DEVELOPING A NATURAL ACOUSTIC BARRIER FOR URBAN AREAS

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DECLARATION PAGE OF THE CANDIDATE & SUPERVISOR

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ABSTRACT

Increasing noise pollution has severally effected the urban areas where noise generated by traffic is considered as the major noise polluter. As a solution to the noise problem using noise barriers is an approach proven to be effective but due to land scarcity and social needs in urban areas applying noise barrier solution is challenging. Using a natural barrier as a noise barrier is a promising approach. Natural barriers are large or small closely grown tree belts, vegetation walls, natural stone structures, tree fences etc. Natural barriers, have emerged as the new trend to address problems in urban areas and has developed into vertical gardening, green roofs and hybrid natural barriers presently. The use of natural barriers as a solution is highly dependent on the human perception.

The research was carried out to identify the human perception and human acceptance of natural barriers in Sri Lankan context and find out the level of acoustic disturbance people are facing. Focusing urban and suburb areas a quantitative approach was adopted via a questionnaire survey and actual sound measurements were taken in the western province of Sri Lanka. Secondly field testing was carried out to evaluate the performance of existing natural barriers to identify their acoustic performance. Closely grown tree belts which assumes a cuboid shape were used as test barriers. Multiple Linear Regression (MLR) models Artificial Neural Network (ANN) models were used to evaluate the performance of natural barriers. Cuboid shape natural barrier with 85% of green cover or more and overall height closer to 2 meters or more has proven to be an effective acoustic barrier for urban areas.

DEDICATION

I dedicate this work to my loving parents and Mrs Sandani Molligoda

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LIST OF ABBREVIATIONS

	Abbreviation	Phrase
01	*ANN*	*Artificial Neural Networks*
02	*ANSI*	*American National Standards Institute*
03	*ASTM*	*American Society for Testing and Materials*
04	*GC*	*Green Cover*
05	*IEC*	*International Electro-technical Commission*
06	*MLP*	*Multi-Layer Perceptron*
07	*MLR*	*Multiple Linear Regression*
08	*NIOSH*	*National Institute for Occupational Safety & Health*
09	*SLM*	*Sound Level Meter*
10	*SPL*	*Sound Pressure Level*
11	*US EPA*	*United States Environmental Protection Agency*
12	*VGS*	*Vertical Greenery System*
13	*WHO*	*World Health Organization*

LIST OF SYMBOLS

	Description	Symbol	Unit
01	*Sound level*	dB	*dB*
02	*A weighted time averaged noise level*	L_{Aeq}	*dB*
03	*Time averaged noise level*	L_{eq}	*dB*
04	*Equivalent Diurnal Noise Levels*	L_{eqD}	*dB*
05	*Sound intensity*	I	W/m^2
06	*Height*	h	*m*
07	*Temperature*	T	^0C
08	*Relative humidity*	RH	-
09	*Time (duration)*	t	*s*

THESIS

1. INTRODUCTION

1.1. BACKGROUND

It is evident that urbanization is rapidly taking place in the world. From the total population 54% lives in urban areas. In 1950 only 30% of the world population lived in urban areas and it has been projected that by 66% of the total population of the world will be living in urban areas. The urban population of the world has grown rapidly since 1950, from 746 million to 3.9 billion in 2014 (United Nations, 2014).

It is a fact that urbanization occurring rapidly. It is required to share the benefits of urbanization equally in the world while reaching for a sustainable approach, while mitigating most of the problems occurred by rapid development and urbanization .Urbanization is quickly transitioning communities from the natural environment to man-made urban engineered infrastructure (United Nations, 2002).Under anthropogenic influence, moving away from nature and rapid urbanization has lead the world in to many kinds of pollutions. As a result more sustainable and nature friendly approaches are critically in demand. Noise pollution is one of the results from the above mentioned scenario and noise pollution goes in parallel with urbanization. Noise pollution problems are mostly neglected and overlooked. With the development and increase in population and human needs, noise pollution has increased in an alarming rate. Increase of human activities in congested main cities has turned the problem from bad to worse.
Prevailing situation regarding urbanization in Sri Lanka is not much different from the macro view of the world. Urbanization in Sri Lanka occurs at a rapid rate as a developing country. Over the past decades urban areas like city of Colombo, has gone through a rapid development in many sectors as in industrial, commercial, educational, health and other social activities. Population density has also grown up along with development. Population density of Colombo 17669/ km^2 (Sri Lanka Census of Population and Housing, 2011). It is justifiable to assume more congested the urban areas get, noisier the surrounding will be. Noise pollution in urban areas can be categorized as follows.

1. Industrial noise pollution.
2. Vehicle noise pollution.
3. Public noise pollution.

Excessive sound levels in urban areas have become a disturbance to daily life style. Acceptable noise level in municipal councils and urban council areas are 63 dB during day time and 50 dB during night (Minister of Transport, Environment and Women's & Affairs , Sri Lanka, 1996). There are reasons to believe that the existing noise levels are higher than the recommended noise levels in highly congested city areas like Colombo in the country.

It has been identified that the traffic noise to be the main noise polluter in the city areas. Due to severity of sound pollution, actions have been already taken by the government of Sri Lanka to amend the Motor Traffic Act to accommodate the new legal provisions of noise pollution, as the transport sector is the main noise polluter in the urban areas of the country.

According to Sri Lankan National Environmental Noise Control Regulations No 1 of 1996, Gazette No 924/12, accepted noise levels considering human comfort and health are as in Table 1-1.

Table 1-1. Permissible Noise Levels According to Sri Lankan Regulations

Area	**L_{Aeq},T (dB)**	
	Day time	**Night time**
Low Noise (Pradeshiya Sabha area)	55	45
Medium Noise (Municipal /Urban Council area)	63	50
High Noise (EPZZ of BOI & Industrial Estates)	70	60
Silent Zone (100 m from the boundary of a courthouse, hospital, public library, school, zoo, sacred areas and areas set apart for recreational environmental purposes)	50	45

After identifying the noise pollution occurring due to vehicular noise, Sri Lankan government has imposed laws to control vehicular noise from vehicle horns. According to regulations made by Minister of Environment under Section 23 Q of the National Environmental Act, No. 47 of 1980 with Section 32 of the aforesaid Act the permissible vehicular horn noise levels are as in Table 1-2. (Ministry of Environment Sri Lanka, 2011)

Table 1-2. Allowable vehicular horn noise levels in Sri Lanka

Distance (m)	Sound pressure levels L_{Amax} in dB(A)
02 m in open space from the front of the vehicle when the vehicle is in a stationary position and the engine is switched on.	105
07 m in open space from the front of the vehicle when the vehicle 93 is in a stationary position and the engine is switched on.	93

1.2. Noise and sound

Sound waves are compressional and oscillatory disturbance that occurs and propagate in a fluid. A Propagating sound wave induce a pressure difference which is sensitive to human ear and we practically experience it as hearing. Human hearing range is defined in 20-20000 Hz, where human ear is more sensitive in 1-5 kHz range. Pure tone of 1000 Hz in a pressure of 20 µPa is considered as the standard threshold of hearing, and threshold of pain is considered as 100 Pa. However the loudness of sound is subjective according to the listener. Normally perception of loudness doubles for every 10 dB for average person. Zero decibel is the lowest limit of perception of sound where 130 dB sound level would induce painful perception. Doubling of sound source may double the sound intensity level at a receiver inducing 3 dB difference. Human hearing pattern is considered to be logarithmic and difference of 1 dB can be detected by human ear while difference of 3 dB is perceived by average human ear more effectively.

It is important to grasp basic facts regarding acoustics. Difference between noise and sound can be expressed as follows. Noise is consist of irregular fluctuations of vibrations and it is considered as a disturbance to human ear. Whereas sound consist of regular fluctuation of vibrations which is also considered as desirable to ear. Where one particular receiver identifies a vibration as noise, there is a possibility that the anther receiver do not consider that particular vibration as noise, this is the subjective perception of noise .Noise characteristics, duration, and time of occurrence can affect the subjective impression of the noise.

1.3. Approach of solution

Providing necessary solutions to remedy excessive noise in a congested area should be done very carefully. Especially when providing a solution for traffic noise, noise barriers will act as an effective method. However installing noise barriers in congested city areas will require space and it is possible that these noise barriers will act as an obstacle to main functionality of commercial buildings by screening them from their customers. For example very tall or very thick noise barriers will not be suitable. Whatever the solution introduced in the city areas should be able to go in line with the lifestyle and society of the particular area.

Noise related problems are highly dependent on the perception of the receiver. Since the perception of noise is highly subjective any remedial action or solution for noise related problems will also be judged by the human perception. Hence it is very important to come up with a solution for excessive noise which is suitable for the conditions in urban areas and also in parallel with the lifestyle and human perception.

There is an opportunity to apply a natural noise barrier which would remedy the noise problem in urban areas. Other than an artificial barriers, natural barriers seems to have an appealing characteristics and blending nature with the human lifestyle. Replacing artificial barriers and fences in urban areas with natural barriers will improve the green cover in the urban areas and it will also be a part of green building concept which is very popular in the world. Exponentially growing green building concept is considered as one of the successful sustainable and environmental friendly movement (Kibert, 2012). Green building trends in the world has been the reason for business opportunities and benefits in new and retrofit market in over 60 countries, and this trend is currently developing at an accelerating rate (McGraw-Hill Construction, 2013).Hence a solution of a green noise barrier will be an appropriate and felicitous solution.

In many countries solution of natural sound barriers have been adopted to reduce the excessive noise levels. If a natural sound barrier solution can be developed to reduce noise levels in urban areas, the solution will be cost effective, environmental friendly and aesthetically appealing in addition to the main benefit of controlling and reducing sound levels

1.4. Natural barriers

Barriers act as a space separation element. Walls, fences and berms can be given as examples. Example for natural barriers are large or small closely grown tree belts, vegetation walls, natural stone structures, tree fences etc. Natural barriers, have emerged as the new trend to address problems in urban areas and has developed into vertical gardening, green roofs and hybrid natural barriers presently. The use of natural barriers is highly dependent on the human perception which is focused on natural barrier's functionality, maintainability, effectiveness of performance, security and aesthetic appeal.

1.5. Scope of the research

The scope of the research is to investigate and evaluate the performance of suitable natural barriers as a noise barrier which can be applied in urban context. The type of natural barrier investigated in this research is closely grown vegetation belts without canopy. Investigation of public perception regarding noise disturbances and natural barriers is included in the scope. The study area of the research limits to selected urban and sub-urban areas in Western Province Sri Lanka.

1.6. Objectives of the research

Concept of noise barriers is effective method in controlling noise levels created by traffic. Walls and berms are most common types of noise barriers, however building berms structures would require more space and land which is scare in urban areas. Providing buffer zones to control noise would be an inappropriate and un-economical approach in urban areas. Hence as a solution a noise barrier with less space requirement is required.

In urban context a large barrier or wall will obstruct the buildings access and appearance which will eventually become a disturbance to the expected functionalities and urban life style. A barrier which will blend well with the urban context and accepted by the people is required. A natural barrier built using vegetation possess a great potential in blending with the urban nature without disrupting and bring about many benefits to the surroundings eventually being well accepted by the urban society as a solution. As an added advantage a natural tree barrier concept will also go parallel with the green building concepts.it would be most appropriate to create a natural barrier which can replace the artificial walls and fences in current urban environment.

Following objectives were defined from the literature survey, evaluation of resource availability and trail tests carried on natural barriers.

1. Investigate possible natural and artificial barriers for sound insulation.
2. Investigate the user acceptance of natural barriers.
3. Evaluate the performance of a selected type of natural barrier for sound insulation.
4. Evaluate the performance of artificial barriers in sound insulation and compare with the proposed natural barrier type.
5. To propose a replacement to artificial sound barriers with natural sound barriers.

From the information gathered in the literature review and few trail tests carried on natural barriers it was possible to narrow down the type of natural barrier to be focused in the research.

1.7. NATURAL BARRIER TYPE

The natural barrier should be mainly based on vegetation and should not consume space unnecessarily. Overall barrier shape would be a cuboid and barrier should be able to accommodate itself in a more or less space requirement of a normal wall. The natural barrier should be made with ever-green plants to make sure consistence performance throughout the year. Overall height of the barrier should be appropriate to attenuate noise and should be a suitable height appropriate to urban environment.

2. LITERATURE REVIEW

A literature review was carried out to mainly focusing on investigating following topics. These topics were formulated to support to reach the objectives and goals defined in the research.

1. Noise related problems and their causes
2. Noise related health risks.
3. Public perception of noise and natural barriers
4. Artificial noise barriers and materials
5. Natural noise barriers
6. Relevant regulations and guidelines

2.1. Noise related problems and the causes.

Increasing in noise levels in congested city areas have not gone un-noticed. Nemours researches have being carried out regarding the subject. Traffic generated noise was found to be the main noise polluter in urban areas. Other main sources of noise pollution are industrial generated noise and public noise.

To facilitate good communication and prevent any speech interference ambient noise levels have been suggested. For good communication at normal distances the noise level should not exceed 65 dB(A) for 'young' and 'middle aged', and 55 dB(A) for 'old' aged persons. (Zaheeruddin & Jain, 2005)

Special characteristics such as buildings, building heights, streets, open areas and building materials of a congested area will decide the noise propagation in urban areas. Previous researches have been carried out regarding urban sound propagation through urban fabric form and how verity of factors such as height of buildings, street width like geometric parameters and effect of acoustic characteristics of materials effects the sound propagation(Ismail, 2009)

Noise is consist of different frequencies with different sound intensity levels.it has been found that higher frequencies are easy to attenuate whereas low frequencies are difficult to attenuate**.** Due to diffraction effect of low frequency sound waves tends to bend around obstacles making it difficult to attenuate. At higher frequencies the sound attenuation is due to scattering effect and absorption (Bullen & Fricke, 1982)**.** Human ear is widely sensitive to 20 Hz- 20000 Hz range of frequency spectrum which includes low to high frequency range.

Traffic will contribute to increase in noise in different ways by; noise of engines, noise of tiers contacting the surface of the roads and noise of vehicle horns. Increase of traffic jam in the congested cites magnifies the noise generated from the transport sector. Researches carried out in many countries have given evidence that traffic generated noise to be the main noise polluter. Study carried on a densely populated area in Madrid(Spain) has indicated 80% of the unwanted noise generation is due to traffic (Tobías, Recio, Díaz, & Linares, 2015). Other several researches which identifies traffic to be the major noise polluter (Hickling, 1997; Williams & McCrae, 1995; Zannin, Diniz, & Barbosa, 2002). Research carried on finding the influence of traffic related noise to the human work efficiency of working places in Agartala revealed high annoyance and disturbance levels resulted by traffic noise (Pal, Bhattacharya, Pal, & Bhattacharya, 2012).

Study carried on noise pollution of the city of Messina (Italy) revealed that that more than 25% of the population are victims of high disturbance due to traffic noise (Piccolo, Plutino, & Cannistraro, 2005).

Environmental impact assessment regarding noise impacts have become mandatory in most countries (Arenas, 2008). The mentioned noise related problems and facts in this section gives insight to the prevailing noise problems in a macro view. Hence mitigation approaches for the noise problems are in high demand.

2.1.1. Noise related health risks

Noise related health risks can be categorized as auditory and non-auditory adverse effects to health. Studies previously conducted on investigating the health risk from noise, suggests that the excessive noise leads to stress and annoyance. According to few non-consistent studies, environmental noise is responsible for higher rates of minor psychiatric disorders(Stansfeld & Clark, 2011). According to a survey done in Oslo Norway, positive but statistically significant association between excessive noise exposure from traffic noise and physiological distress among respondents with poor sleep has been identified (Aasvang, Aamodt, Oftedal, & Krog, 2014).The results suggest that road traffic noise may be associated with poorer mental health among subjects with poor sleep.

Effects of poor sleep quality have being investigated in many researches and it has being revealed that sleep loss is responsible for impairing emotional and social functions(Beattie, Kyle, Espie, & Biello, 2015). Annoyance, sleep disturbance, hypertension, cardiovascular risks, and poor performance are the major non auditory impacts of exposure to excessive noise (Istamto, Houthuijs, & Lebret, 2014).

World Health Organization(WHO) has descriptively categorized adverse effect of excessive noise in to seven categories, which are mentioned as; hearing impairment, interference to verbal communication, cardiovascular disturbances, mental health problems, impaired cognition, negative social behaviors and sleep disturbances (Halperin, 2014). However the main auditory impact is the hearing impairment by the exposure to prolonged excessive noise levels (Basner et al., 2014)**.**

A study carried on quantify avoidable deaths resulting from reducing the impact of Equivalent Diurnal Noise Levels **(L_{eqD})** on daily cardiovascular and respiratory mortality among people aged ≥65 years in Madrid has revealed that a reduction of 1 **dB(A)** in L_{eqD} implies an avoidable annual mortality of 284 (31, 523) cardiovascular-and 184 (0, 190) respiratory-related deaths in the study population (Tobías et al., 2015).

Cardiovascular and physiological effect to human health from loud noise have been discovered to be temporary and permanent. A loud noise can induce a temporary situation of high blood pressure and increased heart rate. Prolonged high sound pressure levels will induce hypertension and ischemic heart disease (Passchier-Vermeer, 2000; Berglund, Birgitta., Lindvall, Thomas., World Health Organization, Karolinska Institute (Sweden). Institute of Environmental Medicine., & Stockholm University. Dept. of Psychology., 1995).As a result of loud noise, ringing of the ear can occur, which is also called as tinnitus.

Research done on noise sensitivity and factors effecting human reactions suggests that noise disturbances effect of residential behaviors influencing anger, disappointment, dissatisfaction, depression anxiety and exhaustion (Job, 1999). A positive relation to higher noise levels to the human errors made at work was found (Smith & Stansfeld, 1986).

The amount of daily exposure level to noise decides the severity of harmful effects to human health by noise, research carried in Abuja the capital city of Nigeria has revealed that the day time noise levels in the study area is 73.2-83.6 dB (A) and during night time it falls down to 44- 56.8 dB(A).The findings also suggests that for the people who engaged in daily activities in excessive noise areas should at least take 10 hours of recovery time daily in an environment where sound levels are lesser than 65 dB(A) to prevent harmful effects from noise (Anomohanran, 2013).

The above evidence proves that exposure to excessive noise is a significant risk, which will physiologically and psychologically effect the human. The harmful effects will be long term and short term. A person who is stressed by the noise levels will lose his calm, and reduce the predictable nature of his actions. People need to talk louder or shout out in an environment where interference to verbal communication occurs due to high noise levels, prolonged exposure to this type of situation will cause harmful effects to vocal chords and speaking ability of humans. For example high noise levels will adversely effect on heart patients.

Hence it can be concluded that the need to mitigating high noise conditions to preserve public safety is very important.

2.2. PUBLIC PERCEPTION ON NOISE POLLUTION AND NATURAL BARRIERS

Noise related problems and the effectiveness of the solutions are highly dependent on the perception of the receiver. For example rock music is preferred by some listeners whereas rock music is considered as noise or disturbance by others. Loudness of sound is also subjective, depending on the listener. Human perception plays a vital role in deciding the severity of noise related problems and how effective are the solutions provided for noise related problems.

Why perception is so important in noise related problems. Noise and sound is directly relate to the environment we live and we perceive environment with several main modalities. Main modalities are vision, sound, touch, smell and taste, these modalities may act individually or act simultaneously in deciding perception (Shams, Kamitani, & Shimojo, 2002). Parallel interaction of vison and hearing is considered as a major modality (*Crossmodal Space and Crossmodal Attention*, 2004; Vroomen & de Gelder, 2000).

2.2.1. Human perception regarding noise

It has been found that the average listener is more sensitive to the noise when the visual screening is higher(Watts, Chinn, & Godfrey, 1999). According to (Aylor & Marks, 1976; Mulligan, Lewis, Faupel, Goodman, & Anderson, 1987) when the respondents could see the sound source, they actually overestimated its ability to attenuate noise. Psychological effect of sense of vision in noise attenuation can be seen from the above results. These information can be very important designing noise barriers by controlling the visibility of sound source.

Previous research suggests that the subjective evaluation of the sound level generally relates well with the mean **Leq** sound level especially when the sound level is below a certain level, which is 73 dB (W. Yang & Kang, 2005). The background sound level has been found to be an important index in evaluating soundscape in urban open public spaces. Background noise can be used as a masking noise to mask an undesirable noise which will influence listeners' perception.eg:-sound from water fountains, sound from leaves in wind can be soothing and pleasant. Differences have been found between the subjective evaluation of the sound level and the acoustic comfort evaluation. Hence research result suggest introducing a pleasant sound can considerably improve the acoustic comfort. No significant difference was found amongst different age groups in terms of the subjective evaluation of sound level, whereas in terms of acoustic comfort, there were considerable differences (eg:- teenagers, elders etc).

According to (Kang & Zhang, 2002) comfort–discomfort, quiet–noisy, pleasant–unpleasant, natural–artificial, like-dislike and gentle–harsh, is a main factor for people's soundscape evaluation in urban open public spaces. Other than noise levels.

Visual impact and information of the surroundings is not neutral but it influences the auditory impression of the receiver, it has been found that more urban the visual setting disturbance indicated by auditory judgment also increases and more pleasant and appealing the noise barriers auditory judgment on noise attenuation more likely to be positive (Viollon, 2003).

According to (Hong & Jeon, 2014) noise barriers implemented in urban areas should be evaluated and thought about in landscaping aspects as well as noise attenuation.

2.2.2. Human perception regarding natural barriers

According to the previous researches it has been identified that the people's opinion about sound barriers are mostly dependent on a subjective perception(Aylor & Marks, 1976; J.L.R Joynt, 2005).

There seems to be a widespread popular belief that tall hedges and narrow belts of trees cause a significant reduction in traffic noise. Psychological effect of vegetation towards sound attenuation is a possible effect. In a situation where vegetation along an existing road had been replaced by a solid barrier, those survey respondents residing close to the road indicated that the vegetation had given the better noise reduction (Perfater, 1979). People tend to expect more than noise reduction from natural noise barriers such as pleasing visual aspect to the community and serenity (Bailey & Grossardt, 2006).

As an adverse outcome of noise barriers, instill a perception of increased risk of crime has being mentioned highlighting a possibility of concealment in of crime (Perfater, 1979). Urban community concern for security and privacy provided by barriers can be a leading factor in deciding barrier type. It has been revealed that privacy of individuals are being largely compromised by activities such as visual surveillance in urban areas (Padilla-López, Chaaraoui, & Flórez-Revuelta, 2015) .

Study carried on five types of noise barriers such as aluminum, timber, translucent acrylic, concrete, and vegetated barriers has revealed important findings regarding visual and auditory perception of the barriers in urban condition. The results showed that the preconceptions of noise attenuation by barriers affected the overall preference for noise barriers at 55 dB(A); esthetic preferences for noise barriers were affected significantly at 65 dB(A). Noise barriers with vegetation indicated increase in perceived noise barrier performance with increasing in esthetic preference (Hong & Jeon, 2014).

A survey done in Hong Kong using 509 respondents revealed that the majority of them held positive perspective for tree planting in street canyons. The respondents also preferred high permeability as the most preferred planning option. (Ng, Chau, Powell, & Leung, 2015).A pilot survey carried at an area where noise barriers were introduced, resulted in most residents felt that sleeping conditions improved after the barrier was built. But the most negative respond from the residents were the loss of sunlight and visual impact (Arenas, 2008).

Household perception of urban greenery is vital to realize and understand methods to implement urban sustainability and also leads to understand public participation in urban green infrastructure initiatives. It was found that average house hold keep least number of 1-9 plant species (Barau, 2015). It can be concluded that the perception and involvement of urban household is vital to implement greener solutions like natural barriers as a solution. Involvement of household and encourage them to implement greener solutions would be a useful and effective strategy in implementing greenery in urban areas.

Sustainable, nature friendly solutions have become a popular trend and attraction in modern society. However it is still a challenge to incorporate green concepts with the modern society without being rejected by the people and without disturbing the urban culture and lifestyles. This is where the people's perception on greener solutions plays a vital role in making greener solutions a practical reality. The given evidence in this section suggests that natural barriers or artificial barriers covered with vegetation can improve the perception of environmental quality and comfort as well as the perception of noise attenuation from a barrier.

2.3. ARTIFICIAL NOISE BARRIERS AND MATERIALS

There are main three methods of providing solutions for noise related problems.

1. Controlling the noise level at source
2. Controlling the noise level along the path of propagation
3. Controlling the noise level at the receiver

Use of noise barriers falls in to the second category in the list, which reduce the noise level along the path of noise propagation. The barrier type, shape, material like factors decide the effectiveness of acoustic performance of barriers. Barriers may act as means of reflecting noise or absorbing noise as a noise reduction approach. For example a noise barrier put up keeping the highway noise away from the buildings will be more effective as a reflective barrier where as a walls in a room to reduce noise should have more sound absorptive properties to reduce reflection and reduce noise levels in the enclosure.

Traditional sound absorbing elements are made from glass wool and expanded polystyrene. Kenaf, coco fiber, sheep wool, cork, cotton, hemp, wool, clay, jute, cork, sisal, coir, feather and cellulose can be identified as natural products which can be used in producing sound insulation elements (Faustino et al., 2012).

Sound energy can be mainly reduced by spreading or by attenuation. According to inverse square law the acoustic intensity is reduced in proportion to the square of the range due to spreading alone. Sound attenuation is occurred by turning sound energy in to heat by friction, reflection, refraction and turbulence.

The frequencies and amplitudes of sound absorption materials are related to the following factors: the void ratio, air flow resistance, and tortuosity of material (Descornet, Fuchs, & Buys, 1993).

Glass fiber reinforced concrete panels containing recycled tires, has shown remarkable acoustic performance in attenuating sound in the range of high frequencies 2000 Hz-3150 Hz, proving that improved ductility and impact resistance of rubberized concrete has effectively increased the noise attenuation of the panels against traffic noise (Pastor, García, Quintana, & Peña, 2014). Sound absorbing elements can be made from polyester fibers (Kino & Ueno, 2008)

Sand has being identified as a good material for sound attenuation with material qualities such as high mass, low stiffness and high damping (Sharp, Wyle Laboratories, United States, & Department of Housing and Urban Development, 1973). As an integration method we can use a sand substrate in green roofs the root structure of green roof can be used to hold the sand in place.

