing_Threshold_8 kHz	9.492	9.832	0.711						

Paired Samples Test

		Paired Differences				
		95% Confidence Interval of the Difference				
		Lower	Upper			
Pair 1	Hearing Threshold_ 250 Hz after 1yr – Hearing Threshold 250 Hz	2.341	4.381			
Pair 2	Hearing Threshold 500 Hz after 1yr – Hearing Threshold 500 Hz	4.232	5.161			
Pair 3	Hearing Threshold 1kHz after 1yr - Hearing Threshold 1 kHz	5.976	7.249			
Pair 4	Hearing Threshold 2 kHz after 1yr – Hearing Threshold 2 kHz	8.244	9.882			
Pair 5	Hearing Threshold 3 kHz after 1yr – Hearing Threshold 3 kHz	11.346	13.461			
Pair 6	Hearing Threshold 4 kHz after 1yr – Hearing Threshold 4 kHz	17.157	19.890			
Pair 7	Hearing Threshold 6 kHz after 1yr – Hearing Threshold 6 kHz	7.068	11.634			

Pair 8	Hearing Threshold 8 kHz after 1yr – Hearing Threshold 8 kHz	8.089	10.895			

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	Hearing Threshold 250 Hz after 1yr – Hearing Threshold 250 Hz	6.500	184	0.000
Pair 2	Hearing Threshold 500 Hz after 1yr – Hearing Threshold 500 Hz	19.933	184	0.000
Pair 3	Hearing Threshold 1 kHz after 1yr – Hearing Threshold 1 kHz	20.502	184	0.000
Pair 4	Hearing Threshold 2 kHz after 1yr – Hearing Threshold 2 kHz	21.829	184	0.000
Pair 5	Hearing Threshold 3 kHz after 1yr – Hearing Threshold 3 kHz	23.136	184	0.000
Pair 6	Hearing Threshold 4 kHz after 1yr – Hearing Threshold 4 kHz	26.738	184	0.000
Pair 7	Hearing Threshold 6 kHz after 1yr – Hearing Threshold 6 kHz	8.079	184	0.000
Pair 8	Hearing Threshold 8 kHz after 1yr – Hearing Threshold 8 kHz	13.342	184	0.000