Concrete is one of the mainly used materials for barriers and its sound insulation properties are and advantage. Numerous researches have been done to find methods to improve acoustic performance of concrete elements such as panels and walls

Porous concrete absorb sound by transferring sound energy to heat, by refraction and reflection and turbulence. Porous concrete panels can be used for pavements, walls etc to achieve these effects. According to (Gerharz, 1999) porous concrete with 4–8 mm aggregates was effective for sound absorption. It was reported that fiber reinforced porous concrete with 1.5 vol.% of polypropylene fibers provided good sound absorption characteristics(Narayanan Neithalath, Jason Weiss, Jan Olek, 2014). The conventional concrete acoustic absorption coefficient range was found to be $\alpha = 0.05$-0.1 which is low (Neithalath, Weiss, & Olek, 2006) .

Use of crumb rubber as a replacement of a portion of aggregate in pre-cast concrete panels has proven that the process can improve the thermal insulation properties and sound insulation properties of the panels while making the pre cast concrete panels light in weight. Crumbed rubber concrete panels have shown improvement in sound insulation in mid-range of frequency band (Sukontasukkul, 2009). Rubberized concrete is an effective absorber of sound and vibration (Khaloo, Dehestani, & Rahmatabadi, 2008).

Industrial carpet waste can be used to produce industrial underlays to insulate against impact sounds which is also considered as a sustainable approach recycling industrial waste (Rushforth, Horoshenkov, Miraftab, & Swift, 2005). Corn cob particleboard has been under research for its acoustic performance, it was proved that 30 dB sound insulation could be achieved by applying a corn cob panel on the floor of the emitting room (Faustino et al., 2012)

Chip boards made out of cotton waste, fly ash and epoxy resin resulted in showing good acoustic insulation properties and sample with cotton waste has shown better sound insulation properties. This is also a approach to reuse textile waste (Binici, Gemci, Kucukonder, & Solak, 2012).Rice straw–wood particle composite boards which has the specific gravity of 0.4-0.6 have been suggested for sound attenuation in timber constructions (H.-S. Yang, Kim, & Kim, 2003).

Multi-layer panels and structures have been in used for sound attenuation, previous research suggest that multi-layer structures using a Micro Perforated Panel (MPP) can work well in sound insulation since multi-layer structure effectively prevents mass-air-mass resonance (Mu, Toyoda, & Takahashi, 2011).

Fiber reinforced mud bricks have proved to be effectively used to attenuate industrial noise, basaltic pumice can be used as an ingredient to improve sound insulation properties of fiber reinforced mud bricks (Binici, Aksogan, Bakbak, Kaplan, & Isik, 2009) .

It has being found that dry walls made out of plaster boards can act well as a noise barrier. Double drywalls made with two plaster board layers can act well in noise attenuation. Considering Weighted Sound Reduction Index **(R_w)** value, a double drywall of $R_w = 61$, a double drywall of $R_w = 64$, a triple drywall of $R_w = 86$ and a quadruple drywall of $R_w = 90$ were developed (Matsumoto, Uchida, Sugaya, & Tachibana, 2006).

Topic of noise reducing road surfaces can be introduces as another approach to mitigate sound (Malcolm J. Crocker, Zhuang Li, & Jorge P. Arenas, 2005; Morgan, 2006; Sandberg & Ejsmont, 2002). Porous surfaces can be used to reduce sound energy created by tires contacting the road surface. However noise reduction surface solutions can be expensive and not cost effective.

2.4. NATURAL NOISE BARRIERS.

Concept of green barriers is a very environmental friendly move. Use of green barriers will enhance the green cover in modern city areas and act as a remedy to man-made concrete jungles. As the green building concept getting popular in the industry, there is an opportunity to find ways to incorporate vegetation in modern constructions. Hence replacing artificial barriers with green barriers will be an added advantage. The question arises as “what is the potential of a green barrier to act as a noise reduction solution?”

Previous research have proven that noise reduction from a vegetation belt is small unless the vegetation belt is wide(Kragh, 1981). According to (Huddart L, 1990) compared with grassland a densely planted belt of trees 30 m thick was required to reduce noise by 6 dB(A). It gives the hint that a natural barrier to perform without reducing its performance the barrier should be made out of ever green plantations. The sound absorption ability of the natural barrier increases with the amount of green coverage(Bullen & Fricke, 1982). Plantation with dense spared of leaves can perform as a good noise barrier. A study on roadside vegetation barriers in Sri Lanka on acoustic properties has revealed that vegetation barriers were able to reduce $\mathbf{L_{Aeq}}$ noise levels by 4dB, approximately controlling 40% of acoustic energy (Kalansuriya, Pannila, & Sonnadara, 2009). Study carried on urban screen plantings in southeastern Nebraska has shown that Trees, shrubs or combinations of trees and shrubs can attenuate noise up to 5- 8 dB, In general, wider the belt of trees the effectiveness increases of the barrier and species do not appear to differ greatly in their ability to reduce noise levels (Cook & Haverbeke, 1971). Previous research also indicates the possibility of using modular form of green walls system for noise attenuation. The modular system is based on recycled polyethylene modules hence the total system is a hybrid of natural and artificial components. The test result has shown a weighted noise reduction index of (R_w) 15dB and weighted sound absorption of (α) 0.4. Furthermore the research indicates the use of a green wall for noise attenuation should be improved with design adjustments.(Azkorra et al., 2015).

Natural barriers in the form of tall tree belts, berms combined with vegetation belts are already being used by many countries to attenuate traffic noise generated by highways. For an example 4m height 2.5m wide, square type tree barriers are successfully being used in Switzerland and Holland for traffic noise attenuation (Kotzen, 2004)**.** It has been proved that vegetation belts can reduce traffic noise effectively , especially noise composed of higher frequencies are reduced greatly (Tyagi, Kumar, & Jain, 2006)**.**

It has being found natural barrier sound attenuation capability reduce significantly below 1 kHz (Bullen & Fricke, 1982). It has been found by experiment in a reverberation chamber regarding sound absorption by vegetation that, sound absorption is governed mainly by the leaves rather than the trunks (Watanabe & Yamada, 1996). Sound energy can be presumed to be converted in to thermal energy by the friction of leaves

According to a study carried on Vertical Greenery System (VGS) installed in HortPark, Singapore, the sound absorption properties of a VGS increases with the green coverage. Research also reveals a stronger attenuation in low to mid frequencies by vegetation due to absorption of sound and in higher frequencies sound attenuation is due to scattering effect by greenery (Wong, Kwang Tan, Tan, Chiang, & Wong, 2010).

Vertical gabion structures have been tested for their effectiveness in traffic noise attenuation. The objective of research related to this type of barriers have been sub divided in to barriers height lesser than 1m and tall barriers more than 1m height. The research results showed that low height gabion barrier can be used to attenuate traffic noise levels up to 8dB(A), and research also suggests that gabions barriers, which are originally used as retaining structures or hydraulic protections, can be used as effective noise barriers (Koussa, Defrance, Jean, & Blanc-Benon, 2013). According to (Anai & Fujimoto, 2004) barriers with height not more than 1 m can be effectively used to reduce traffic noise levels up to 5dB(A) for the receiver.

Studies carried on investigating global effectiveness of low height noise barriers with different shapes, which are covered with an absorbent layer has proven that 6-10dB(A) noise reduction behind the barriers (Baulac, Defrance, Jean, & Minard, 2006; Margiocchi, Baulac, Poisson, Defrance, & Jean, 2009).

Research have been carried out to find a relationship of different factors effecting the noise absorption of vegetation barriers. Road traffic noise propagation through a 15 m depth of a vegetation belt of limited depth (15 m) made out of periodically arranged trees is numerically assessed by means of 3D finite-difference time-domain (FDTD) calculations and has been proved that a considerable noise reduction is predicted to occur for a tree spacing of less than 3 m and a tree stem diameter of more than 0.11 m.in addition to that the research predict an additive effect from presence of tree stems, shrubs and tree crowns to the noise attenuation (Van Renterghem, Botteldooren, & Verheyen, 2012). A positive logarithmic relationship between relative attenuation and the width, length or height of the tee belts was also found in previous research carried by (Fang & Ling, 2003) using stepwise multiple regression analysis method.

Green roof structures can be used as means to reduce sound intrusion in to buildings, experimental investigation on the sound transmission by green roofs made with deep rooted coastal meadow and shallow-rooted sedums have proved that vegetation has increased transmission loss of a tested wood frame roof was 5‑13 dB in the 50‑2000 Hz frequency range, above 2000Hz up to 8 dB transmission loss was experienced. For the light-weight metal deck, the increased transmission loss was up to 10 dB, 20 dB, and >20 dB in the low, mid, and high frequency ranges, respectively (Connelly & Hodgson, 2013). According to article a variation in the moisture content of the substrate had not contribute a measurable change in transmission loss.

In green roofs, it has been found that substrate, plants species and the trapped layer of air between plants and the façade surface can be used as insulation against sound by absorption, reflection and deflection. Furthermore, substrate and plants tend to block sound with lower and higher frequencies respectively(Dunnett & Kingsbury, 2008).

Positive relationship with the fraction of green covered area of the roofs and noise attenuation was found by pervious research, it was also proved that the thickness of 20 cm of green roof can effectively attenuate 1000Hz octave band up to 10dB(Van Renterghem & Botteldooren, 2008).

It has been found that there is only a small noise reduction above 4kHz on the green roofs by adding pruned leaves, but optimized absorption treatment could bring the noise reduction up to 4 dB for traffic noise (H. S. Yang, Kang, & Choi, 2012).Even though vegetative, transparent timber barriers were rated as pleasing and highly aesthetical, they were deemed as less effective in controlling noise with respect to less aesthetical rated structures made with concrete or metal (Jennifer L. R. Joynt & Kang, 2010).

Incorporating natural barriers will lead to increase in green cover in urban areas and resulting in many more benefits other than noise reduction capabilities. Hence using natural barriers as a replacement of artificial barriers will be a sustainable and environmental friendly approach.

Study carried in London suggests that street trees may be a positive urban asset to decrease the risk of negative mental health outcomes (Taylor, Wheeler, White, Economou, & Osborne, 2015). It has been suggested that strategically planting trees to gain shade and increasing the reflectivity of building and pavement can very effectively reduce energy use for cooling, and prevent the formation of smog (Gorsevski, Taha, Quattrochi, & Luvall, 1998).

A suitable and appropriate placement of type of vegetation has a potential of saving up to 55% of residential cooling demand during summer and it also has the capability to reduce surrounding air temperature up to 5°C (Misni & Allan, 2010).

Vertical green walls and extended green gardens and roofs offer multiple benefits socially, economically and environmentally(Alexandri & Jones, 2008; Dunnett & Kingsbury, 2008; Fioretti, Palla, Lanza, & Principi, 2010; Getter & Rowe, 2006; Jantunen, Saarinen, Valtonen, & Saarnio, 2006).

Study done in Danish city of Odense regarding the influence of urban green space to the residence reveled that, reduce of stress levels, reduction of fatigue and overall positive impact on health and well-being of urban population (Schipperijn, Stigsdotter, Randrup, & Troelsen, 2010).

Numerous benefits can be expected from incorporating natural tree barriers in urban areas. Using natural barriers will increase the amount of trees in urban areas increasing green space. Benefit from increasing vegetation cover in urban areas is mainly reducing all most any kind of air pollution (Gorsevski et al., 1998). Other identifiable benefits from natural barriers are acoustic insulation,(Kalansuriya et al., 2009; Kotzen, 2004) thermal insulation, (Brown, Katscherian, Carter, & Spickett, 2013) air quality improvement, reduction of heat island effect around the vicinity (Alexandri & Jones, 2008; Golden, 2004; Ismail, 2013; Misni & Allan, 2010; Solecki et al., 2005) and reduction of dust and smoke intrusion in to road side buildings (Georgia Forestry Commision, 2008). Previous research has verified that percentage of green space in living environment has a positive association with the perceived general health of residents (Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006).

2.5. STANDARDS AND GUIDELINES RELEVANT TO THE RESEARCH.

Investigation was carried out to gather information on relevant standards and regulations to the research.

Permissible noise level according to Sri Lankan Standards are as in Table 1-1. (Minister of Transport, Environment and Women's & Affairs, Sri Lanka, 1996)

Environmental noise testing and evaluation ASTM E 1014:84 Standard guide for measurement of outdoor "A" weighted sound levels and ASTM C 634-2 Standard

Terminology Relating to Environmental Acoustics (*Annual Book of ASTM Standards*, 2004).

According to United States Environmental Protection Agency(US EPA), 24 hours exposure of 70 dB $L_{eq(24)}$ or higher noise level would induce permanent hearing loss. The limit defined by 55 dB $L_{eq(24)}$ and 45 dB $L_{eq(24)}$ outdoor and indoor noise levels respectively represent the allowable limit to prevent interference to speech and activities. These noise levels are considered to permit sleep, speech, working, recreation and prevent any annoyance induced by noise. Eight hour exposure limit is limited to 75 dB $L_{eq(8)}$ whereas energy contained in 75 dB $L_{eq(8)}$ is equivalent to 70 dB $L_{eq(24)}$ (U.S environmental Protection Agency, 1974; US EPA, n.d.)

Considering exposure limits for industrial noise levels, National Institute of Occupational Safety and Health (NIOSH) has recommended the safe exposure limits. Exposure to as and above 85 dB, “A” weighted time averaged noise level of 8 hours is considered as hazardous (National Institute for Occupational Safety & Health, 1998). Safe exposure limits are indicated in Table 2-1.

Table 2-1. Safe exposure limits according to NIOSH

Exposure Level (dBA)	**Duration Time - t - (s)**		
	Hours	**Minutes**	**Seconds**
80	25	24	
81	20	10	
82	16		
83	12	42	
84	10	5	
85	8		
86	6	21	
87	5	2	
88	4		
89	3	10	
90	2	31	
91	2		
92	1	35	
93	1	16	
94	1		

Exposure Level (dBA)	Duration Time - t - (s)		
	Hours	Minutes	Seconds
95		47	37
96		37	48
97		30	
98		23	49
99		18	59
100		15	
101		11	54
102		9	27
103		7	30
104		5	57
105		4	43
106		3	45
107		2	59
108		2	22
109		1	53
110		1	29
111		1	11
112			56
113			45
114			35
115			28
116			22
117			18
118			14
119			11
120			9
121			7

Exposure Level (dBA)	Duration Time - t - (s)		
	Hours	Minutes	Seconds
122			6
123			4
124			3
125			3
126			2
127			1
128			1
129			1
130			1
-140			< 1

Appropriate Day-night Average Sound Level (DNL) for residential conditions have been suggested as 50-55 dB , which will lead to positive community responses and prevent annoyance by noise levels (Schomer, 2005).

3. METHODOLOGY

The below explained methodology was carried out to achieve the objectives of the research.

1. Literature survey was carried out to find information relevant to subject and to find out the state of the art methods of using natural noise barriers to reduce noise levels.
2. A field survey was done to evaluate the existing noise levels in a selected urban areas.
3. A questioner survey was carried out to determine the user acceptance of natural noise barriers and to investigate the public perception regarding noise levels
4. Field testing was carried out on existing artificial barriers and natural barriers to determine and compare the performance of them as noise barriers.

3.1. METHODOLOGY FOR QUESTIONER SURVEY.

Questionnaire survey was conducted to identify the public perception on the level of sound disturbance and public acceptance of a natural barrier if introduced as a solution. Questions relating directly or indirectly to other issues than acoustic disturbance, were not asked from the respondents. Questions and respective responses in questionnaire survey were categorized in 3.1.1.

3.1.1. Respondent Result Categories

1. Public perception on disturbance from day to day noise levels in urban areas.
2. Public perception on natural barriers as a solution.
3. Public perception on natural barriers already applied on urban roads.

3.1.2. Rating Method

Rating scale for evaluation of a particular criterion in questionnaire survey is mentioned in Table 3-1.

In order to obtain a fair point of view from respondents,

1. Respondents were not given prior instruction about sound disturbance levels in respective areas.
2. Respondents were not informed of benefits from natural barriers.

Respondents were given an idea of what natural barriers are and how they can be applied in normal life via series of pictures along with the survey (ex: vertical gardens, vegetation walls, vegetation barriers alongside urban roads etc.). Pictures of artificial barriers (walls, fences etc.) were also provided to make it possible for respondents to distinguish among artificial and natural barriers. For sample questionnaire survey refer Appendix D.

Table 3-1. Rating Scale

Scale	Rating	Example; criteria = Aesthetic appeal
1	Negligible or Very Low	Very low aesthetic appeal
2	Low	Low aesthetic appeal
3	Moderate	Moderate aesthetic appeal
4	High	High aesthetic appeal
5	Extreme or Very High	Very high aesthetic appeal

3.2. METHODOLOGY FOR INVESTIGATION OF ACTUAL NOISE LEVELS

Base on the questionnaire survey responses, daily duration of critical noise disturbance was evaluated to decide field survey duration for actual noise levels. Urban locations (Field survey locations) for measuring actual noise levels were decided according to the locations related to locations in questionnaire survey data. “A” weighted time averaged environmental noise levels at particular locations were measured according to ASTM E 1014:84 (*Annual Book of ASTM Standards*, 2004). Measurements were taken during weekdays and averaged to arrive at a representative noise level at particular location. The actual noise levels were compared with the questionnaire survey responses.

Noise levels were measured using a class 2 sound level meter with 1:1 octave band capability. Single measurement was allocated 10-15 minutes for assuring the $\mathbf{L_{Aeq}}$ noise level settles during the duration of measurement.

3.3. METHODOLOGY FOR TESTING SOUND INSULATION PERFORMANCE OF A NOISE BARRIER

The testing of barriers was done in in-situ condition. The testing procedure was created after few trails and errors and adopting the method of testing explained in ASTM E 1014:84 (*Annual Book of ASTM Standards*, 2004). “A” Weighted sound levels were recorded as the main reading.

Class 2 sound level meter according to BS EN 61672-1:2003, with 1:1 octave band was used for noise level measurement.

A Sound buzzer was used as a source to generate a source noise (record of traffic noise).All noise readings was taken in negligible wind conditions and no precipitation conditions. Sample of each measurement was taken within a duration of 2 – 5 minutes until the sound level settles. (To make sure sound levels are representative of the specific condition).Ambient noise without the source was measured beside the barrier to decide the front face and leeward face of the barrier.

Firstly two ambient noise readings (amb1 and amb2) were taken with the influence of the barrier as shown in Figure 3-1 to decide the natural direction of noise flow at a particular location .

Second set of readings were taken with the effect of barrier by producing the source sound directly targeting the barrier front face as shown in Figure 3-2. Reading “R1” measured at location 01 and reading “R2” measured at location 02.

Third set of reading were taken without the influence of the barrier within the same vicinity and same natural sound flow direction as shown in Figure 3-3. Reading “R3” measured at location 03 and Reading “R4” measured at location 04.

The dimensions of barrier was recorded with temperature and the humidity levels.

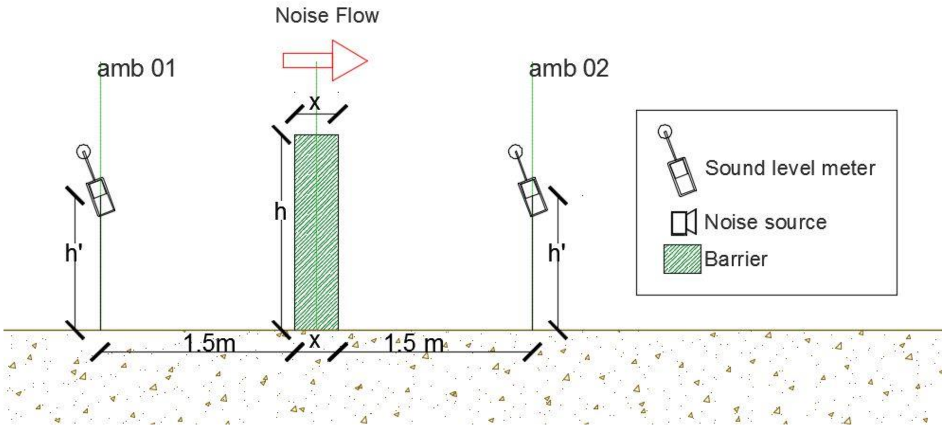


Figure 3-1. Sound level measuring of ambient noise

Amb01	Ambient noise reading one	**h**	Height of the barrier
Amb02	Ambient noise reading two	**h’**	Instrument height
x	Thickness of the barrier	**w**	Length of the barrier

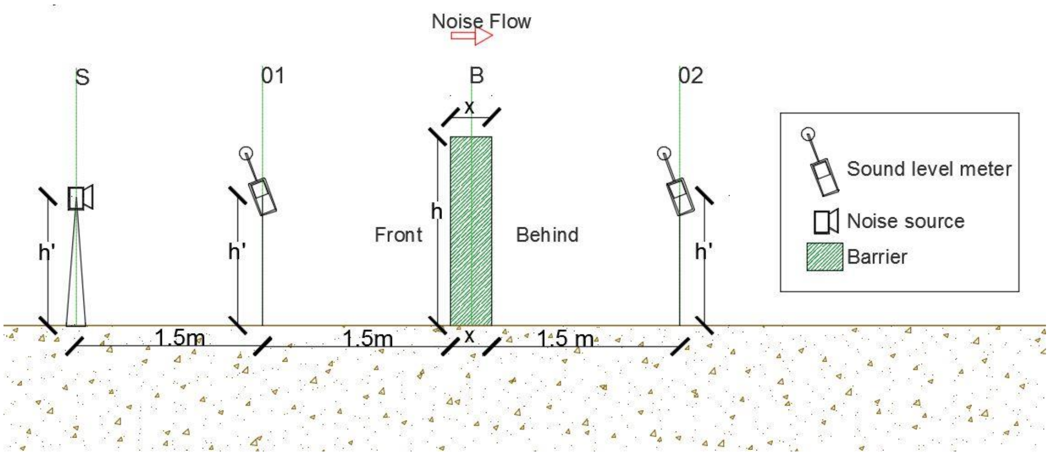


Figure 3-2. Sound level measurement with the influence of barrier

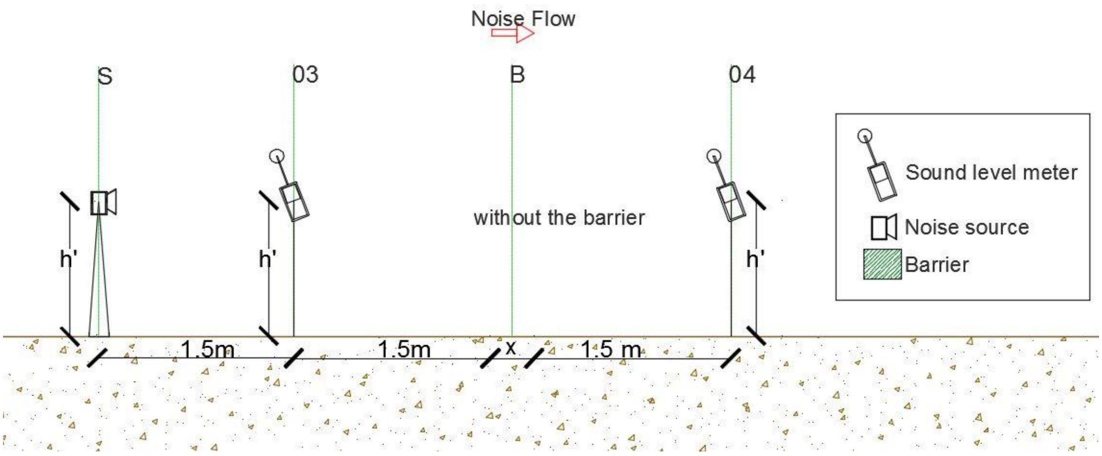


Figure 3-3. Sound level measurement without the influence of barrier

Set up was arranged to minimize any adverse effect of refection surfaces nearby. Instrument height was kept at 1.3 m according to procedure explained in ASTM 1014: 84. The distance of 1.5 m was kept from source and barrier between measuring location to reduce the scattering effect.

Class 2 sound level calibrator was used to ensure the accuracy of the sound level meter during taking of measurements before and after.

Sound level measurement were not taken in the presence of impulse noise conditions, equipment was set to 1s time history data interval of recording data.

4. QUESTIONNAIRE SURVEY

The questionnaire survey carried to investigate public perception regarding the noise levels and natural barriers revealed valuable information. The questionnaire survey method is explained in 3.1. The survey results were analyses under three sub categories as mentioned in 4.2. The questionnaire survey objectives are narrowed down in 4.1.

4.1. OBJECTIVES

1. Investigating human perception on noise disturbance
2. Investigating human perception regarding natural barriers
3. Investigating human perception regarding natural barriers already applied in urban road designs

4.2. EVALUATION CRITERION FOR QUESTIONNAIRE SURVEY

Human perception about the disturbance of sound levels, faced during day to day life was evaluated under;

1. The self-evaluated intensity of sound disturbance according to a scale as in Table 3-1.
2. Time frame and duration of critical daily sound disturbance.
3. Whether respondent actually require a solution for sound disturbance.
4. The reason for excessive sound levels according to the respondent's point of view.
5. Whether respondent has already taken preventive actions for excessive sounds.

Human perception on natural barriers is evaluated under;

1. Human choice of artificial or natural barrier solution.
2. Human capability and desire on planting and maintaining a natural barrier.
3. Expected performances from a barrier.
4. Desired type and dimensions of a barrier.
5. Desired vegetation type.
6. Personal evaluation of expected security levels from both natural and vegetation barriers.
7. Personal evaluation on aesthetic appearance of artificial and natural barriers.
8. Whether respondent has already came across such natural barriers in practical

Public perception on natural barriers already applied on urban roads is evaluated under;

1. Suitability of application.
2. Point of view as a pedestrian and a motorist regarding possible disturbance from street plantations.
3. Point of view on aesthetic appeal generated by street plantation.

4.3. RESPONDENTS & STUDY AREA

Respondents were chosen from urban and sub urban areas in Colombo, Gampaha & Kaluthara in western province of Sri Lanka. Total number of respondents were 300. Nature of the research required respondent to possess a good level of educational background and understandability. According to the details found out, more than 75% of respondents are permanently living within the study area. The residual respondents are frequent visitors to the study area or temporary accommodated in the study area.

Population details of Western province is as shown in Table 4-1.(Department of Census & Statistics-Sri Lanka, 2012).

Table 4-1. Population details of Western province 2012

	POPULATION DETAILS OF WESTERN PROVINCE		
District	**Total**	**Urban population**	**Urban population as a %**
Colombo	2324349	1802904	77.57
Gampaha	2304833	360221	15.63
Kaluthara	1221948	109069	8.93
Total	**5851130**	**2272194**	**38.83**

*Source (Department of Census & Statistics-Sri Lanka, 2012)

4.3.1. Sample size

For the research sample of 300 people was considered.

Sample calculation considering proportions for (Yes /No) answers as survey results. Confidence Level considered was 90% and confidence interval considered to be 0.05%. Total population size 2272194 (Urban population in Colombo, Gampaha & Kaluthara districts).

Confidence Level	*(CL)*	90%
Confidence interval	*(CI)*	±0.05%
Population size	*(N)*	2272194
Z value (relate to CL)	*(Z)*	1.645
Proportion	*(p)*	0.5
Margin of error	*(ME)*	±0.05
Sample size	*(n)*	To be decided

$$n = \frac{\{(Z^2\, p * (1-p) + ME^2)\}}{\left\{ME^2 + \left(Z^2 * p * (1-p)/_{N}\right)\right\}}$$

Eq: 1

$$n = \frac{\{(1.645^2 * 0.5 * 0.5 + 0.05^2)\}}{\left\{0.05^2 + \left(1.645^2 * 0.5 * 0.5 / 2272194\right)\right\}}$$

$$n = 271 < 300$$

Sample size justification for determining proportions, (Yes /No) answers for the survey. Critical proportion was taken as 50% for estimating. When confidence level is 90% margin of error was estimated. Sample size = 300

$$ME = Z * \sqrt{\frac{p * (1 - p)}{n}}$$

Eq: 2

$$ME = 1.645 * \sqrt{\frac{0.5 * 0.5}{300}}$$

ME= 0.047 < 0.05

Hence selected sample size 300 is appropriate for the study.

4.3.2. Distribution of Respondents Considering Distance from a Main City

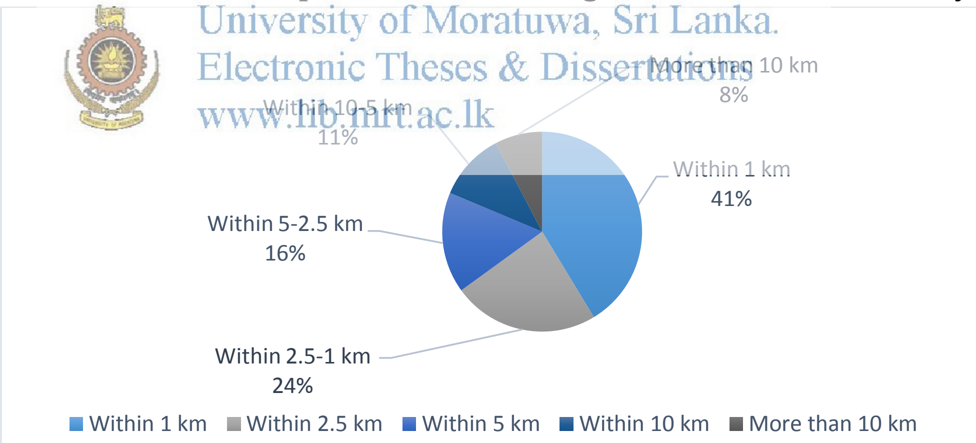


Figure 4-1. Approximate distance to respondents' residents from nearest city.

Respondent's point of view about the disturbance level of sound during day to day life is compared with the distance from the main city to their residents. According to Fig. 4.1 it is evident that 65% of the respondents are living within the 2.5 km radius from the respective main cities, where as 81% of total respondents are living in 5 km radius from the main cities.

5. HUMAN PERCEPTION ON EXISTING NOISE LEVELS.

This chapter reveals the results obtain from the questionnaire survey regarding human perception on existing noise levels in urban areas. This will give insight to the present noise problem. It is important to find whether the public demand a solution for noise problems prior to implement a solution.

Respondents evaluated the disturbance of sound levels they face during day to day life and also evaluated the disturbance of sound level they face at nearest main city. Considering sound disturbance as the evaluation criteria and using rating scale in Table 3-1, respondents have rated the sound levels as in Figure 5-1.

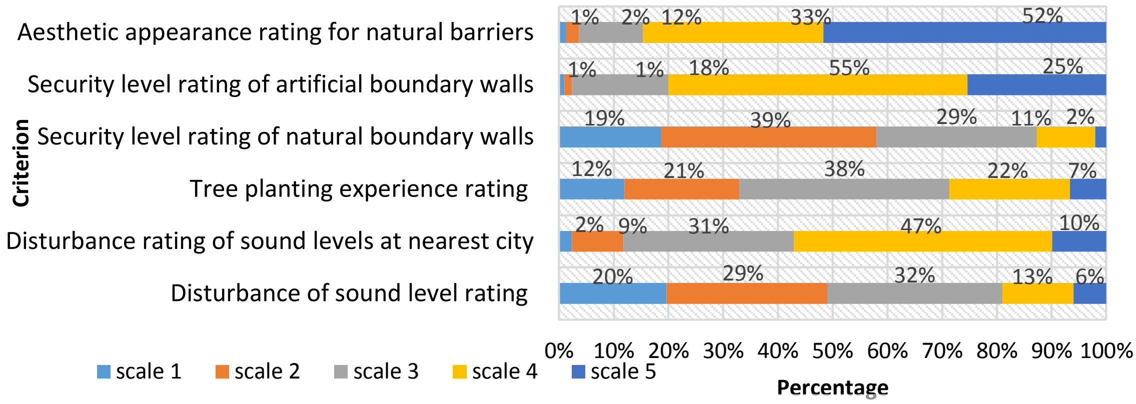


Figure 5-1. Ratings for sound levels & natural barriers

According to survey 51% of respondents indicated a sound disturbance within the range of moderate to extreme, whereas 49% of respondents complained negligible to low sound disturbance in day to day life. Only 6% of respondents have rated sound disturbance in extreme level. Information in Table 5-1 reveals that moderate to high sound level complaints are mostly within 2.5 km radius from main city. When the residential locations are closer to the cities people are more likely to complain moderate to high sound levels.

Table 5-1. Percentage of responses indicating moderate to high sound disturbance according to respondents distance from the main city

Category according to distance of residence from closest main city.	Percentage of responses from each category indicating moderate to high sound disturbance.
within 1 km	64.52 %
within 1-2.5 km	27.42 %
within 2.5-5 km	14.52 %
within 5-10 km	8.06 %
More than 10 km	8.87 %

Individual perspective on approximate starting time of the sound disturbances are as shown in Figure 5-2. The morning and evening peak hours 7.00- 9.00 A.M and 5.00-7.00 P.M are the time durations of high sound levels occurrence. Therefore, excessive sound levels are more in line with the traffic patterns. This hints that most of the excessive sound levels are generated by motor traffic and people are aware and sensitive to traffic noise. A study on traffic patterns carried in the main city of Colombo indicate 3 peak durations. Morning peak (busiest) from 7.00 A.M to 9.00 A.M and evening peak 5.00 P.M to 7.00 P.M. with an intermediate peak time from 1.00 P.M to 3.00 P.M. (Japan International Cooperation Agency & Oriental Construction Co.Ltd, 2014). Hence, traffic peak durations are in line with the excessive sound time stamps indicated by the respondents when compared with Figure 5-3.

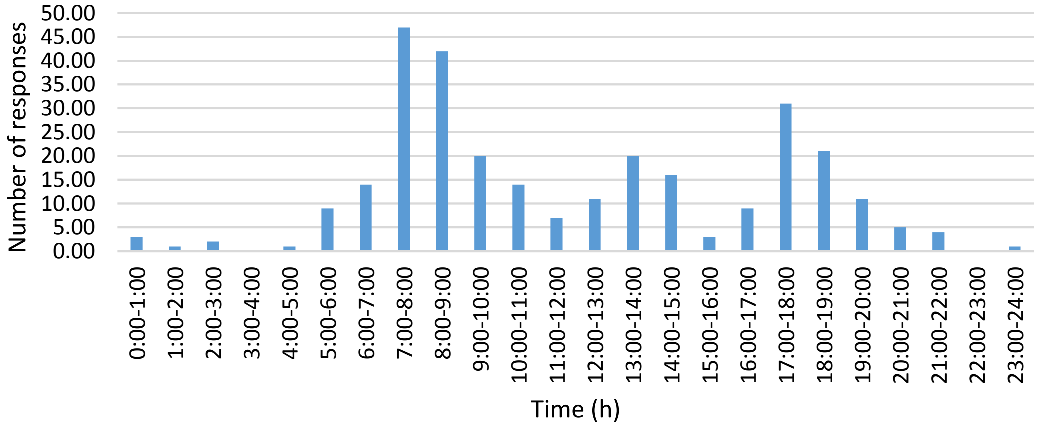


Figure 5-2. Starting time stamp of daily high sound levels

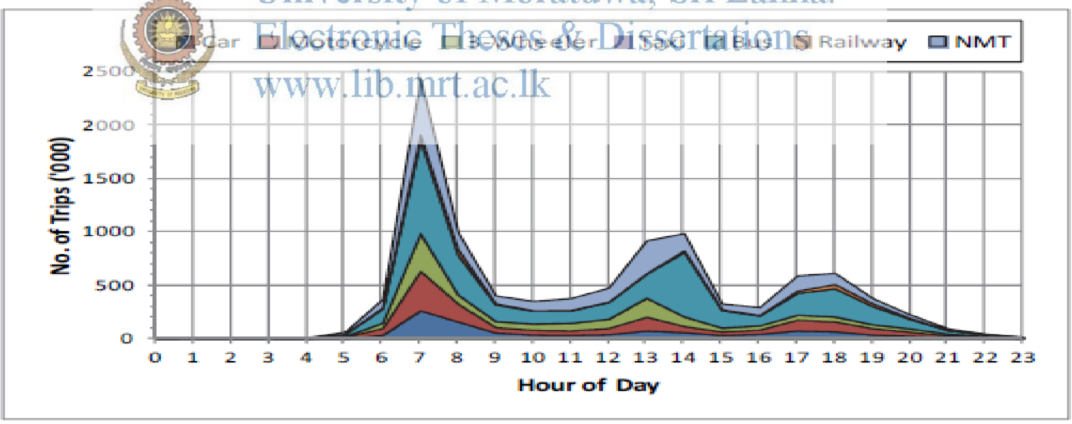


Figure 5-3. Hourly fluctuation by Mode at Trip destinations in Western Province*.

*Source: Urban transport system development project for Colombo metropolitan area and suburbs, Home visit survey, 2013.

Individual perspective regarding the average number of daily hours of exposure to excessive noise is shown in Figure 5-4. This information will provide an understanding about the severity of excessive noise problem. According to Figure 5-4, nearly 70% of respondents are facing excessive noise, 0-4 hours per day. Critically, 15% of respondents have declared that they are facing excessive noises more than 6 hours daily.

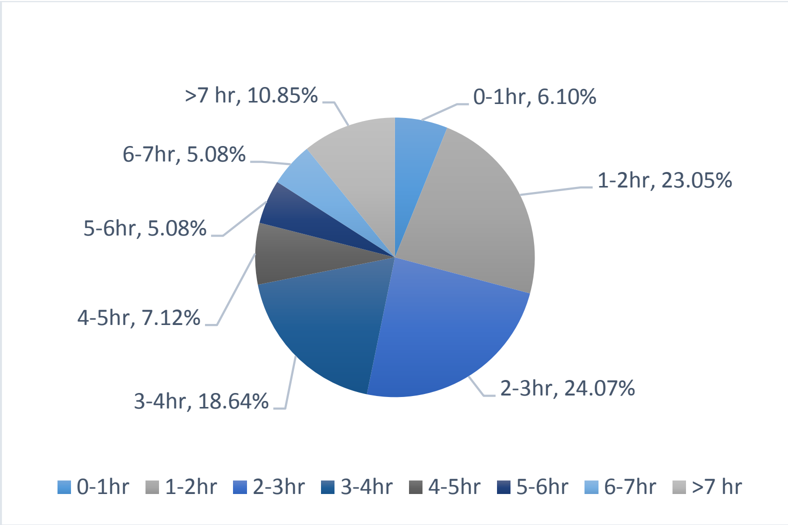


Figure 5-4. Number of daily sound disturbing hours experienced individually.

As shown in Figure 5-5, 69% of positive answers were given when respondents were asked whether the noise level in the nearest city is disturbing or not. Only 29% of respondents have declared that the excessive sound levels in the nearest city are in the scale of Negligible to low range as in Figure 5-1.

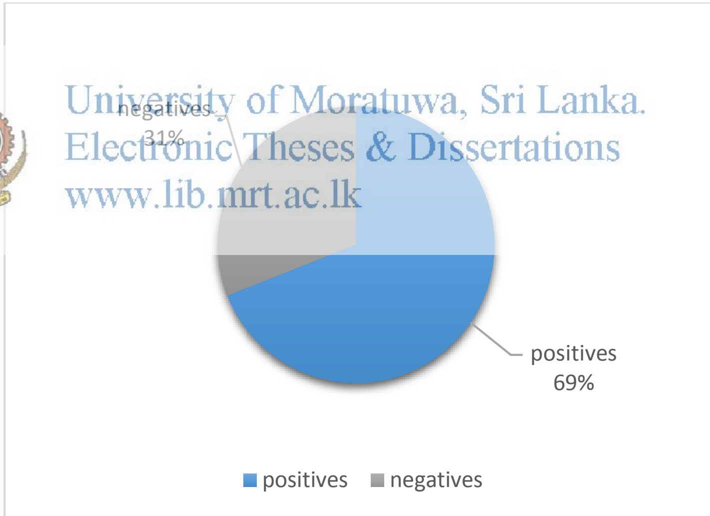


Figure 5-5. Positive & negative responses for sound disturbance complaints at nearest city

From the responses indicating the possible reasons for excessive noise, most of the answers directly or indirectly pointed out to identifiable common sources. According to summarized data presented in Figure 5-6, 78% of respondents have pointed out traffic to be the main source of sound pollution. This is evidence that the traffic noise is the main reason for excessive noise levels in urban areas.

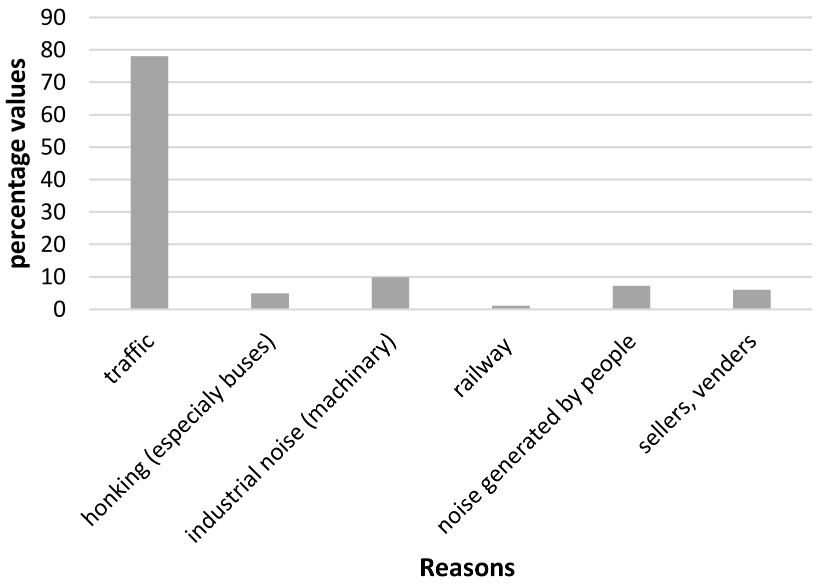


Figure 5-6. Summarized reasons for excessive noise.

It is vital to understand whether public is in need of a solution to excessive noise or have they ignored it or accepted it as a part of their lives. Considering the disturbance of sound levels which is being experienced, 62% of respondents have declared that they are in need of a solution for the excessive sound levels as in Figure 5-7. Even though most of the respondents are facing excessive sound levels and yearning for a solution, only 8% of respondents have already taken remedial actions to prevent the noise problem. These particular remedial actions could be narrowed down to common answers such as, using a boundary walls, keeping the windows and doors closed at day times, using thick curtains etc.

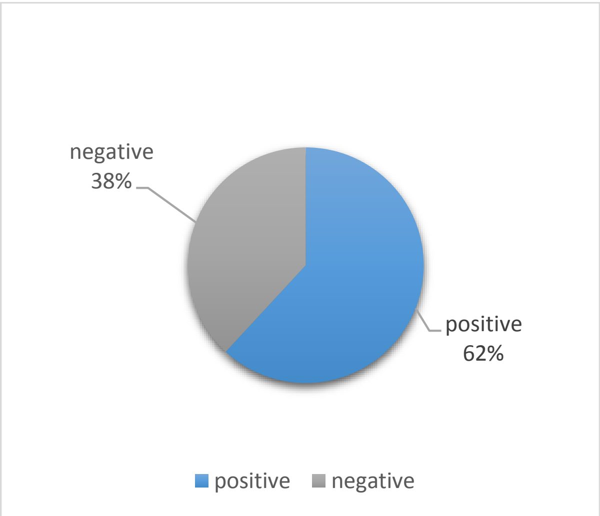


Figure 5-7. Positive and negative responses for in need of a solution for excessive noise problem.

6. HUMAN PERCEPTION ON NATURAL BARRIERS.

Barriers work as a means of separation of space or as an obstacle. In the society artificial barriers are well known as walls, berms, fences etc. natural barrier concepts can be introduced as a replacement for the artificial barriers but it's necessary to identify how the public will embrace a natural barrier solution.

Even though the word "barrier" is familiar to the respondents, concept of "natural barrier" in a glance seemed to be alien. Hence photographs of such natural barriers were shown during the survey. 86% respondents declared that they prefer a natural barrier on their land boundaries as shown in Figure 6-1. However it is important to find out whether respondents would like to maintain a natural barrier if planted at their land boundaries. Taking care of a vegetation growth would require more dedication and concern from the inhabitants other than maintaining an artificial barrier. 87% of respondents indicated the willingness to take the responsibility of maintaining such a natural barrier as in Figure 6-1.

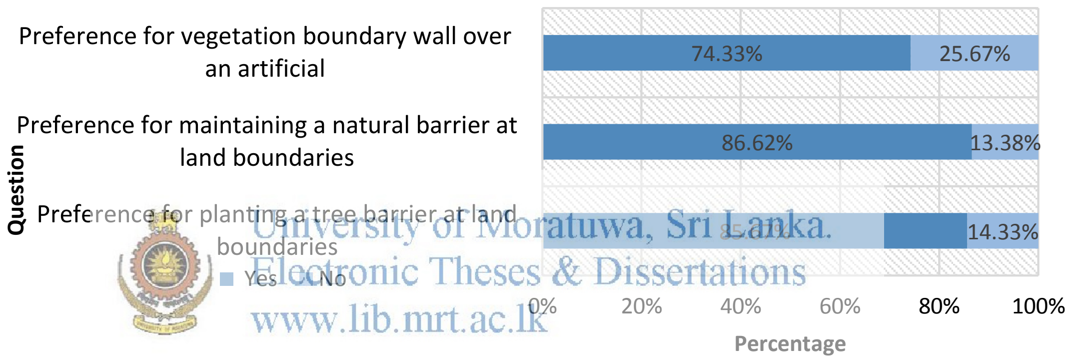


Figure 6-1. Preference for natural barriers.

Majority of the respondents favor natural barriers over an artificial wall. According to Figure 6-1, 74% of respondent have preferred a natural barrier over an artificial barrier.

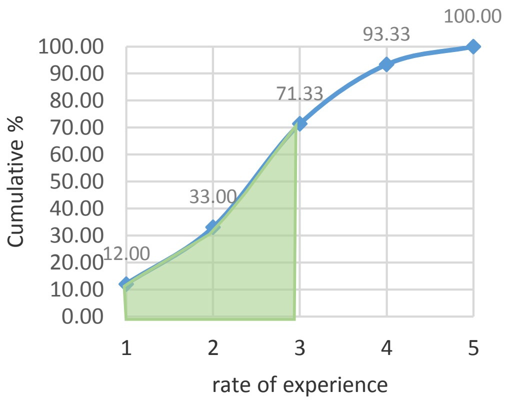


Figure 6-2. Cumulative percentage of experience rating.

The experience and ability to plant and maintain a tree barrier was evaluated under self-confidence of the respondents. The rating scale mentioned Table 3-1 was used to evaluate respondent's experience and capability in planting trees as in Figure 5-1. According to Figure 6-2, 70% of the respondents claimed that their capability and experience in tree planting is bellow or equal to medium level.

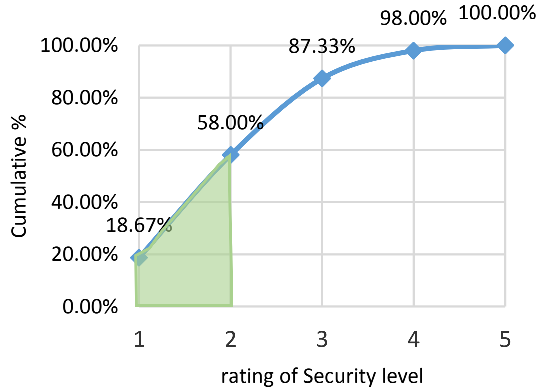


Figure 6-3. Cumulative percentage of security level of natural boundary walls

From the total respondents, 27% has responded positively to the fact of being aware and had come across natural barriers. As indicated in Figure 5-1, the level of security provided by a vegetation boundary wall was rated under the rating scale on Table 3-1, considering the personal expectation regarding security level on the subject as the criterion. The expected security level from a boundary wall tends to be a critical factor. Nearly 60% of the respondents have agreed to the fact that vegetation boundary wall security level would be bellow medium level as in Figure 6-3. According to Figure 5-1 and Figure 6-4, it was evident that security level from an artificial boundary wall is considered as high where 97% of respondents have rated security level of an artificial boundary wall to be equal or more than or equal to medium level.

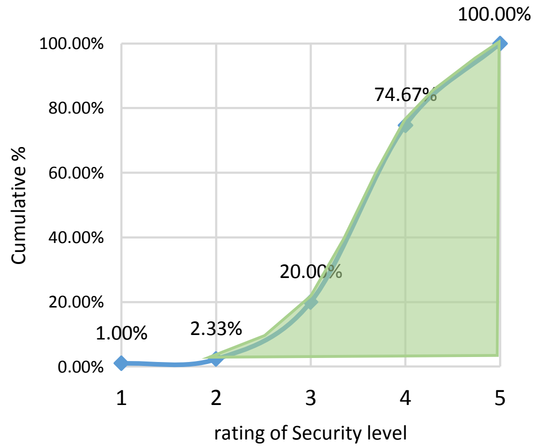


Figure 6-4. Cumulative percentage of security level of artificial boundary walls

Most desirable height of a boundary wall was indicated as 5-7 feet. Nearly 50% of total responses were in favor for the 5-7 feet height range. The responses indicate that human acceptance for barriers more than 12 ft height is negligible. According to Figure 6-5, barriers in the height range of 5 – 9 feet are more likely to be accepted by the society.

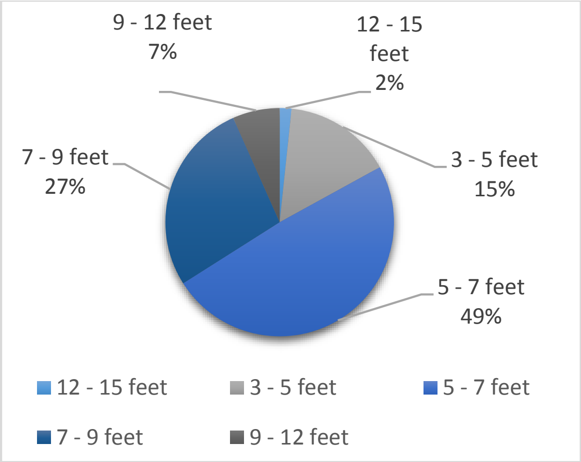


Figure 6-5. Height preference for a boundary walls

Aesthetic appearance of a natural boundary wall was evaluated under the rating scale in Table 3-1 and shown in Figure 5-1. Accordingly 96% of respondents have declared natural barriers provide medium to very high scale of aesthetic appeal as in Figure 6-6. High demand for aesthetic value in natural barriers is highlighted by 52% of respondents rating it as very highly aesthetically appealing.

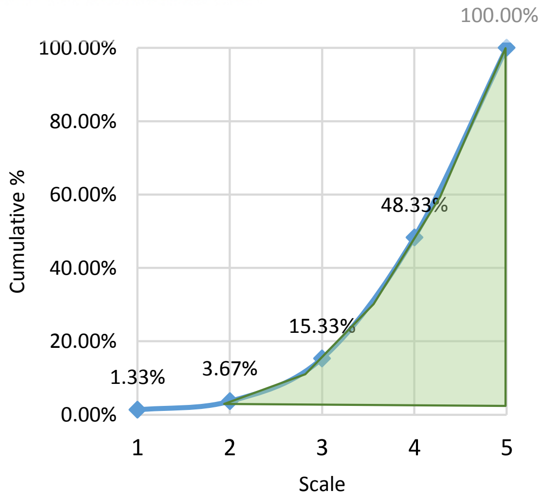


Figure 6-6. Cumulative percentage for aesthetic rating of natural barriers

In deciding the type of the boundary barriers, 57% of responses are in favor of opaque type barriers whereas only 3% of responses in favor of transparent barrier types. Residual responses are in favor of semi-transparent barriers. Respondent's requirement in ensuring privacy is highlighted by these results in Figure 6-7, where opaque or semi-transparent barrier types are preferred by the majority of respondents.

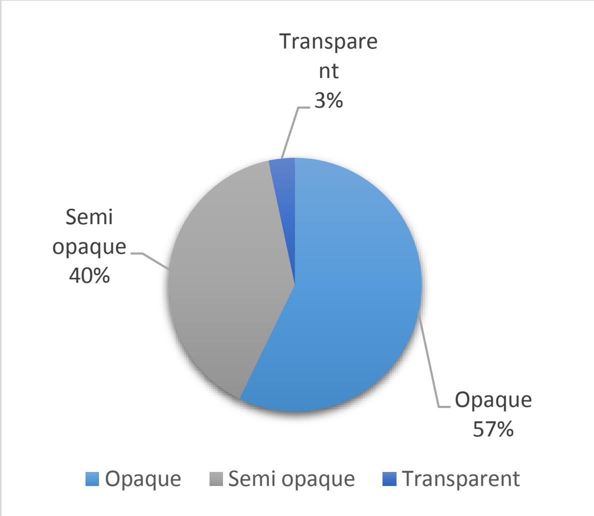


Figure 6-7. Preferred boundary wall types

The results obtained in the section 6, helps to arrive at an idea of preference of natural barrier in the urban society and the expected characteristics of such natural barriers. The study also revealed the possible complications to be faced in the application of natural barriers in urban society. It should be noted that natural barrier applications in urban society will directly have an impact on urban infrastructure such as streets, roads and the road users. However, it has been observed that such natural barriers have been already implemented in urban road planning. Investigation of human perception of these urban street plantations can reveal valuable facts regarding human acceptance of natural barriers.

6.1. RESULTS ON PUBLIC PERCEPTION ON NATURAL BARRIERS ALREADY APPLIED ON URBAN ROADS

Plantation of vegetation in urban roads has become a major trend in road planning concepts. The main objectives of urban road plantations are to provide shade, reduce dust, provide screening from head lights beams during night times , enhancing aesthetic appeal in road planning etc. Suitability of urban road plantations was measured by the rating scale in Table 3-1 under individual perspective indicated in Figure 6-8. More than 95% of the respondents have declared the suitability rate for street tree plantation equal and above moderate level. Only 1% of respondents declared that street plantation is unsuitable as in Figure 6-9.

There is a possibility of disturbance from street tree plantations to motorists due to reduction of their line of sight. Especially at horizontal curvatures and near pedestrian crossing. However the human perception about the scenario is different from the predicted. As shown in Figure 6-10 **,** 67% of respondents were in favor of negligible disturbance or low disturbance category. Figure 6-8, indicates the disturbance levels rated according to rating scale in Table 3-1.

Street plantations may cause disturbance to pedestrians by limiting their distance of sight in events like crossing roads and also disturbing the available space for pedestrians to walk. Disturbance levels were scaled according to rating scale in Table 3-1, and 75% of respondents rated the disturbance as negligible to low disturbance levels as in Figure 6-11. According to findings in Figure 6-8, only 3% of respondents indicated very high disturbance levels.

Respondents have indicated a very high demand for aesthetic appeal generated by the street plantation in the urban areas. Aesthetic appeal was rated according to rating scale in Table 3-1, where 58% of respondents have voted on very high aesthetic appeal as in Figure 6-8. Significant amount as 97% of the total respondents have rated the aesthetic appeal of street plantation as moderate to very high level as indicated in Figure 6-12.

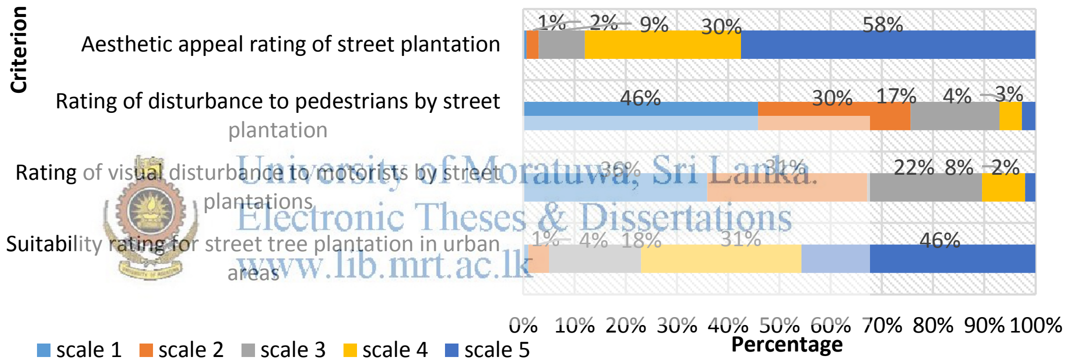


Figure 6-8. Rating for street tree planation in urban areas

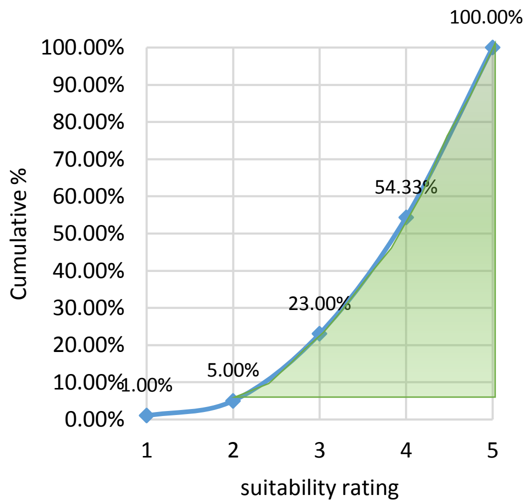


Figure 6-9. Cumulative percentage of suitability rating of street plantations

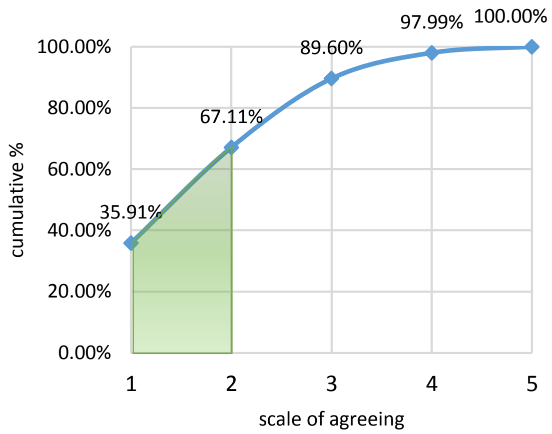


Figure 6-10. Cumulative percentage of disturbance to motorists by street plantations

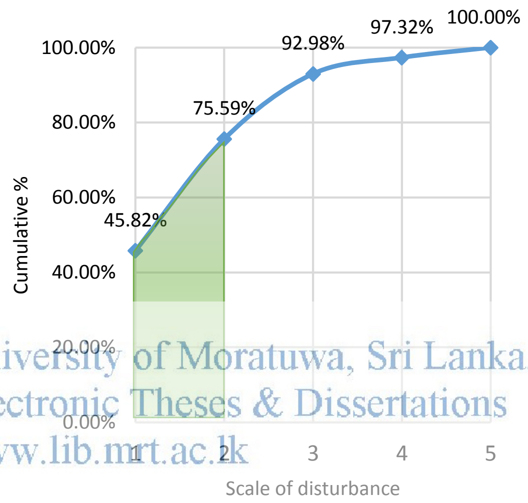


Figure 6-11. Cumulative percentage for disturbance to pedestrians by street plantation

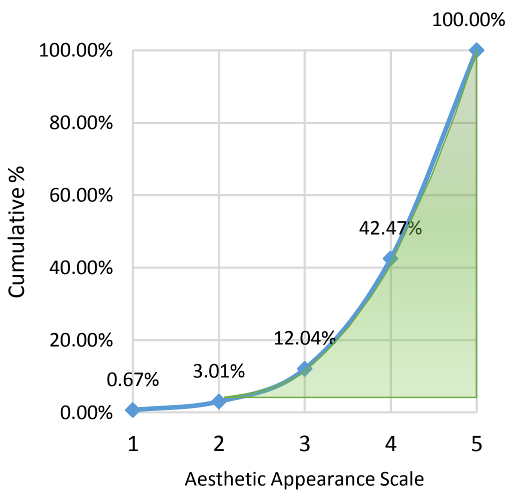


Figure 6-12. Cumulative percentage rating for aesthetic appeal of street plantations.

7. RESULTS FROM ACTUAL NOISE LEVELS DURING PEAK HOURS.

"A" Weighted time average noise level of each selected location was measured to determine the noise level during peak hours. Noise levels were recorded during ten average week days according to the methodology explained in section 3.2.

Table 7-1. Average noise levels of survey locations

Location	Average noise level (LAeq, dB)	Location	Average noise level (LAeq, dB)
Pettha	81.5	Kiribathgoda	77.2
Kollupitiya	78.0	Kadawatha	76.0
Bambalapitiya	77.4	Kaduwela	74.9
Dehiwala	79.8	Gampaha	74.2
Mout lavinia	76.6	Miriswaththa	73.5
Katubedda	76.4	Balummahara	75.8
Batharamulla	77.7	Kaluthara	76.3

7.1. SELECTION OF LOCATIONS

With respective to the areas where questionnaire survey was carried, locations mentioned in Table 7-1 in western province were selected for actual noise level measurements.

7.2. DATA COLLECTION DURATION

As revealed in the questionnaire survey results in Figure 5-6, motor traffic is the main source of sound pollution. The critical noise level durations were in line with the traffic peak hour durations. According to results in Figure 5-2, majority of respondents have declared that the morning traffic peak to be the most disturbing. Hence morning traffic peak duration (7 .00 A.M to 9.00 A.M) was selected as the data collection duration for sound level measurements. Sound level at a particular location was measured 10- 15 minutes for each reading. Noise levels **(LAeq)** data during average 10 week days at city center of urban locations were average to arrive at a representative noise level.

7.3. COMPOSITION OF NOISE AT EACH LOCATION IN 1:1 OCTAVE BAND

Noise data gathered from Bambalapitiya, Pettah, Kollupitiya, Wellawaththa, Dehiwala, Mount lavinia & Katubedda was further analyzed to understand the composition of noise levels during peak hours in 1:1 octave bands.

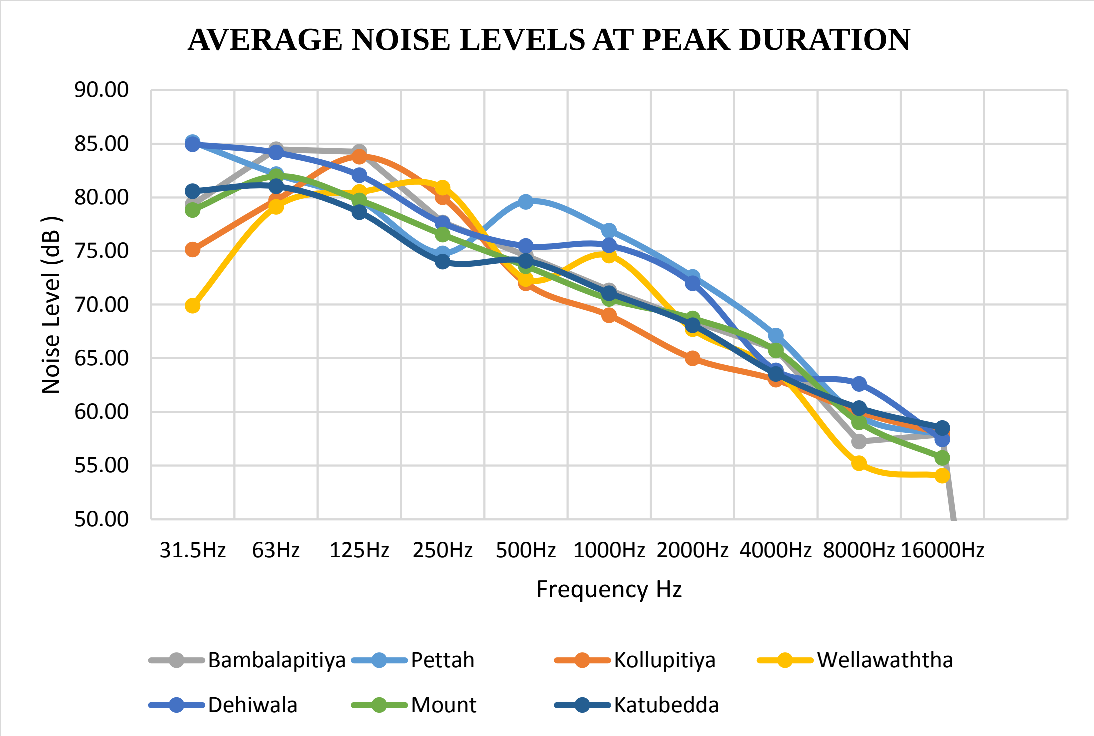


Figure 7-1. Composition of noise in 1:1 octave bands at some urban locations during peak hours

According to Figure 7-1, frequency distribution of noise in the tested locations shows a similar pattern and characteristics. Major part of the noise generated at these location are from low frequency range and mid frequency range.

Audio spectrum is the audio frequency ranges which human can hear. Total range width is 20 Hz- 20 000 Hz and the range can be divided in to seven sub ranges called bands as shown in Table 7-2.

Table 7-2. Audio spectrum

Frequency range	Bands	Category
20 Hz- 60 Hz	Sub-base	Low range
60 Hz- 250 Hz	Base	
250 Hz- 500 Hz	Low Midrange	Mid-range
500 Hz- 2 kHz	Midrange	
2 kHz- 4 kHz	Upper-midrange	
4 kHz- 6 kHz	Presence	Upper range
6 kHz- 20 kHz	Brilliance	

Frequency distribution of actual peak noise captured in all the location suggest with that fact that the noise levels above 60 dB are generated by Low and Mid-range frequencies. Base created in low ranges can be felt more than heard. However excessive noise in the mid-range can cause ear fatigue (eg:- boosting around 1000 Hz gives a horn like quality). Human ear is more sensitive to mid-range. The captured actual noise levels during peak hour duration shows 70-80 dB output in mid-range frequencies. This is evidence that the peak hour traffic noise if more sensitive and disturbing to the public.

Table 7-3Average noise levels at urban locations during peak hours

Location	**Average noise level (LAeq, dB)**	**Location**	**Average noise level (LAeq, dB)**
Pettha	81.5	Kiribathgoda	77.2
Kollupitiya	78.0	Kadawatha	76.0
Bambalapitiya	77.4	Kaduwela	74.9
Dehiwala	79.8	Gampaha	74.2
Mout lavinia	76.6	Miriswaththa	73.5
Katubedda	76.4	Balummahara	75.8
Batharamulla	77.7	Kaluthara	76.3

According to the Table 7-3 the noise levels during peak levels at selected urban locations have exceeded the allowed noise levels in Sri Lankan regulations shown in Table 1-1. The actual noise levels in the study areas during peak hours are in the range of 75- 82 dB.

8. FIELD TESTING OF NATURAL BARRIERS

8.1. EQUIPMENT

For carrying out field testing following equipment were used

8.1.1. Class 2: Sound Level Meter (SLM)

Class two sound level meter with 1:1 octave fitters was used for the testing.(1:1 Octave Band Filters to IEC 61260 & ANSI S1.11-2004 (C & D variants)). Class 2 SLM is in accordance with IEC 61672-1:2002 class 2 and ICE 60651:2001 type 2.
Measurable range 20dB – 140 dB, with fast slow and impulse measured simultaneously. Time history data collection range starting from 10 ms.

8.1.2. Class 2 Sound level calibrator

CR: 514 sound level calibrator accordance to IEC 60942:2003 Class 2 specifications of sound level calibrators.

8.1.3. Speaker to generate Source noise

Speaker was used to generate continues source noise.

Make	Beats
Power	2W x 2
Frequency range	20Hz – 20 000 Hz

8.1.4. Other equipment

1. Measuring tape
2. Adjustable tri-pod
3. HD digital camera
4. Humidity Meter

8.2. ASSUMPTIONS

Following assumptions were made during the research

1. The ambient noise levels without the source noise during the time period of recording noise data, remains unchanged or change in ambient noise level is to be negligible.
2. Effect of impulse noises and unacceptable noise level readings can be eliminated by removing noise data collected in the particular time period of such noise occurrence form the gathered noise date file from data logging noise level meter
3. Wind effect to be negligible while collecting noise data.
4. It is assumed that the temperature and humidity level change to be negligible or no change during conducting testing of the same barrier
5. Source noise assumed to be propagating directly at the noise barrier face hence all indirect propagation pathways of sound were not assumed and all readings

were taken 3 m away from other surrounding surfaces or obstacles to minimize the effect of noise refection from other surfaces.

6. Effectiveness of the natural barriers in sound attenuation is considered independent from their difference in species.
7. It was assumed that the amount of leaves covering the barrier (green cover) to be a major factor of sound attenuation from the natural barrier.

8.3. LIMITATIONS AND REMEDIES TAKEN

8.3.1. Testing location and testing environment

The natural barriers are to be design for use in urban conditions. In urban areas noise fluctuation is higher. Congested nature limits the space required for testing and man-made constructions create numerous reflective surfaces around the area. It is also rare to find the type of natural barrier required for testing in urban areas. Hence the testing cannot be carried in the urban environment. As a remedy the testing of natural barriers were carried in suburban and rural conditions.

8.3.2. Ambient noise levels and impulse noises

Higher ambient noise levels does not facilitate to measure the noise differences. As a remedy, areas with low ambient noise levels were selected (eg:- 40-50 dB recommended).Impulse noises and kinked noise patterns were excluded by removing the particular noise data recorded during the particular time period in data logging sound meter.

8.3.3. Barrier shape

Due to the random shapes of tree growth it is hard to define a proper shape of a barrier. It was necessary to define and measure height, thickness and length of the barrier for research data collection. Barriers with tree crowns were omitted. Hence closely grown tree belts which assumed a cuboid shape approximately was selected. Refer Appendix A.

8.3.4. Difference in species

It was observed that in some occasions certain tree barriers which is suitable for the research contains different species defining a tree barrier would get more complex if it was to be also defined by its different species and the composition of difference of species. Hence testing the effect by different species was not considered as a part of the research scope. Instead the effect of total foliage cover (Green cover) was considered.

8.3.5. Barrier density and Green Cover

Most of the tested tree barriers were belong to common people who has grown them to be used a fence for their land. Due to their rejection in extracting a sample from the tree belts, nondestructive method had to be used to achieve a measurement instead of measuring tree belts density directly. Hence photographic method was used to define a parameter named Green Cover for each barrier. Refer Appendix B.

9. FIELD TESTING DATA

Natural barriers and selected artificial barriers were tested to determine their acoustic performance. Number of 75 natural barriers and 25 artificial barriers were tested during the research.

Table 9-1 Field testing data set for natural barriers

No	Barrier Number	Length (m)	Height (m)	Thickness (m)	Temp (ºC)	Humidity (%)	Green cover (%)	Energy Reduction (%)	*dB reduction (dB)*
1	B01	4.5	2	1	30	67	89.65	55.94	***3.56***
2	B02	4	2	0.6	30	59	92.88	61.10	***4.1***
3	B03	4	2.2	1	30	59	81.69	58.50	***3.82***
4	B04	4.5	2.1	1.1	30	59	91.81	61.98	***4.2***
5	B05	5	1.9	1.2	30	59	75.93	45.05	***2.6***
6	B06	5	2	0.7	29	80	81.05	61.98	***4.2***
7	B07	5.25	2.1	0.75	29	80	75.64	39.74	***2.2***
8	B08	5.5	1.65	0.8	28	80	59.68	33.93	***1.8***
9	B09	5	1.6	0.6	29	71	85.86	59.26	***3.9***
10	B10	4.5	2.5	0.85	29	71	88.90	60.19	***4.0***
11	B11	4	2.35	0.85	28	71	88.86	70.42	***5.29***
12	B12	5	1.4	0.6	28	71	84.55	51.81	***3.17***
13	B13	4	2.5	1	31	57	89.34	68.16	***4.97***
14	B14	4.5	1.5	0.8	30	57	81.04	44.02	***2.52***
15	B15	4.25	1.5	0.8	30	57	78.86	41.12	***2.3***
16	B16	4.5	1.8	0.65	30	57	90.24	50.34	***3.04***
17	B17	5	1.6	0.6	27	73	87.02	46.79	***2.74***
18	B18	5	1.6	0.8	27	73	81.57	45.92	***2.67***
19	B19	6	1.8	1.1	28	73	80.38	58.31	***3.8***
20	B20	5.5	1.8	1.1	28	73	74.60	43.38	***2.47***
21	B21	5	2	0.7	28	70	89.51	57.54	***3.72***
22	B22	7	1.3	1.2	28	70	86.66	43.77	***2.5***
23	B23	10	1.5	0.9	29	70	86.47	48.95	***2.92***
24	B24	8	2	0.8	28	70	74.97	45.67	***2.65***
25	B25	4	2.1	0.9	28	70	89.61	51.81	***3.17***
26	B26	3	1.8	0.7	28	68	90.97	53.23	***3.3***
27	B27	6	2.2	1	28	68	87.95	58.41	***3.81***
28	B28	4.5	6	1	31	58	87.82	56.15	***3.58***
29	B29	3.75	1.8	1.3	31	58	90.35	50.45	***3.05***
30	B30	2.5	2.75	0.8	31	58	83.89	62.16	***4.22***
31	B31	3.5	1.65	0.4	28	74	76.04	47.03	***2.76***
32	B32	3.6	1.8	0.55	28	69	83.90	52.03	***3.19***
33	B33	5	1.55	0.55	29	69	71.80	48.60	***2.89***

No	Barrier Number	Length (m)	Height (m)	Thickness (m)	Temp (°C)	Humidity (%)	Green cover (%)	Energy Reduction (%)	*dB reduction (dB)*
34	B34	3	1.35	0.5	29	69	83.45	43.38	***2.47***
35	B35	3	1.35	0.5	29	69	92.63	65.41	***4.61***
36	B36	8	1.8	0.3	29	69	75.55	43.51	***2.48***
37	B37	7	1.6	0.6	29	69	91.85	70.89	***5.36***
38	B38	5.5	2.5	0.8	30	69	92.70	69.80	***5.2***
39	B39	3.5	2.4	0.85	30	69	92.55	70.15	***5.25***
40	B40	10	1.7	0.3	30	67	75.30	41.92	***2.36***
41	B41	11	2.2	0.5	30	67	89.74	58.31	***3.8***
42	B42	3	1.8	0.65	30	67	90.25	50.11	***3.02***
43	B43	3.5	2	1	30	67	92.84	54.61	***3.43***
44	B44	5.5	1.8	0.45	31	68	90.46	58.70	***3.84***
45	B45	2.5	1.7	0.5	31	68	90.82	57.93	***3.76***
46	B46	20	2	0.6	30	67	86.08	66.89	***4.8***
47	B47	20	2.3	0.6	30	67	91.10	72.96	***5.68***
48	B48	3.5	1.9	0.3	31	67	90.73	54.81	***3.45***
49	B49	5	1.7	0.7	31	67	83.31	44.41	***2.55***
50	B50	8	1.8	0.9	31	67	91.46	52.79	***3.26***
51	B51	7	1.8	0.9	31	68	90.12	58.60	***3.83***
52	B52	4	1.65	1	32	60	80.59	63.10	***4.33***
53	B53	20	1.4	1	33	60	89.95	50.80	***3.08***
54	B54	20	1.3	0.7	33	60	82.92	48.95	***2.92***
55	B55	7	1.6	1.1	33	61	82.90	48.12	***2.85***
56	B56	10	1.75	0.8	33	67	86.90	53.12	***3.29***
57	B57	5	1.7	0.7	33	67	89.96	50.00	***3.01***
58	B58	3	1.75	0.8	33	67	88.64	53.33	***3.31***
59	B59	9.5	1.7	0.9	32	67	85.79	50.45	***3.05***
60	B60	9	1.7	1.1	32	67	87.18	51.81	***3.17***
61	B61	5	1.6	0.5	32	67	50.99	22.20	***1.09***
62	B62	4	1.65	0.7	31	65	88.75	46.79	***2.74***
63	B63	12	1.9	0.8	31	65	80.22	46.05	***2.68***
64	B64	8	2.2	1.1	31	65	81.38	52.79	***3.26***
65	B65	20	1.55	0.6	31	65	91.03	58.70	***3.84***
66	B66	50	1.6	0.6	33	60	87.33	58.41	***3.81***
67	B67	3.5	1.55	0.45	28	74	76.39	52.79	***3.26***
68	B68	3.5	1.8	0.55	29	69	75.01	39.74	***2.2***
69	B69	8	1.7	1.2	33	61	82.28	52.14	***3.2***
70	B70	6.5	1.45	0.45	32	67	51.65	27.56	***1.4***
71	B71	8	2	0.75	29	69	91.62	67.04	***4.82***
72	B72	4.25	1.5	0.4	32	67	50.99	25.87	***1.3***

No	Barrier Number	Length (m)	Height (m)	Thickness (m)	Temp (°C)	Humidity (%)	Green cover (%)	Energy Reduction (%)	*dB reduction (dB)*
73	B73	9	1.65	0.35	30	67	71.69	41.92	***2.36***
74	B74	5.75	1.65	0.5	29	69	75.74	49.77	***2.99***
75	B75	6.25	1.75	0.45	32	67	57.66	32.39	***1.7***

10.ANALYSIS AND RESULTS

Analysis of the data is done in two methods using Multiple Linear Regression analysis (MLR) and Artificial Neural Networks (ANN).

10.1. MULTIPLE LINEAR REGRESSION (MLR) ANALYSIS

Multiple linear regression model attempt to decide the relationship with series of variable input values to a dependent output variable. MLR is an expansion of Simple Linear Regression model with one independent variable to a one dependent variable.

Table 10-1 Multiple Linear Regression analysis

Y	Dependent variable or desired output	
$\hat{Y}$	Predicted value of the dependent variable	
y	Standardized dependent variable	
$\hat{y}$	Predicted value of the standardized dependent variable	
X	Independent variable or predictor variable	
x	Standardized independent variable	
B_0	Regression coefficient representing output variable when all independent variables are zero	
B_n	Regression coefficient for nth independent variable	
β_n	Standard regression coefficients	
i	i^{th} Iteration	
n	Number of predictor variable	
ε	Residuals or predicted error.	
ε'	Standard residuals or standard predicted error.	

$Independent\ variables = X_1, X_2, X_3, X_4 \dots \dots \dots . X_n$

$Dependent\ variable = Y$

Simple linear regression formula is shown as Eq: 3

$$Y_i = B_0 + B_1 X_{1i} + \varepsilon$$

Eq: 3

The standard formula for first order model can be represent in Eq: 4 and Eq: 5.

$$Y_i = B_0 + B_1 X_{1i} + B_2 X_{2i} + B_3 X_{3i} + \dots \dots \dots \dots \dots + B_n X_{ni} + \varepsilon$$

Eq: 4

$$\hat{Y} = B_0 + B_1X_{1i} + B_2X_{2i} + B_3X_{3i} + \dots\dots\dots\dots\dots + B_nX_{ni}$$

Eq: 5

When independent and dependent variables are standardized, standard formula for first order model can be shown as Eq: 6 and Eq: 7

$$y_i = \beta_0 + \beta_1x_{1i} + \beta_2x_{2i} + \beta_3x_{3i} + \dots\dots\dots\dots\dots + \beta_nx_{ni} + \varepsilon'$$

Eq: 6

$$\hat{y} = \beta_0 + \beta_1x_{1i} + \beta_2x_{2i} + \beta_3x_{3i} + \dots\dots\dots\dots\dots + \beta_nx_{ni}$$

Eq: 7

Independent variables can be higher order terms such as $X_{ni}^2, X_{ni}^3. X_{ni}^k$ .... in higher order models.

Difference in predicted values and desired values represent the error in the function which is called the residuals. Residuals represent the portion of the variability of dependent variable which is not explained by the given predictor variables.

10.1.1. Interpretation of regression coefficient

Regression coefficients are as B_0,B_1,B_2…… B_n. Coefficient named as B_0 is the intercept where any other coefficient indicates the amount of change in dependent variable due to respective increment of independent variable in one.

Eg:- B_1=3.5 indicates that increment of one unit in variable X_1 while keeping other X_i variables constant, the mean value of dependent variable would change in 3.5.

The above interpretation is valid only for first order models with quantitative variables. There can be quantitative and qualitative variables in real problems. Qualitative variables have to be converted in to numerical values prior to be included in a model.

10.1.2. Least square method

Least square methods reduces the sums of errors, fitting the model as closely as possible to the actual pattern. Aim is to minimize sums of squares of errors (SSE).

$$SSE = \sum_{0}^{n}(Y_i - \hat{Y}_i)^2$$

Eq: 8

10.1.3. Error and goodness of fit.

The fitness of the predicted function to the actual data is measured by the R^2 value, which is also known as Coefficient of determination of multiple regression shown in Eq: 11.

$$\sigma^2 = \frac{SSE}{(n-p-1)} = MSE$$

Eq: 9

The Eq: 9 represent the mean square error (MSE) of the model where n= sample size, p= number of independent variables. The estimate of the standard error "s" is the square root of the MSE. Assuming a normal distribution due to Figure 11-1, we expect the model to give predictors of dependent variable in 95% confidence level, where the predicted values falls within ± 2s (±two standard deviations). According to Eq: 10 accuracy of prediction improves as the "n" increases.

$$s = \sqrt{\frac{SSE}{n-p-1}}$$

Eq: 10

The R^2 value represent the percentage of variation of the dependent variable explained by the model

$$R^2 = \left(\frac{Explained\ variation}{Total\ variation}\right) = \frac{SS_{yy} - SSE}{SS_{yy}} = 1 - \frac{SSE}{SS_{yy}}$$

Eq: 11

Where;

SSE = sums of squares of errors, SS_{yy} = Total sums of squares (variability of the dependent variable) also shown in Eq: 12 . ($\bar{Y}$= sample mean of dependent variable.

$$SS_{yy} = \sum_{i=1}^{n} \left(Y_i - \hat{Y}\right)^2$$

Eq: 12

Considering R^2 alone will not give a clear picture regarding the model fitness. The R^2 cannot determine whether the coefficient estimates and predictions are biased. Hence residual plot should be made and distribution of residuals should be examined. If residuals shows a normal distribution and no pattern it can be concluded that the model is a good model which explains the given problem.

10.1.4. Adjusted R^2 value.

With number of predictor variables there is a possibility of developing several multi linear regression models. In reality some of the variables will be significant to the model and some will not. It should be ensured which are the variables and how many variables actually constitute a good model. Adding an extra predictor variable will not always improve the model. R^2 value does not reflect this phenomenon. The adjusted R^2 is a modified version of R^2 that has been adjusted for the number of predictors in the model which is indicated in Eq: 13.

$$R_a^2 = 1 - \left\{ \frac{(n-1)}{(n-p-1)} (1 - R^2) \right\}$$

Eq: 13

10.1.5. Assumptions in Multiple Linear Regression (MLR)

Linearity assumption is one of the main assumptions, multiple regression technique assumes that the relationship between the Y and each of Xi's is linear.

Dependent variables do not show multicollinearity causing to a dilemma in model in deciding which variable is actually responsible for the regression.

It is assumed that the residuals to be in a normal distribution.

The data shows homoscedasticity, meaning that the variances along the line of best fit remain similar as progress along the line.

No significant outliers exists in the sample or sample has been filtered from the outliers.

10.1.6. Significance of multi linear regression coefficients.

To check the influence of individual variables to the dependent variable is significant or not, a statistical method of testing the null hypothesis can be carried out. In null hypothesis, the relevant regression coefficient is presumed to be zero and unless sufficient evidence rejects the null hypothesis the relevant coefficient is considered to be insignificant to the model. This can be done using t-test.

10.1.7. Outliers, Box and Whicker plots

Outliers were determined using Box and Whicker Plots. By determining the spread of data set using Inter Quartile Range (IQR) and the central value it is possible to determine which data falls too far away from the central value. Where Q_3 is the tired quartile and Q_1 is the first quartile of the data set.

$$IQR = (Q_3 - Q_1)$$

Eq: 14

Table 10-2. Outlier Limits

Outlier Limit	Formula
Lower Limit (LL)	$Q_1 - (1.5 \times IQR) = LL$
Upper Limit (UL)	$Q_3 + (1.5 \times IQR) = UL$

Eliminating outliers in linear regression models is vital since one extreme outlier could significantly change the regression equation.

10.2. ARTIFICIAL NEURAL NETWORKS (ANN)

Artificial neural networks can be used to obtain solutions for many sophisticated problems in numerous fields. ANN is inspired by biological neural networks mimicking the central nervous systems and the brain of the living beings. This method can be used to model behaviors and approximate and estimate functions which are dependent on number of inputs and factors effectively.

A single neuron can be presented as the simplest form of ANN. Biological neuron combines the received inputs and perform nonlinear operation and generate a result. A number of interconnected highly interconnected neurons constitute a network mimicking the process of decision making of the human brain. These networks are adoptive and gain experience and evolve by each encounter to a particular scenario or problem.

Biological neuron receives inputs via dendrites and process the inputs through soma and delivers the outputs from axon and synapses as shown in Figure 10-1.

This process is mimicked through a mechanical learning approach where adoptable weights will influence the learning of the ANN from the given inputs until the network is trained to approximate the desired output. These adoptive weights are tuned by a learning algorithm during the training process of ANN.

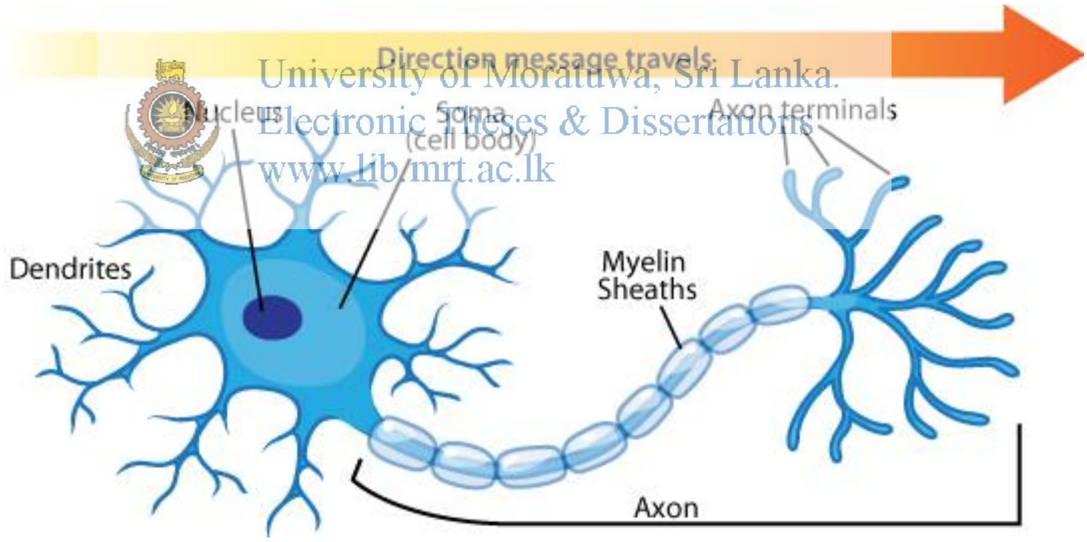


Figure 10-1 Neuron

Artificial Neural Network model have three layers which are;

1. Input layer
2. Hidden layer
3. Output layer

Input layer include all the inputs or predictors. The hidden layer consists of neurons also known as processing elements. However in the mathematical model it’s justifiable to use the word perceptron instead of a neuron. Perceptron is defined as an artificial representation of an actual biological neuron where the biological neuron gets activated by a set of electrical signals, in the perceptron these electrical signals are represented as numerical values. Electrical signals are modulated at the synapses between the dendrite and axons, in different amounts. This process is done at perceptron by multiplying each input value by a weight.

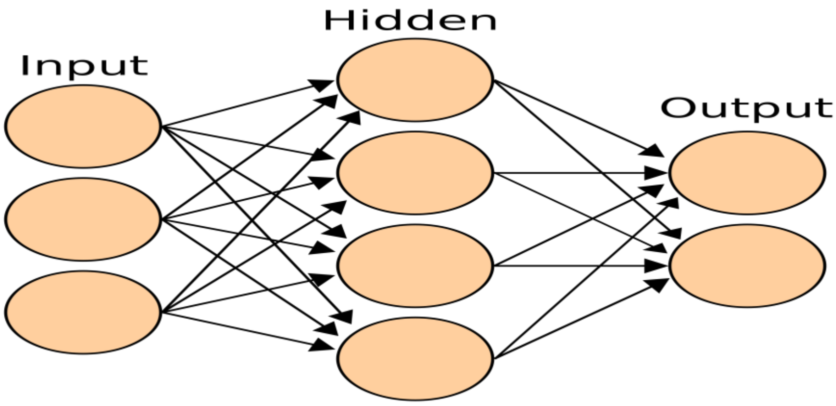


Figure 10-2 Neural network with one hidden layer

Hidden layer can be represented by only one layer of perceptron in the simplest form of Artificial Neural Network. Adding few layers of perceptron will improve the model and make the network architecture more complicated. The number of perceptrons in a layer can vary depending on the network architecture. In the hidden layer one neuron can be connected to several other neurons and likewise the architecture of the network can get complex with limitless combinations.

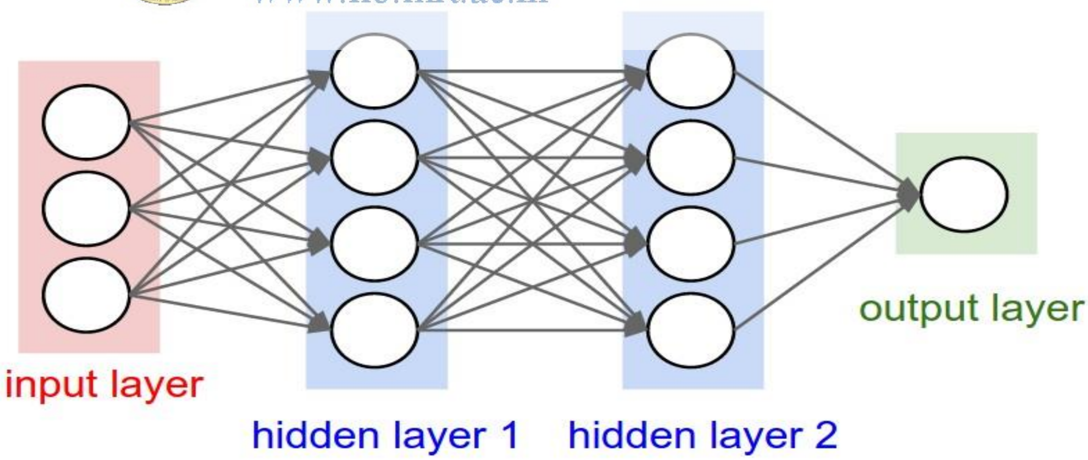


Figure 10-3 Neural network model with two hidden layers

Output layer consist of the out puts. Single node can represent only one output where as a complex network with several output nodes can produce several outputs. In biological neuron a signal is only processed and transfer forward in the network by a neuron if only the signal exceeds a certain threshold. In a perceptron this process is mimicked by calculating the weighted sum of the inputs which represent the strength of the input signals, and then the activation function on the sum determines the output from the particular neuron. The weights of the network can be adjusted via training to give the best desired output.

10.2.1. Process in single perceptron

Process of a single perceptron is explained in this section using “n” number of input variables connected to a single perceptron with “n” number of weights. First model architecture indicates a bias which is then modified as X_0 variable (where X_0=1), and added to the model via W_0 weight in order to simplify the model.

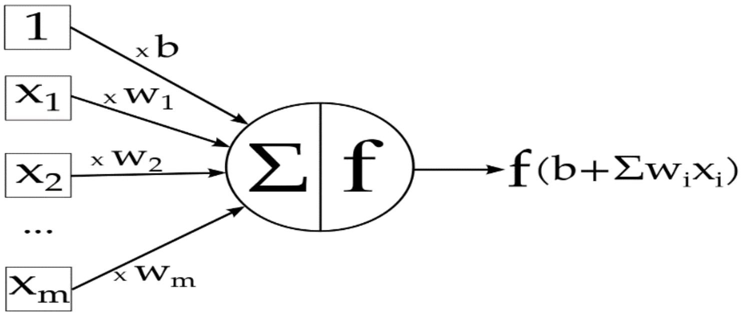


Figure 10-4Figure 10-5 Single perceptron and how it processes

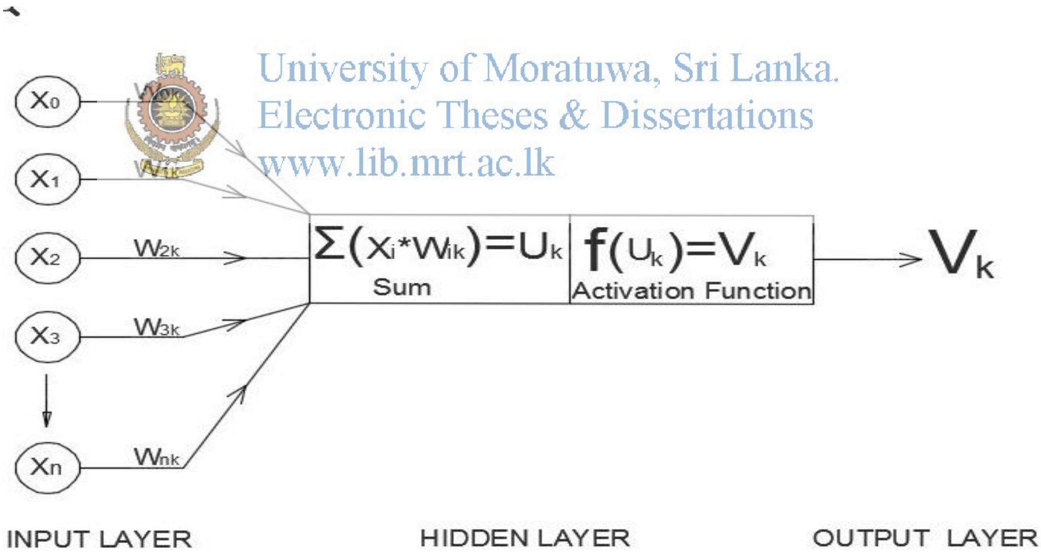


Figure 10-6 Detail explanation of process in a perceptron

First the inputs will be multiplied by the weights and then summing function will add these values together. Summed value will be processed through an activation function which will give the output from the perceptron (V_k). The output will become input to anther perceptron in the network until the final output of the network is processed.

$$f\left(b+\sum_{i=1}^{n}(W_{ik}*X_i)\right)=f\left(\sum_{i=0}^{n}(W_{ik}*X_i)\right)=V_k$$

Eq: 15

Mathematical process of the perceptron is shown in Eq: 15. Where;

X_i	i^{th} input
W_{ik}	Weight value of the i^{th} input of k^{th} perceptron
b	Bias
$f(\,)$	Activation function

During the training the weights of the network will be adjusted to give out the best output matching the expected output.

10.2.2. Re-scaling Variables

Considering the variables used in this research all the dependent and independent variables are quantitative variables. No categorical variables are present in the data set.

However Inputs are in different scales for example "Height" variable units are in meters while range is from 0m to 5m and "Green cover" variable is in percentages while range is from 0% to 100%. Hence variables are in different units and scales and these variables will not equally contribute to the model, Transforming the data to comparable scales can prevent this problem from having different scaled variables. Hence variables should be re-scaled. Two rescaling methods are adopted in the research.

Standardizing data.

Standardization rescales the variable to have zero mean and unit variance. Eq: 16

(μ= mean, σ= standard deviation)

$$X_{standerdized}=\frac{(X_i-\mu)}{\sigma}$$

Eq: 16

Normalizing data.

Normalizing, scales all numeric variables in the range of (0,1) and shown in Eq: 17. This method is appropriate for scale-dependent variables if the output layer uses the sigmoid activation function. (X_{max} = maximum value of the variable. X_{min}= minimum value of the variable)

$$X_{normalized}=\frac{(X-X_{min})}{(X_{max}-X_{min})}$$

Eq: 17

Adjusted normalizing

Adjusted normalizing is similar to as normalizing data but spread the data set in (-1,1) range. This method is appropriate for scale-dependent variables if the output layer uses the hyperbolic tangent activation function. (Xmax = maximum value of the variable. Xmin= minimum value of the variable)

$$X_{Adjusted\ normalized} = \frac{2(X - X_{min})}{(X_{max} - X_{min})} - 1$$

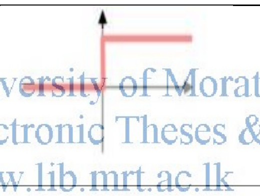
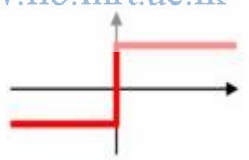
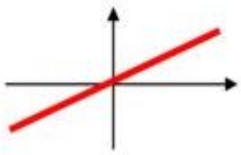
Eq: 18

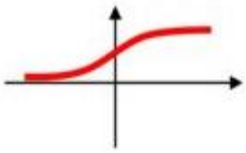
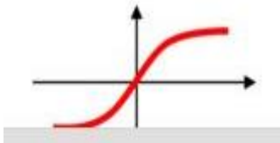
10.2.3. Activation functions

Activation function process the summation of the input values of the perceptron to yield an output. This function is also called the transfer function.

Commonly used activation functions are shown in Table 10-3.

Table 10-3 Activation functions

	Activation function	Graph	Function
1	Unit step (Heaviside)		$\phi(z) = \begin{cases} 0 & z < 0, \\ 0.5 & z = 0, \\ 1 & z > 0, \end{cases}$
2	Sign (Signum)		$\phi(z) = \begin{cases} -1 & z < 0, \\ 0 & z = 0, \\ 1 & z > 0, \end{cases}$
3	Linear (Identity)		$\emptyset(z) = z$
4	Piece-wise linear		$\phi(z) = \begin{cases} 1 & z \geq \frac{1}{2}, \\ z + \frac{1}{2} & -\frac{1}{2} < z < \frac{1}{2}, \\ 0 & z \leq -\frac{1}{2}, \end{cases}$

5	Logistic(sigmoid)		$\emptyset(z) = \frac{1}{1 + e^{-z}}$
6	Hyperbolic tangent (Tanh)		$\emptyset(z) = \frac{e^{z} - e^{-z}}{e^{z} + e^{-z}}$

Among the activation functions sigmoid function and hyperbolic tangent functions are popular in modeling artificial neural networks. Sigmoid functions have similarities to stepwise function and also have a region of uncertainty. Due to this reason sigmoid functions show similar characteristics to an actual behavior of a neuron. Tanh function is also a type of a sigmoid function which is scaled. Where tanh function is zero centered the sigmoid function is non zero centered. While training the network infinite functions efficiently effect tall the weights which improves the overall efficiency of training process.

Continuous and differentiable activation function aids the neural network training process. Due to this reason sigmoid and hyperbolic tangent functions are very suitable for multilayer perceptron models. Symmetrical sigmoid functions have some advantage when it comes to learning of the network hence symmetric sigmoid functions such as hyperbolic tangent function are more useful.

10.2.4. Training methods

During the training process the neural network get adjusted by each iteration. Training algorithms are used to achieve this, where training algorithms globally effect and adjust all the weights and biases.

The backpropagation algorithm focuses on minimizing the error function in weights using the method of gradient descent. This method needs to compute the gradient of the error function at each iteration step. Due to this reason activation function used in the model should have continuity and differentiability. Sigmoid function and hyperbolic tangent function satisfy this requirement.

A neural network is a combination of functions since sum of weighted inputs at each node is converted by an activation function. It is justifiable to conclude that neural network is a composite of functions, which can be also defined as the network function.

(Network function = $\varphi(x_i)$).

Consider a network with a desirable architecture where “n” number of inputs (x_i) and “m” number of outputs (y_i). Under supervised learning this network will have input sets of "p" ((x_1,y_1) ,(x_2,y_2)………(x_p,y_p)).network will produce outputs (o_i) Hence the error of the network function (E) can be expressed as in Eq: 19.

$$E = \frac{1}{2}\sum_{i=1}^{p}(0_i - y_i)^2$$

Eq: 19

Backpropagation algorithm is used to find a minima of the error function, and gradient of the error function is used to updates the weights of the neural network. Error function (E) is a generated from a composition of functions which is continuous and differentiable consisting "g" number of weights, E can be minimized by an iterative process of gradient decent. Eq: 20

$$\nabla E = (\frac{\partial E}{\partial w_1}, \frac{\partial E}{\partial w_2}, \frac{\partial E}{\partial w_3} \dots \dots \dots . \frac{\partial E}{\partial w_l})$$

Eq: 20

Each weight is iteratively modified by the answer from Eq: 21 until the Error function minimized.

$$\Delta W_i = -\eta \frac{\partial E}{\partial w_i}$$

η= learning rate or learning constant.

Eq: 21

First random weight are given to the network and using back propagation off error and gradient descent algorithms the weights are updated. If explained in stepwise following steps will be carried out until the network error function get sufficiently small. This condition is considered as the stopping criteria for learning. When the error function do not decrease further the learning has to be stopped.

1. Feed forward computation
2. Back propagation to the output layer
3. Back propagation to the hidden layers
4. Updating weights

Hence the artificial neural network models in this research was trained using gradient decent training algorithm with backpropagation of error.

10.2.5. Type of neural network

The type of neural network which is suitable for the data collected in this research is supervised neural network. Independent variables and dependent variables shown in Table 11-1 , is used in the supervised network models in this research.

Supervised neural network

A supervised neural network is used to identify pattern or relationship from inputs to outputs. Network is fed with inputs and desired outputs at the beginning and trained to achieve the best pattern or relationship which matches the output.

<u>Unsupervised neural network</u>

Unsupervised neural network is fed with inputs as the network determines the output depending on the inputs given. The network automatically adjust itself and outputs as new input sets are introduced and finally provide a classification scheme or pattern.

10.2.6. Approaches for training.

Training of a neural network can be achieved in different approaches. Three types of training can be identified under gradient decent algorithm.

Online training

Synaptic weights are updated after process of each and every training record until the stopping criteria is reached. Online training is most preferred for larger data sets.

Batch training

Updates synaptic weights only after processing all training records through the network. Batch processing will be continued till stopping criteria is reached. This method is most useful for small data sets.

Mini-batch training

Smaller batches of the data set is used in this method where the synaptic weights are updated after processing of each mini-batch until the stopping criteria is reached. This method is recommended for medium size data set and this method is a compromise between online and batch training methods.

Epoch

Epoch can be explained as a one single pass of data records through the network prior to updating synaptic weights.

Stopping rule

Stopping rule of the network training process will be determined by the maximum allowed number of epochs without decreasing the error, maximum training time, maximum number of epochs allowed or reaching the Minimum relative change in training error ratio.

Learning rate

This is the parameter which will control the change in weights and bias in the network while training. For this research ANN models learning rate used was 0.4.

Momentum

This parameter is used to control the training to prevent the convergence of error function to a local minima. Momentum parameters used in this research, at beginning of training 0.5 and after that 0.9. Higher value for momentum will increase the speed of convergence at the cost of overshooting the minimum, eventually making the system unstable. However using a very low momentum value will not help in avoiding local minimum values.

10.3. NEURAL NETWORK ARCHITECTURE

Neural network architecture is different due to number of inputs and outputs, number of hidden layers, activation functions, how the neurons are connected to each other and how many number of neurons are included in one hidden layer. Hence numerous network architectures can be created for a one particular problem. In the research a fully connected feedforward neural networks were tested. In a fully connected neural network each node in one particular layer is linked to all the nodes in the predecessor layer.

10.3.1. Variables

Variables can be of different types with different attributes. Mainly the variables can be categorized in to three types as shown in Table 10-4.

Table 10-4 Variable types

Type of variable	Description	Eg:
Nominal	values represent categories with no intrinsic ranking	Names, Codes
Ordinal	values represent categories with some intrinsic ranking	Levels, rankings
Scale	Values represent ordered categories with a meaningful metric. Variables are in numerical form	Ages, heights, Distance

In this research only scaled variables are present in the data set.

10.3.2. Number of layers and number of perceptron.

There is no hard and fast rule for the number of layers or number of perceptron in a layer when modeling a network. However it's widely believed that most of the problems can be solved with a network with single hidden layer unless the problem is very complex. As the number of hidden layers increase the ability to solve very complex problems gets high. It has being observed in previous research that the larger network can produce better training and generalization error.(Steve Lawrence, Lee Giles, & Ah Chung Tsoi, 1996)

Different configurations can be tested and trial and error method can be used to model a good network. In addition to that few rule of thumb methods are popular

1. Number of perceptron should not exceed twice the input predictor variables.(Swingler, 1996).
2. Number of hidden layer perceptron should be between the number of output and input variables.(Blum, 1992).

3. Number of perceptron in a layer should be close to number of (output +input)*2/3.
4. Number of perceptron in hidden layer should be closer to the number of inputs.

In most cases use of one hidden layer has proven to be effective. But as the complexity increases in the problem more hidden layers should be implemented. The evidence supporting the argument of using two hidden layer for proper generalization of a network can be found in previous researches(Sontag, 1992). On the other hand some of the researchers suggest that one hidden layer with an arbitrarily large number of units suffices for the "universal approximation" property. Where the number of units are sufficient enough. (Hornik, Stinchcombe, & White, 1989). Neural network with two hidden layers can often give an accurate approximation with the use of few weights than a network with one hidden layer (D.L Chester, 1990) .

There are situations where more than two hidden layers are used depending in the complexity of the problem. For cascade correlation (Fahlman & Lebiere, 1990) and for the two-spirals problem(Kevin J Lang & Michael J. Witbrock, 1988) and ZIP code recognition (LeCun et al., 1989) can be given as examples.

There is no reliable method how to predict the number of layers and neurons required to solve a problem. According to the literature findings it can be concluded that the use of single hidden layer model with many perceptions or use of two hidden layer model would possibly yield a good solution for the problem mentioned in this research. Hence models with single hidden layer and two hidden layers have been tested in this research. Minimum number of neurons for first hidden layer was not to be less than the number of inputs.

10.3.3. Data partitioning

Data set was divided in to two partitions as testing sample and training sample after sorting out of outliers.

Training sample

70%of data was dedicated to the training sample which would train the network

Testing sample

30% of data was dedicated to the testing sample to validate data to prevent overfitting.

10.3.4. Network overfitting

While in training the network, overfitting can occur where network tends to memorize the training data set and failed to generalize to new inputs. In this case the model will over fit according to the noise of the data other than the expected pattern or relationship of the data.

To prevent over fitting small neural networks are preferred for problems which are not very complex. “Regularization” is another method which can be used to prevent over fitting where it will modify the performance function including the sizes of bias and weights. Using a validation set of data in addition to the training data set is also a popular method to prevent overfitting.

11.MULTIPLELINEAR REGRESSION RESULTS

Total number of six independent variables (predictor variables) and one dependent variable are in the data set.

Collected data was first analyzed to determine the spread of data points with respect to each variable. Box and whisker plots were used to determine possible outliers.

Variable details are given in Table 11-1

Table 11-1. Variables

	Variable	Type	unit
1	Noise Reduction / “dB’ Drop / “dB” Reduction (Y)	dependent	dB
2	Height (X1)	Independent	m
3	Thickness (X2)	Independent	m
4	Green Cover (X3)	Independent	%
5	Length (X4)	Independent	m
6	Temperature (X5)	Independent	C^o
7	Humidity (X6) (RH)	Independent	%

Among the variables height (X1), thickness (X2), green cover (X3) and Length (X4) was presumed to be the most important independent variables in deciding the behavior of dependent variable. Descriptive statistic regarding the data set is as shown in Table 11-2 .

11.1.1. Descriptive statistics independent variables

Table 11-2. Descriptive statistics of independent variables

			Statistic	Std. Error	Statistic/Std.Error (-1.96<Z<1.96)
Height_X1	Mean		1.8687	.06606	
	95% Confidence Interval for Mean	Lower Bound	1.7370		
		Upper Bound	2.0003		
	5% Trimmed Mean		1.8083		

	Median		1.8000		
	Variance		.327		
	Std. Deviation		.57209		
	Minimum		1.30		
	Maximum		6.00		
	Range		4.70		
	Interquartile Range		.40		
	Skewness		5.267	.277	19.01
	Kurtosis		36.998	.548	67.51
Thickness_X2	Mean		.7487	.02822	
	95% Confidence Interval for Mean	Lower Bound	.6924		
		Upper Bound	.8049		
	5% Trimmed Mean		.7465		
	Median		.7500		
	Variance		.060		
	Std. Deviation		.24439		
	Minimum		.30		
	Maximum		1.30		
	Range		1.00		
	Interquartile Range		.35		
	Skewness		.170	.277	0.613
	Kurtosis		-.728	.548	-1.328
GreenCover_X3	Mean		83.1731	1.12749	
	95% Confidence Interval for Mean	Lower Bound	80.9265		
		Upper Bound	85.4196		
	5% Trimmed Mean		84.3439		
	Median		86.4675		
	Variance		95.342		
	Std. Deviation		9.76431		
	Minimum		50.99		
	Maximum		92.88		
	Range		41.89		
	Interquartile Range		9.90		
	Skewness		-1.806	.277	-6.51

	Kurtosis		3.394	.548	6.19
Length_X4	Mean		7.0813	.75623	
	95% Confidence Interval for Mean	Lower Bound	5.5745		
		Upper Bound	8.5882		
	5% Trimmed Mean		6.1607		
	Median		5.0000		
	Variance		42.891		
	Std. Deviation		6.54913		
	Minimum		2.50		
	Maximum		50.00		
	Range		47.50		
	Interquartile Range		4.00		
	Skewness		4.387	.277	15.837
	Kurtosis		25.060	.548	45.729
Temp_X5	Mean		30.07	.190	
	95% Confidence Interval for Mean	Lower Bound	29.69		
		Upper Bound	30.45		
	5% Trimmed Mean		30.05		
	Median		30.00		
	Variance		2.712		
	Std. Deviation		1.647		
	Minimum		27		
	Maximum		33		
	Range		6		
	Interquartile Range		2		
	Skewness		.208	.277	0.750
	Kurtosis		-.834	.548	-1.522
Humidity_X6	Mean		66.84	.613	
	95% Confidence Interval for Mean	Lower Bound	65.62		
		Upper Bound	68.06		
	5% Trimmed Mean		66.72		
	Median		67.00		

	Variance	28.217		
	Std. Deviation	5.312		
	Minimum	57		
	Maximum	80		
	Range	23		
	Interquartile Range	4		
	Skewness	-.041	.277	0.148
	Kurtosis	.280	.548	0.510

As a conclusion of the skewness and kurtosis, only X2, X5 and X6 variables shows a significant similarity to a normal distribution. Considering the X5 variable (temperature) the spread is narrow, which is likely to constrain the observation of the influence on dependent variable due to X5 independent variable.

Table 11-3. Percentiles

		Percentiles						
		5	10	25	50	75	90	95
Weighted Average(Definition 1)	Height_X1	1.3500	1.4800	1.6000	1.8000	2.0000	2.3200	2.5000
	Thickness_X2	.3400	.4500	.5500	.7500	.9000	1.1000	1.2000
	GreenCover_X3	56.4580	73.4813	80.2200	86.4675	90.1200	91.6968	92.6440
	Length_X4	3.0000	3.3000	4.0000	5.0000	8.0000	11.4000	20.0000
	Temp_X5	28.00	28.00	29.00	30.00	31.00	33.00	33.00
	Humidity_X6	57.00	58.60	65.00	67.00	69.00	73.00	75.20
Tukey's Hinges	Height_X1			1.6000	1.8000	2.0000		
	Thickness_X2			.5750	.7500	.9000		
	GreenCover_X3			80.3012	86.4675	90.0400		
	Length_X4			4.0000	5.0000	8.0000		
	Temp_X5			29.00	30.00	31.00		
	Humidity_X6			65.00	67.00	69.00		

11.1.2. Descriptive statistics of dependent variable

Table 11-4.descriptive statistics of dependent variable

			Statistic	Std. Error	Statistic/Std.Error (-1.96<Z<1.96)
Noise Reduction_(Y)	Mean		3.3056	.11093	
	95% Confidence Interval for Mean	Lower Bound	3.0846		
		Upper Bound	3.5266		
	5% Trimmed Mean		3.2976		
	Median		3.1900		
	Variance		.923		
	Std. Deviation		.96065		
	Minimum		1.09		
	Maximum		5.68		
	Range		4.59		
	Interquartile Range		1.16		
	Skewness		.300	.277	1.08
	Kurtosis		.182	.548	0.33

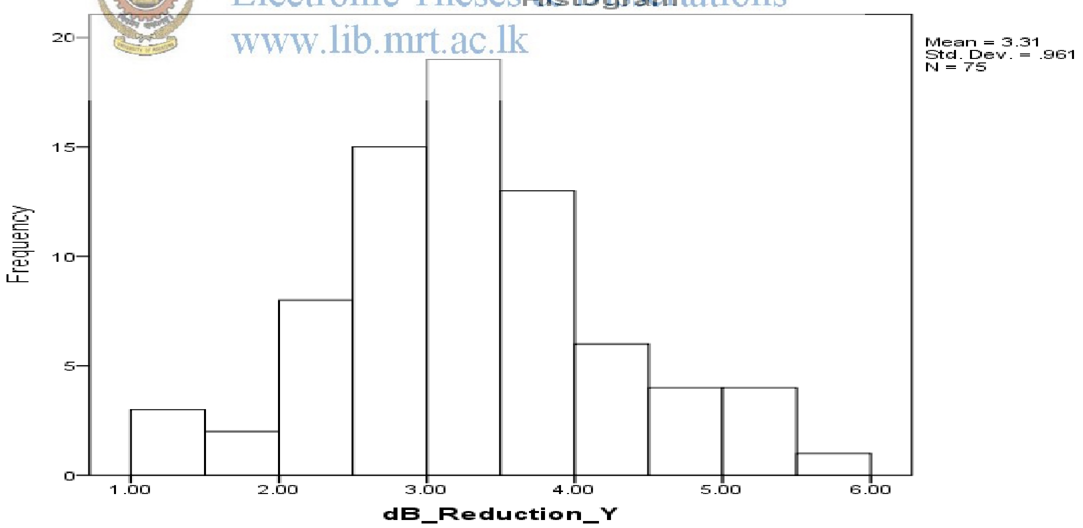


Figure 11-1 Distribution of Dependent variable

According to the results from Table 11-4 and Figure 11-1 the distribution of dependent variable significantly matches a normal distribution. Hence certain results can be highlighted. Overly the natural barriers which is described in 1.7 has shown a mean reduction of 3.3 dB in a confidence level of 95% and confidence interval of ±1.92

.The maximum noise attenuation by the natural barrier type described in 1.7 is recorded as 5.68 dB.

11.2. Box and whisker plots

Box and whisker plots were done to identify outliers and the spread of data.

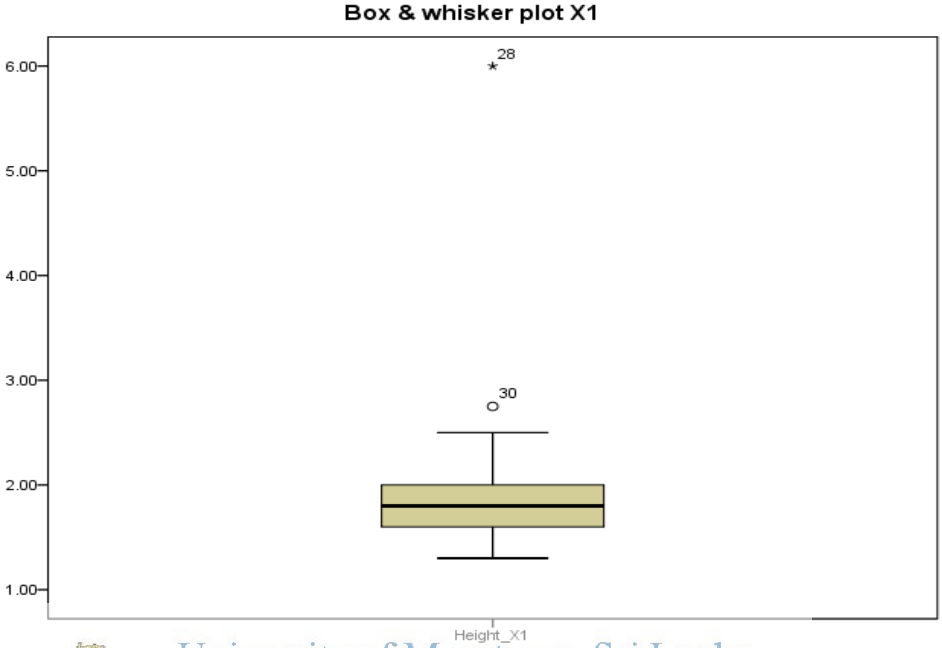


Figure 11-2. Box and whisker plot for X1 variable

Table 11-5 Extreme values of X1 variable

Extreme Values

			Case Number	Value
Height_X1	Highest	1	28	6.00
		2	30	2.75
		3	10	2.50
		4	13	2.50
		5	38	2.50
	Lowest	1	54	1.30
		2	22	1.30
		3	35	1.35
		4	34	1.35
		5	53	1.40[a]

a. Only a partial list of cases with the value 1.40 are shown in the table of lower extremes.

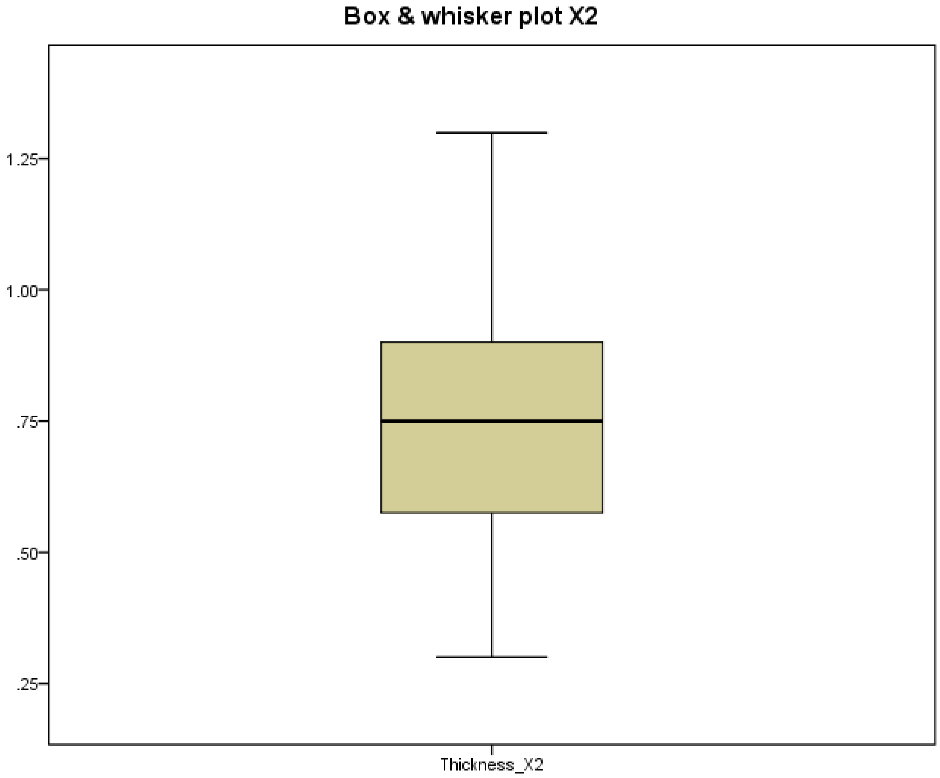


Figure 11-3 Box and whisker plot for X2 variable

Table 11-6. Extreme values for X2 variable

			Case Number	Value
Thickness_X2	Highest	1	29	1.30
		2	5	1.20
		3	22	1.20
		4	69	1.20
		5	4	1.10[a]
	Lowest	1	48	.30
		2	40	.30
		3	36	.30
		4	73	.35
		5	72	.40[b]

a. Only a partial list of cases with the value 1.10 are shown in the table of upper extremes.

b. Only a partial list of cases with the value .40 are shown in the table of lower extremes.

Figure 11-4 Box and whisker plot for X3 variable

Table 11-7 Extreme values for X3 variable

			Case Number	Value
GreenCover_X3	Highest	1	2	92.88
		2	43	92.84
		3	38	92.70
		4	35	92.63
		5	39	92.55
	Lowest	1	72	50.99
		2	61	50.99
		3	70	51.65
		4	75	57.66
		5	8	59.68

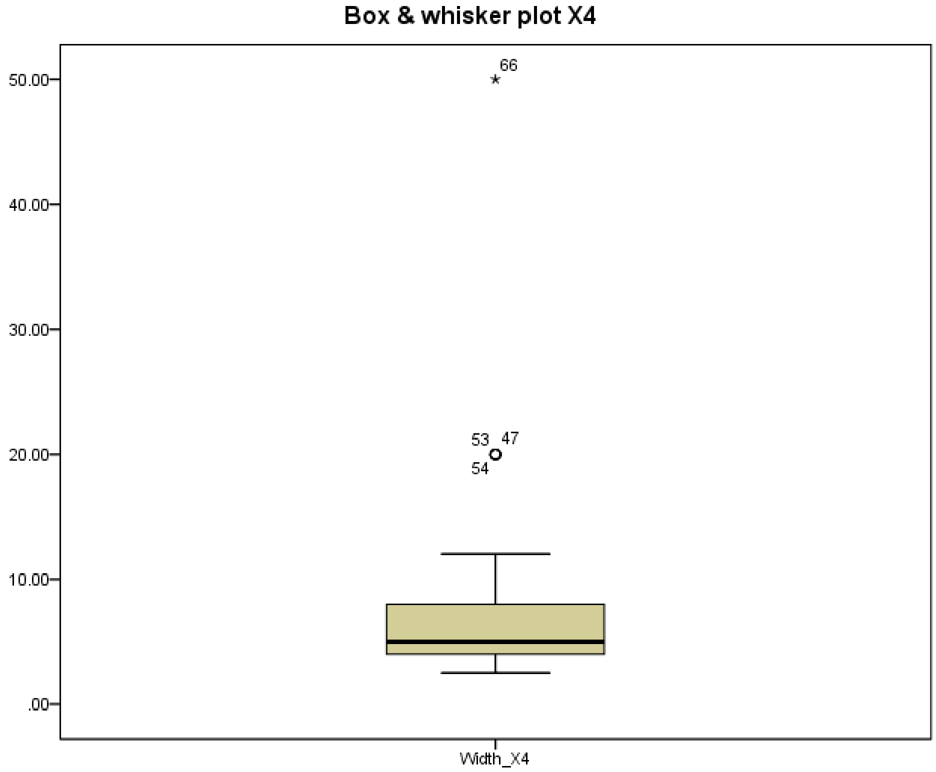


Figure 11-5 Box and whisker plot for X4 variable

Table 11-8 Extreme values for X4 variable

			Case Number	Value
Length_X4	Highest	1	66	50.00
		2	46	20.00
		3	47	20.00
		4	53	20.00
		5	54	20.00[a]
	Lowest	1	45	2.50
		2	30	2.50
		3	58	3.00
		4	42	3.00
		5	35	3.00[b]

a. Only a partial list of cases with the value 20.00 are shown in the table of upper extremes.

b. Only a partial list of cases with the value 3.00 are shown in the table of lower extremes.

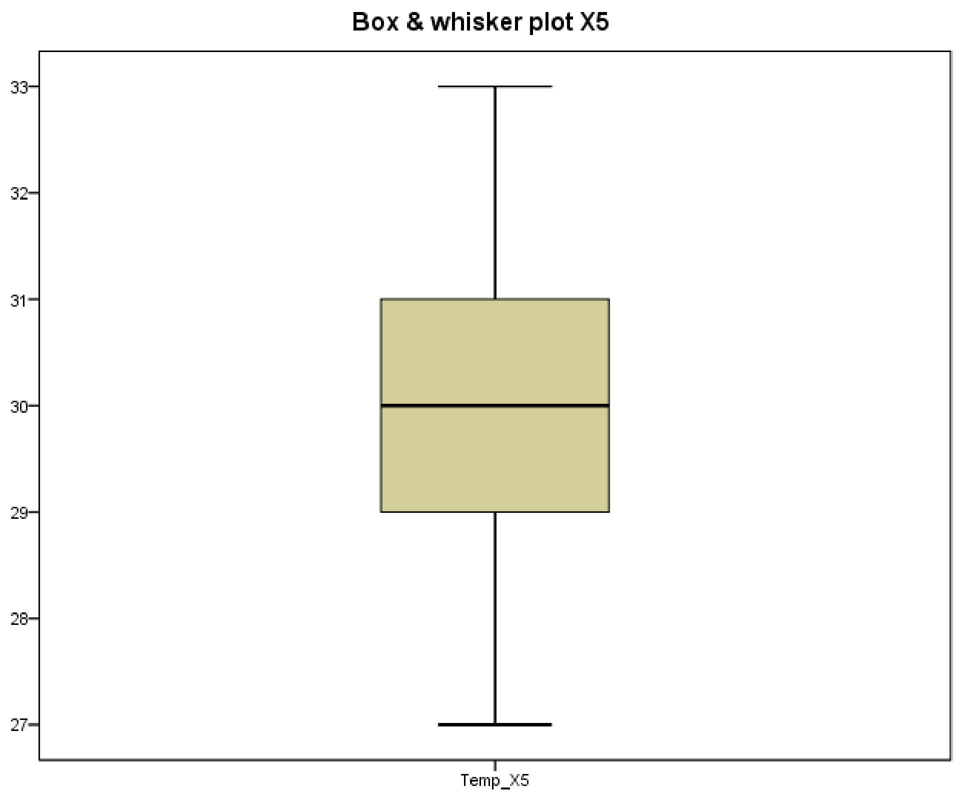


Figure 11-6 Box and whisker plot for X5 variable

Table 11-9 Extreme values for X5 variable

			Case Number	Value
Temp_X5	Highest	1	53	33
		2	54	33
		3	55	33
		4	56	33
		5	57	33[a]
	Lowest	1	18	27
		2	17	27
		3	67	28
		4	32	28
		5	31	28[b]

a. Only a partial list of cases with the value 33 are shown in the table of upper extremes.

b. Only a partial list of cases with the value 28 are shown in the table of lower extremes.

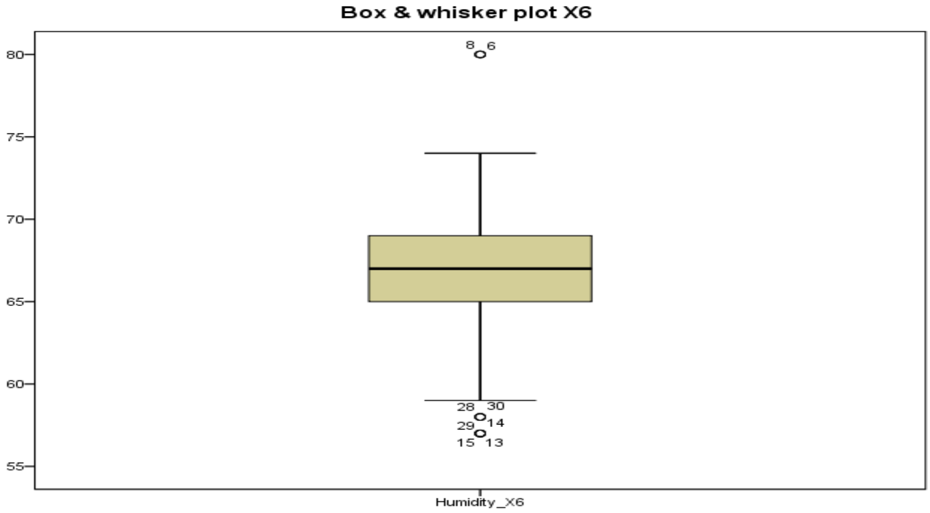


Figure 11-7 Box and whisker plot for X6 variable

Table 11-10 Extreme values for X6 variable

			Case Number	Value
Humidity_X6	Highest	1	6	80
		2	7	80
		3	8	80
		4	31	74
		5	67	74
	Lowest	1	16	57
		2	15	57
		3	14	57
		4	13	57
		5	30	58[a]

a. Only a partial list of cases with the value 58 are shown in the table of lower extremes.

Form the box and whisker plots a general idea of the outliers of each variable were achieved, however the outliers were decided under more rational input and thought, for Eg:- Green cover (X3) variable indicates few outliers in 50-60% region. but those readings were not taken as outliers because barriers with green cover readings below 60% was intentionally put to the model to determine the reliability of model in a wide range of green cover from 50-100% . Outliers found in the analysis were noted and filtered out in developing and testing MLR and ANN models.

11.3. SIMPLE LINEAR REGRESSION ANALYSIS

Simple linear regression analysis was carried out to determine the relation of each independent variable to the dependent variable.

11.3.1. Noise reduction Vs height

Case I

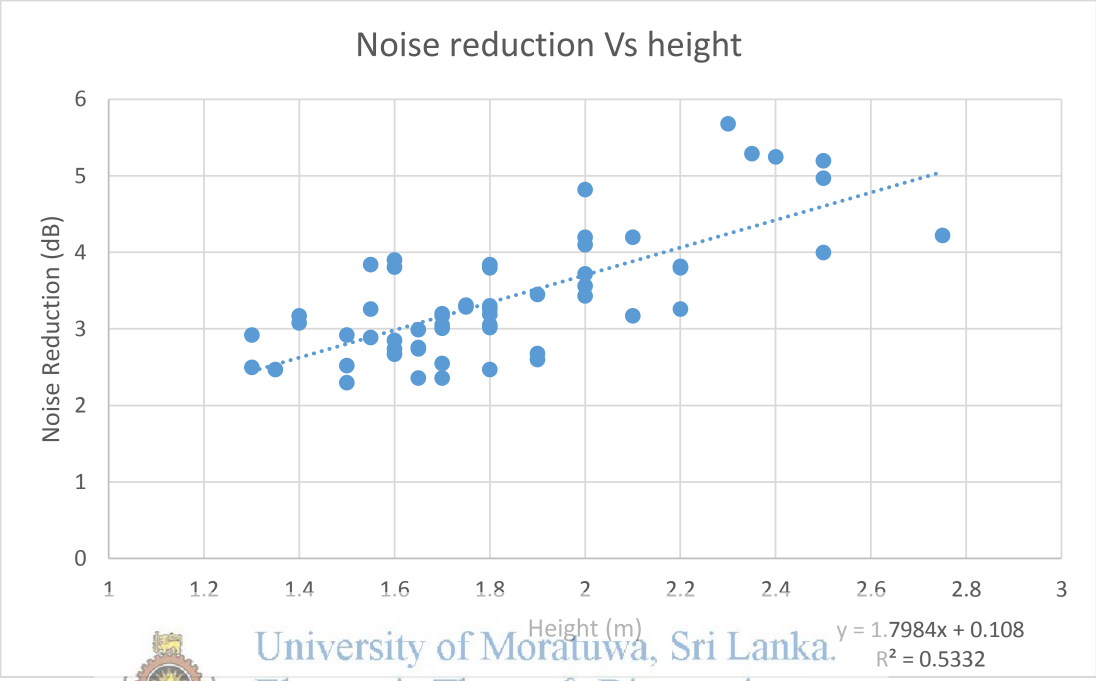


Figure 11-8 Noise reduction Vs height, Case I

Case II

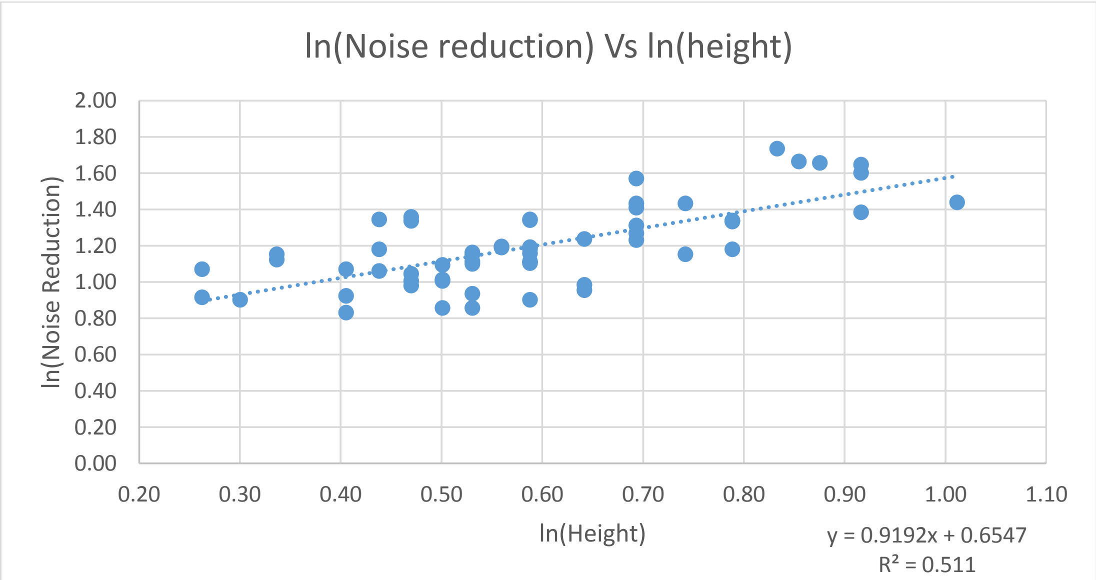


Figure 11-9 Noise reduction Vs height, case II

Case III

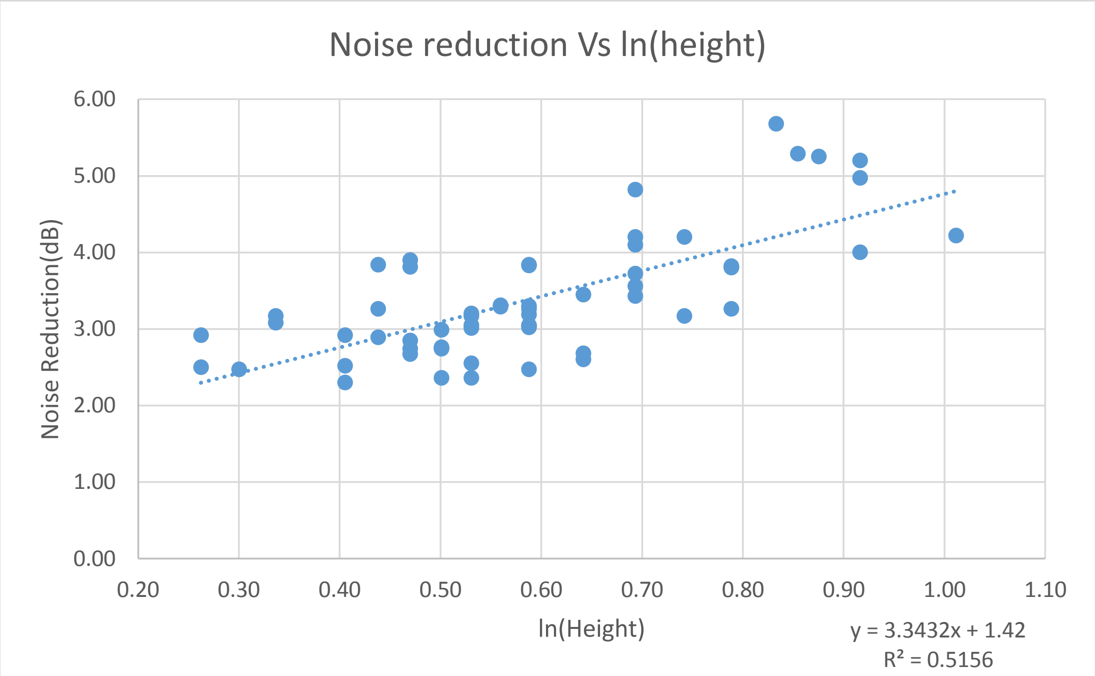


Figure 11-10 Noise reduction Vs height, case III

11.3.2. Noise reduction Vs thickness

Case I

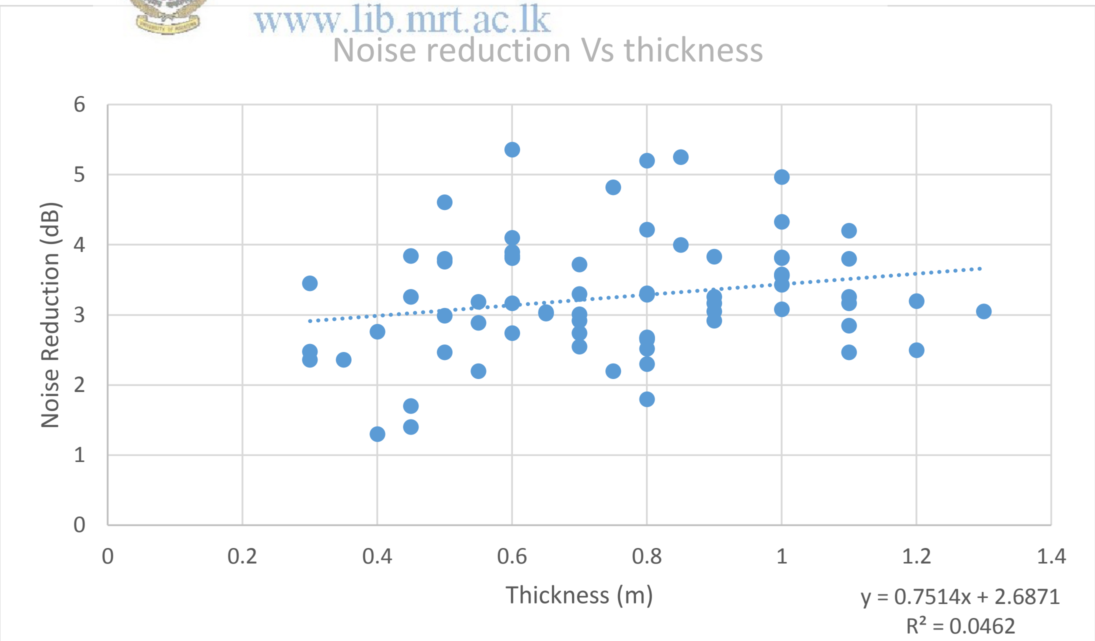


Figure 11-11 Noise reduction Vs thickness, Case I

Case II

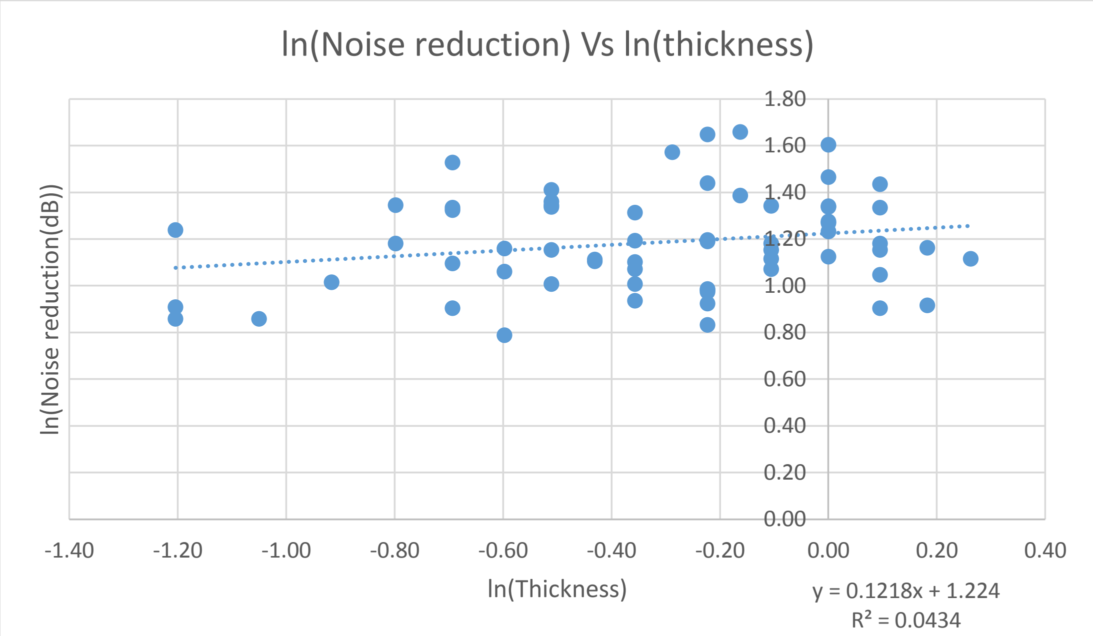


Figure 11-12 Noise reduction Vs thickness, case II

Case III

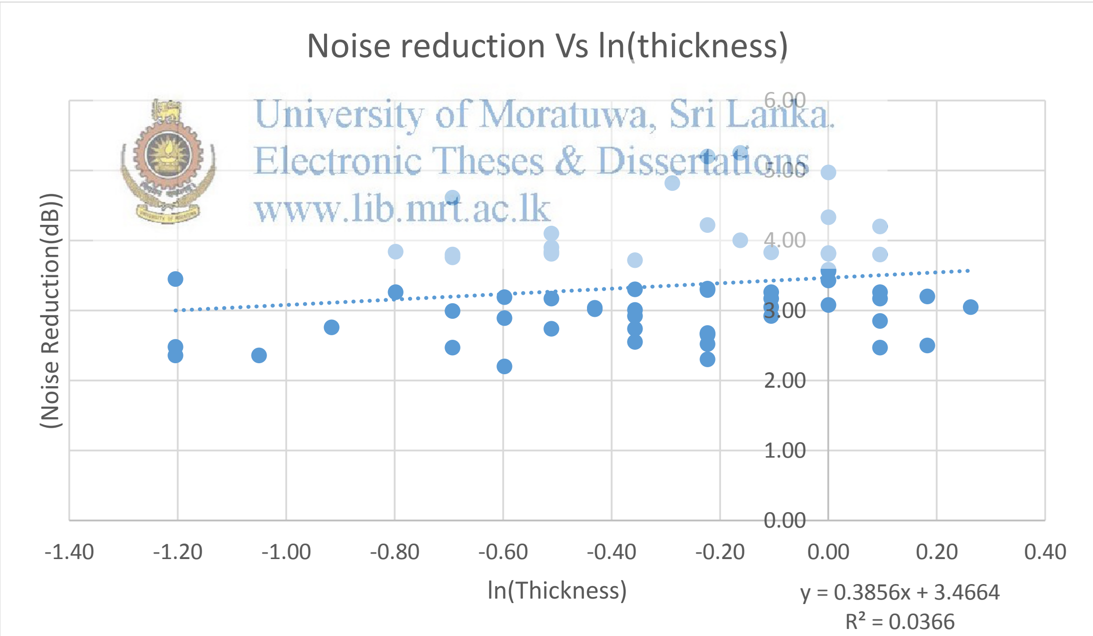


Figure 11-13 Noise reduction Vs thickness, case III

11.3.3. Noise reduction Vs green cover

Case I

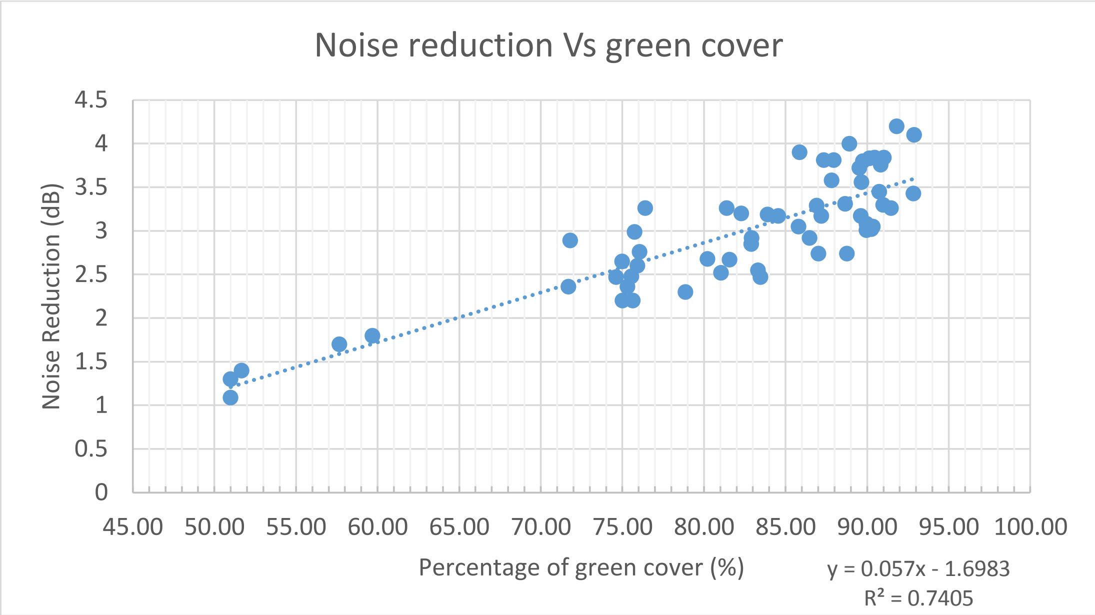


Figure 11-14 Noise reduction Vs green cover, I

Case II

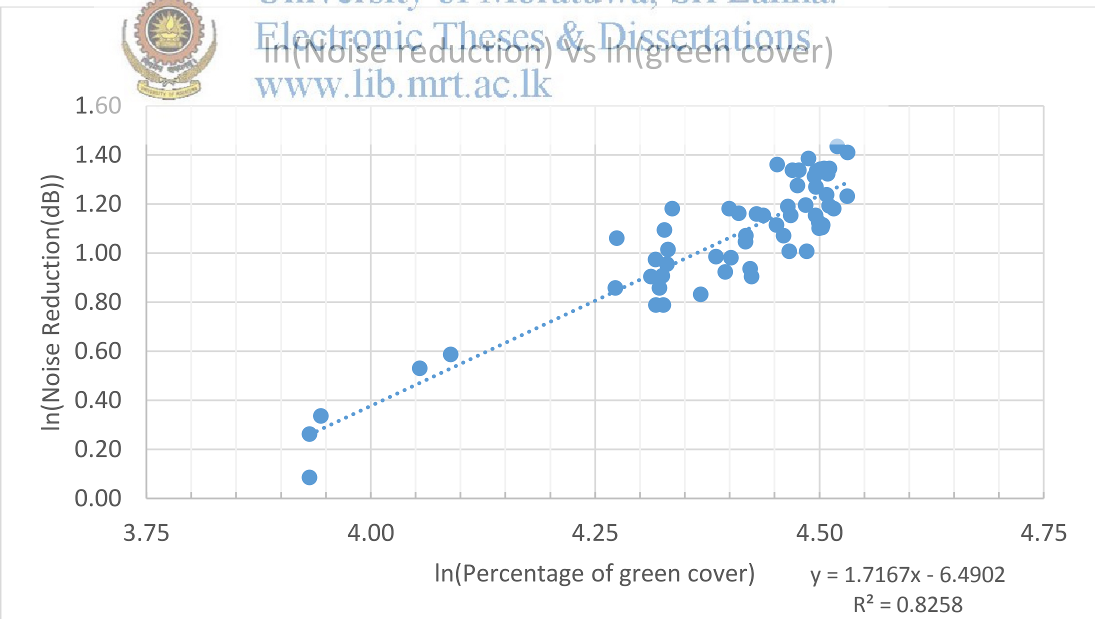


Figure 11-15 Noise reduction Vs green cover, case II

Case III

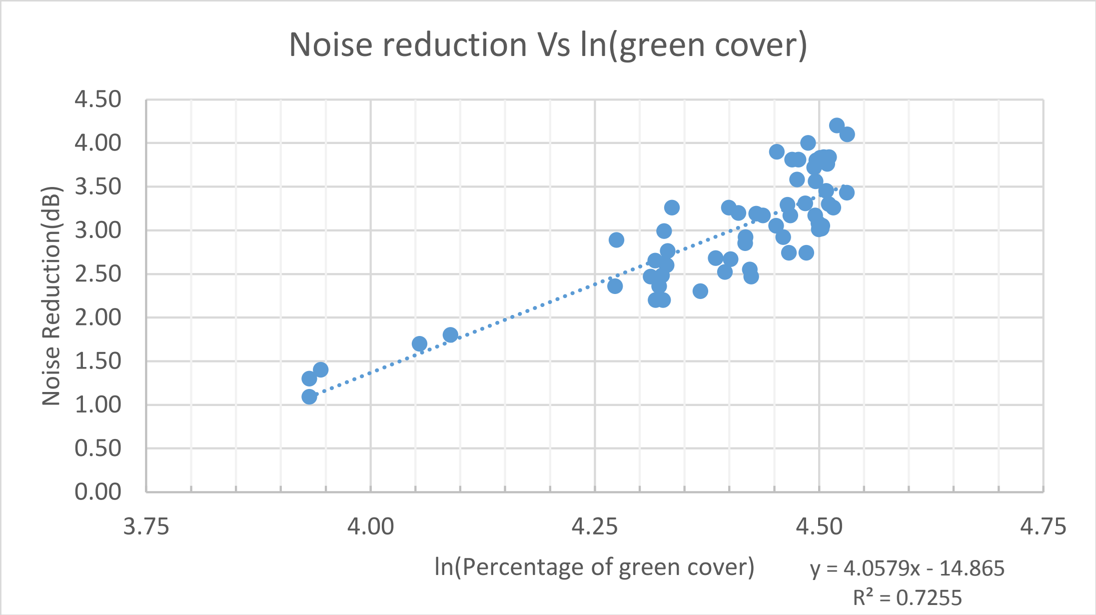


Figure 11-16 Noise reduction Vs green cover, case III

11.3.4. Noise reduction Vs length

Case I

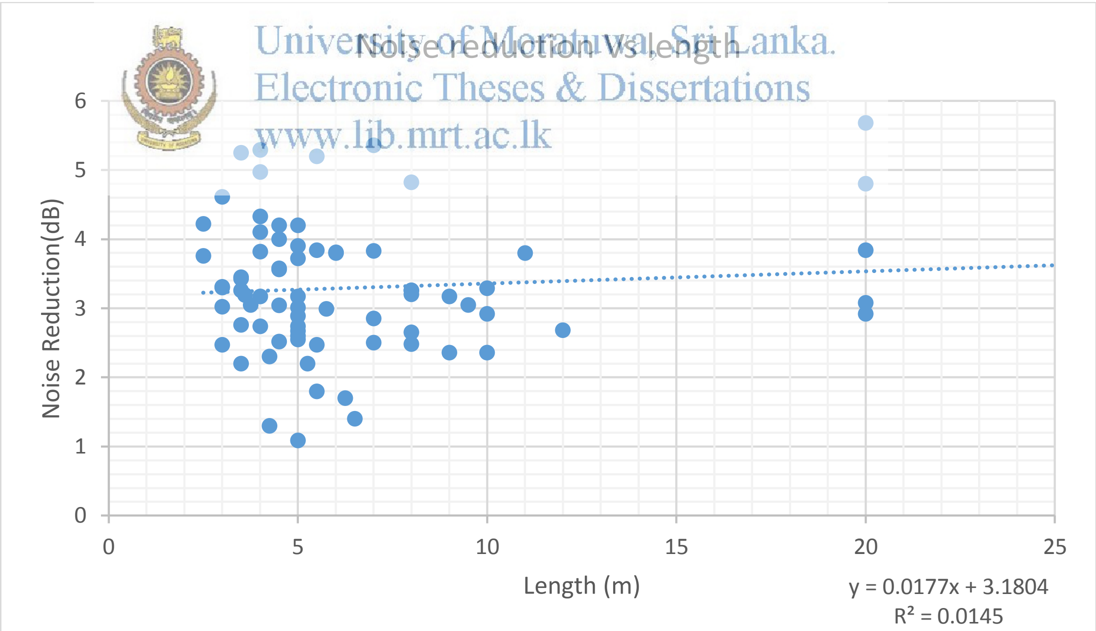


Figure 11-17 Noise reduction Vs length, case I

Case II

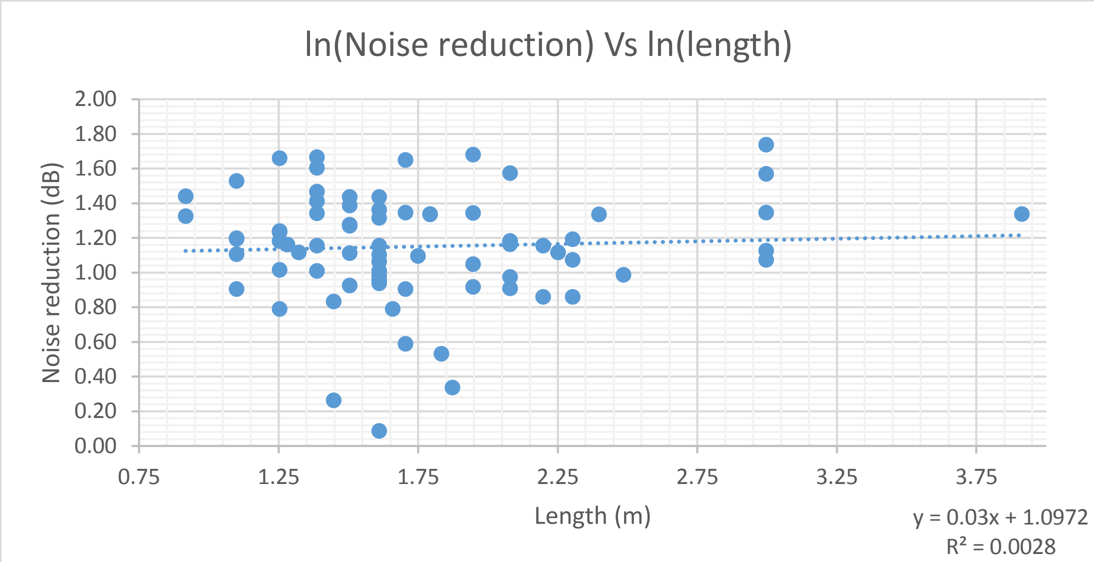


Figure 11-18 Noise reduction Vs length, case II

Case III

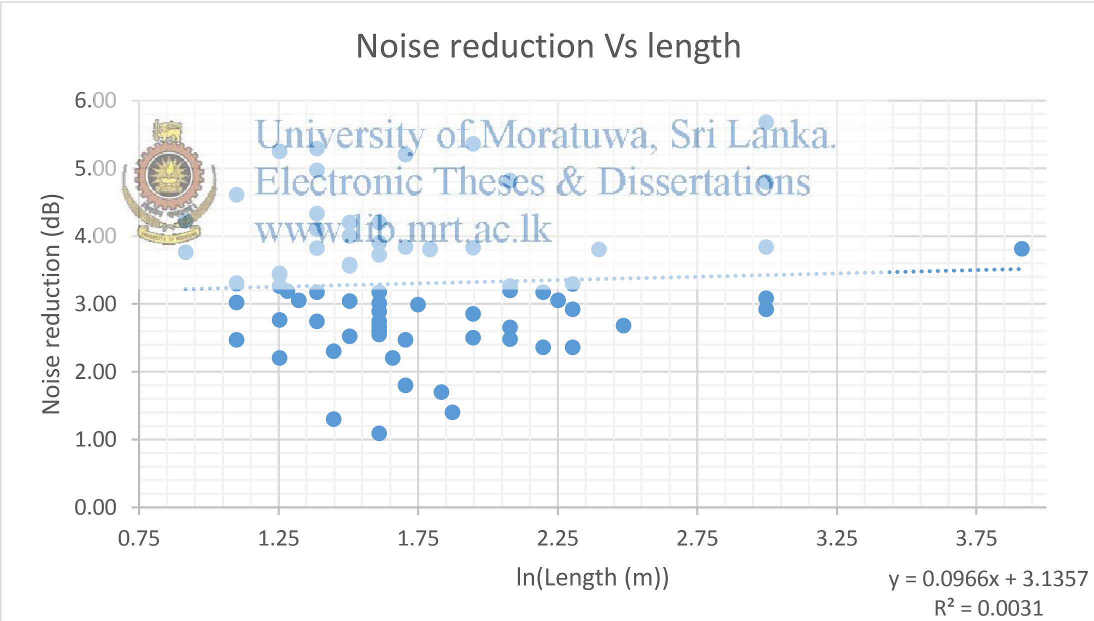


Figure 11-19 Noise reduction Vs Length, case III

11.3.5. Noise Reduction Vs product of height & green cover

Case I

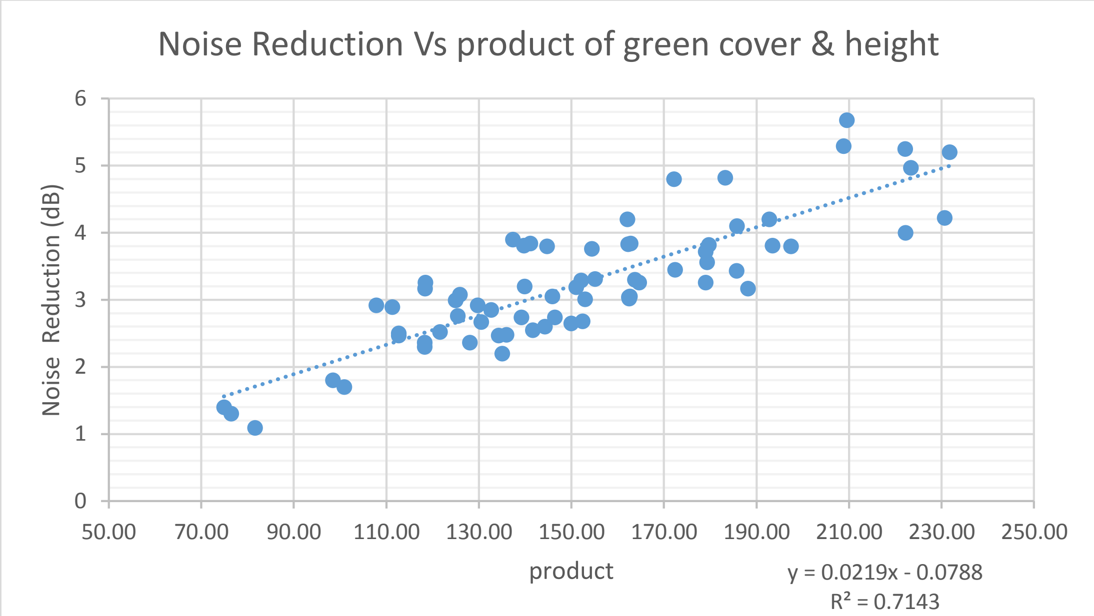


Figure 11-20 Noise Reduction Vs product of green cover & height, case I

Case II

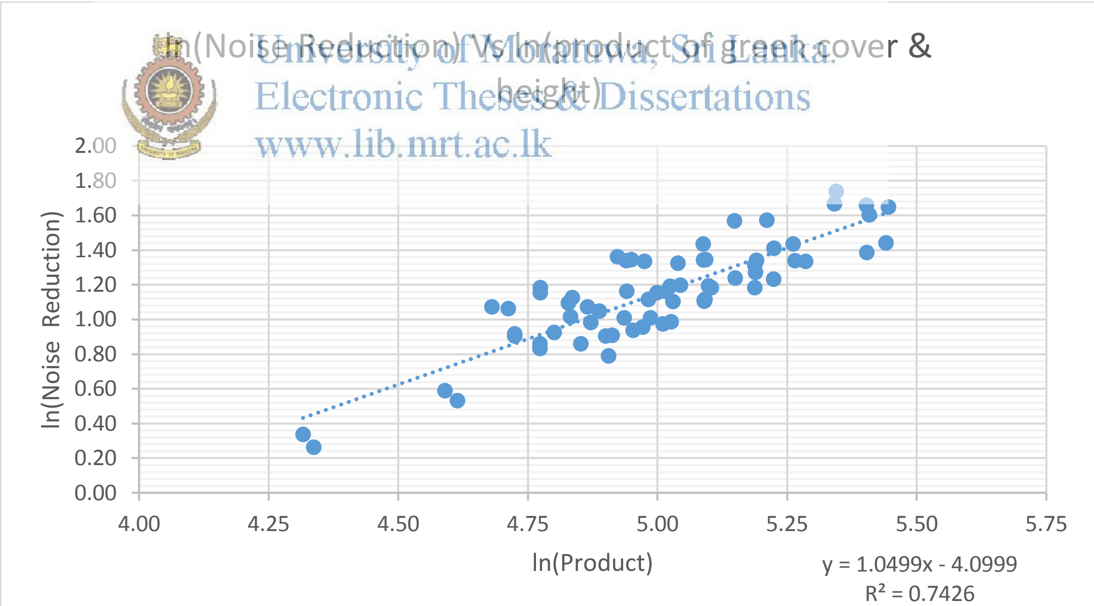


Figure 11-21 Noise Reduction Vs product of green cover & height case II

Case III

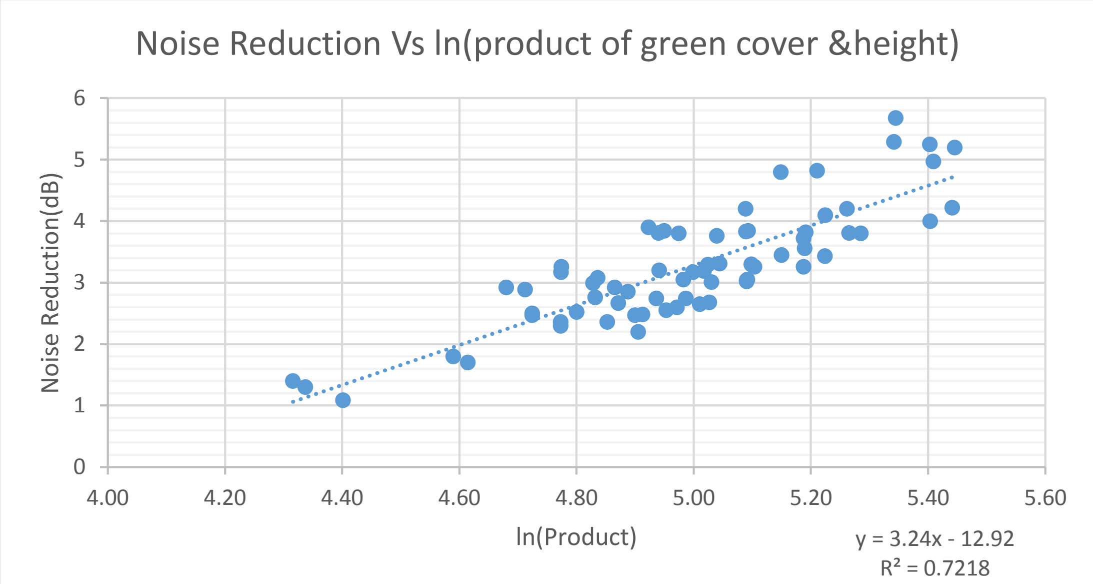


Figure 11-22 Noise Reduction Vs product of green cover & height, case III

11.4. SUMMARY OF SIMPLE LINEAR REGRESSION MODELS

Table 11-11 Summery of simple linear regression models

Description of variables		R^2 of Y Vs X	R^2 of ln(Y) Vs ln(X)	**R^2 of Y Vs ln(X)**
Y	X	Case I	Case II	**Case III**
dB drop (Y)	Height (X1)	*0.533*	0.511	0.515
dB drop	Thickness (X2)	**0.046**	0.043	0.037
dB drop	Green cover (X3)	0.741	**0.826**	0.726
dB drop	Length (X4)	**0.015**	0.003	0.003
dB drop	X1*X3	0.714	**0.743**	0.722

Green cover (X3) and height (X1) shows a good and positive simple linear regression with the dependent variable (Y). Case II type relationship using Green cover(X1) and Noise reduction explains nearly 83% of the model variation. Using independent variable Height (X1) in a simple linear regression, 53% of the relationship between height and Noise reduction can be explained. Using the product Height (X1)*Green cover (X3) constitute a positive correlation with the dependent variable Noise reduction(Y) explaining nearly 75% of the relationship.

Hence it can be concluded that a multiple linear regression model would explain the relationship between the independent variables and the dependent variable mentioned in Table 11-1. Up to certain level but further study is needed to decide the behavior of the dependent variable due to the combined effects of the independent variables.

11.5. MULTIPLE LINEAR REGRESSION MODELS (MLR)

Several multiple linear regression models were tested introducing variables and examining their significance and contribution to explain and improve the model accuracy by following a stepwise regression analysis

11.5.1. Multiple linear regression model (MLR-2) using X1 and X2.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8.594	2	4.297	4.872	.010[b]
	Residual	63.504	72	.882		
	Total	72.098	74			

a. Dependent Variable: Y

b. Predictors: (Constant), X2, X1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.943	.455		4.272	.000
	X1	.503	.196	.292	2.570	.012
	X2	.526	.458	.130	1.147	.255

a. Dependent Variable: Y

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.345[a]	.119	.095	.93915	.119	4.872	2	72	.010

a. Predictors: (Constant), X2, X1

b. Dependent Variable: Y

Table 11-12. Summary of results of MLR-2

REGRESSION EQUATION		
Least Squer Method Equation	$\hat{Y} = B_0 + B_1X_{1i} + B_2X_{2i} + B_3X_{3i} + \ldots\ldots\ldots + B_nX_{ni}$	
Model Equation	$\hat{Y} = 1.943 + 0.503X_{1i} + 0.526X_{2i}$	
REGRESSION COEFFICENTS		
Hypothesis test		
Ho	: $B_i = 0$	
Ha	: $B_i \neq 0$	
Critical p value	: 0.05	**(two tailed test)**
Coefficents	**Condition**	**Conclusion /Result**
	Sig value	
$B_0 = 1.943$	$0.00 < p$	
$B_1 = 0.503$	$0.012 < p$	Significunt (reject Ho)
$B_2 = 0.526$	$0.255 > p$	Fail to reject Ho
Cocnclution	X1 variable significuntly contribute to explaning the variability of dependent variable	
OVERAL MODEL		
	Condition	***Conclution/Result***
R^2	0.119	Very weak corelation
Adjusted R^2	0.095	Very weak corelation
Hypothesis test		
Ho	: $\beta_1 = \beta_2 = \ldots \beta_i = 0$	
Ha	: At least one of the β_i is not zero	
P value	0.05	
F statistic	4.872	
Significunt value	$0.010 < P$	Reject Ho
Residuals	Doesn't show any pattern and scaterd	

Comment	Even thouth the globle test using f statistic indicates that model is useful, overal model R^2 value is very low hence only about 12% of the variability of dependent variable is explained by the equataion, how ever X1 variable singificunty contribute in explaning the relationshiop of the model .Model tend to over estimate barriers which actualy provided 2-3 dB drop where as model under estimates barriers which provided dB drop more than 4 dB (Figure 11-24)

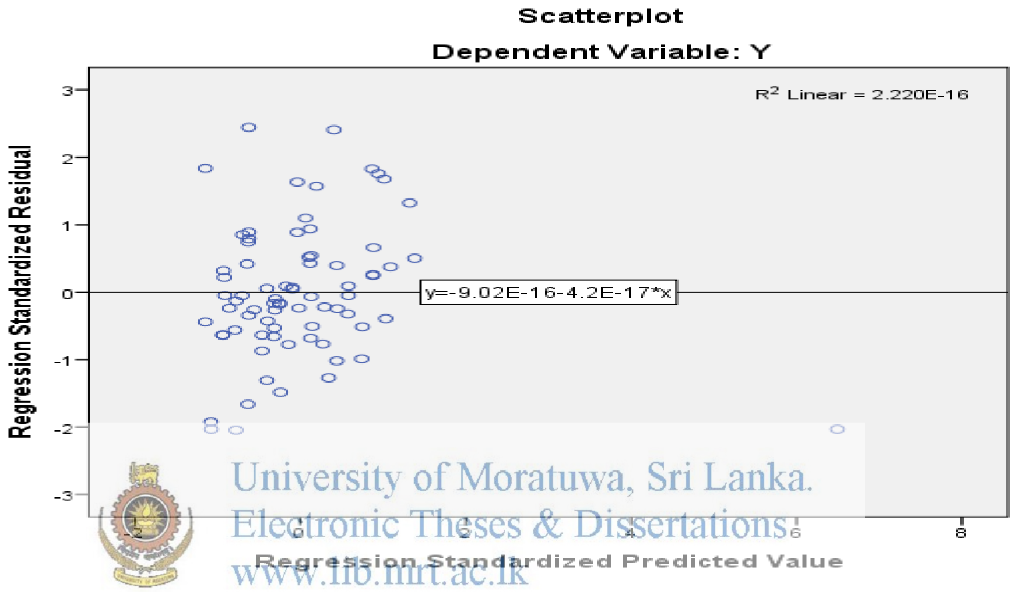


Figure 11-23. Distribution of residuals of MLR-2

Residuals doesn’t show any unbiased case or pattern

11.5.2. Distribution of predicted and desired outputs of MLR-2

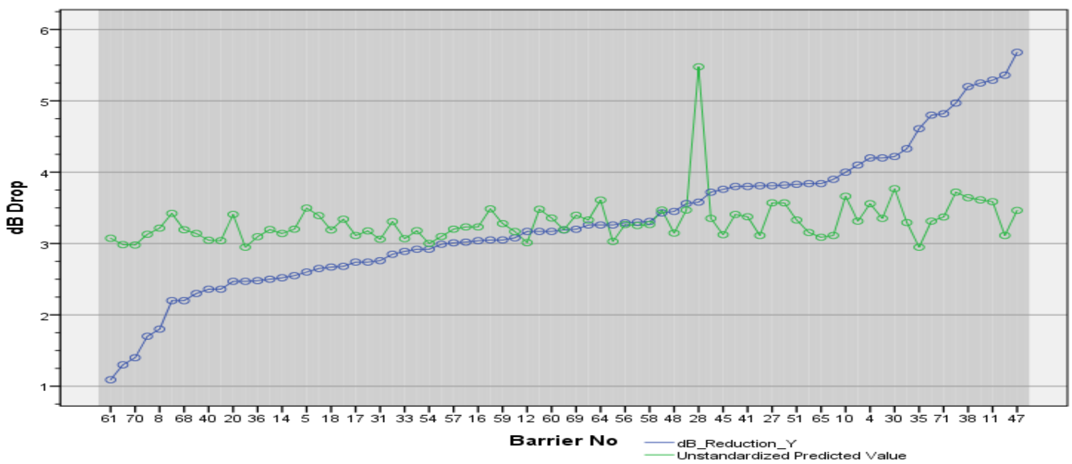


Figure 11-24 Distribution of predicted values and expected values of MLR-2

11.6. Multiple linear regression model (MLR-3) using X1.X2 and X3.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	31.125	3	10.375	46.313	.000[b]
	Residual	12.993	58	.224		
	Total	44.118	61			

a. Dependent Variable: dB_Reduction_Y

b. Predictors: (Constant), GreenCover_X3, Height_X1, Thickness_X2

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3.481	.589		-5.908	.000
	Height_X1	1.341	.215	.481	6.224	.000
	Thickness_X2	-.256	.273	-.073	-.938	.352
	GreenCover_X3	.053	.007	.572	7.222	.000

a. Dependent Variable: dB_Reduction_Y

Note:-introducing X2 variable doesn't improve the model

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.840[a]	.705	.690	.47331	.705	46.313	3	58	.000

a. Predictors: (Constant), GreenCover_X3, Height_X1, Thickness_X2

b. Dependent Variable: dB_Reduction_Y

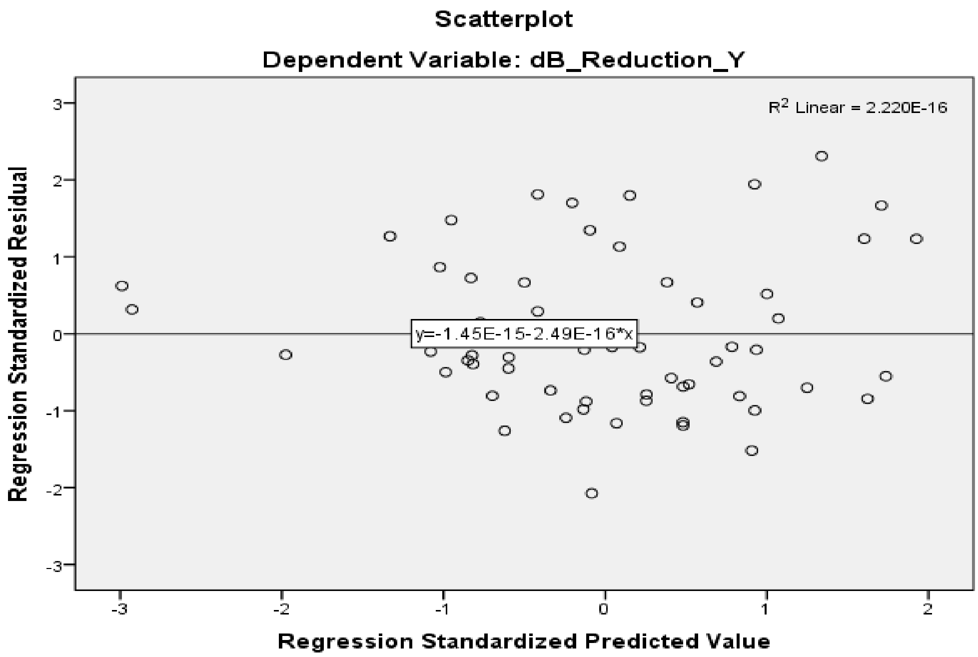


Figure 11-25. Distribution of residuals of MLR-3

R^2 value is negligible residuals doesn't show any pattern or linear relationship.

11.6.1. Distribution of predicted and desired outputs

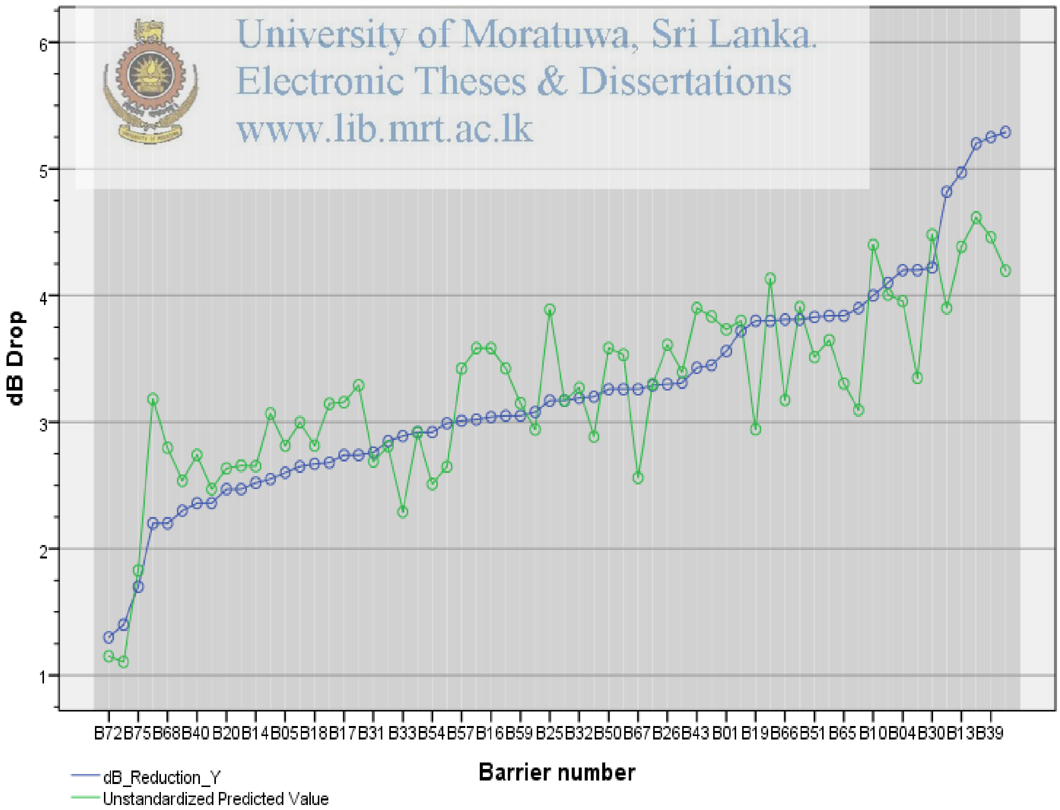


Figure 11-26. Distribution of predicted values and expected values of MLR-3

Table 11-13. Summary of results of MLR-3

REGRESSION EQUATION		
Least Square Method Equation	$\hat{Y} = B_0 + B_1X_{1i} + B_2X_{2i} + B_3X_{3i} + \ \dots \dots \dots + B_nX_{ni}$	
Equation	$\hat{Y} = -3.481 + 1.341X_{1i} - 0.256X_{2i} + 0.053X_{3i}$	
REGRESSION COEFFICENTS		
Hypothesis test		
Ho	: $B_i = 0$	
Ha	: $B_i \neq 0$	
Critical p value	: 0.05	**(two tailed test)**
Coefficents	**Condition**	**Conclusion /Result**
	Sig value	
$B_0 = -3.48$	$0.001 < p$	Significunt (reject Ho)
$B_1 = 1.34$	$0.001 < p$	Significunt (reject Ho)
$B_2 = -0.26$	$0.352 > p$	Insignificunt
$B_3 = 0.05$	$0.001 < p$	Significunt (reject Ho)
Cocnclution	Including X2 variable would not improve the model	
OVERAL MODEL		
	Condition	***Conclution/Result***
R^2	0.705	Good corelation
Adjusted R^2	0.69	Good corelation
Hypothesis test		
Ho	: $\beta_1 = \beta_2 = \dots \beta_i = 0$	
Ha	: At least one of the β_i is not zero	
P value	0.05	
F statistic	48.31	Has improved since MLR-2
Significunt value	$0.001 < P$	Useful model

Residuals	Doesn't show any pattern and scatterd
Comment	the data proivds sufficent eveidence to conclude that the model significuntly contribute to the prediction of dependent variable. How ever according to t-test including variable X2 doesnot proves to be improving the model. Hence model including X1 and X3 would possibaly constitute a better model to predict the dependent variable

11.7. MULTIPLE LINEAR REGRESSION MODEL (MLR-2A) USING X1 AND X3 .

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.911	2	13.956	75.239	.000[b]
	Residual	10.573	57	.185		
	Total	38.484	59			

a. Dependent Variable: dB_Reduction_Y

b. Predictors: (Constant), GreenCover_X3, Height_X1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3.209	.540		-5.942	.000
	Height_X1	1.231	.196	.465	6.277	.000
	GreenCover_X3	.050	.007	.569	7.681	.000

a. Dependent Variable: dB_Reduction_Y

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.852[a]	.725	.716	.43068	.725	75.239	2	57	.000

a. Predictors: (Constant), GreenCover_X3, Height_X1

b. Dependent Variable: dB_Reduction_Y

R2 value has improved and overall model F statistic value has improved
Hence MLR-2a model seems a possible best fit.

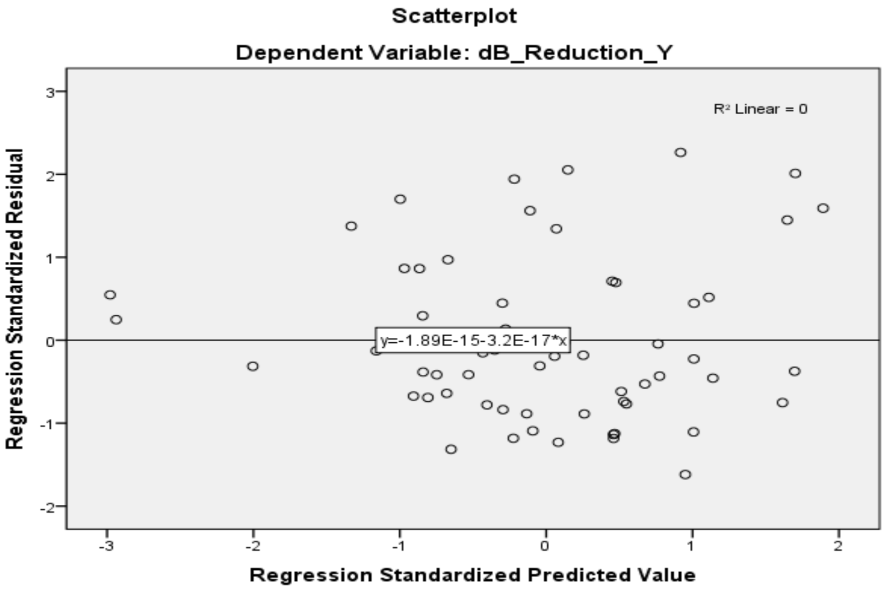


Figure 11-27 Distribution of residuals of MLR-2A

R^2 value is negligible residuals doesn't show any pattern or linear relationship.

11.7.1. Distribution of desired out come and predicted outcome

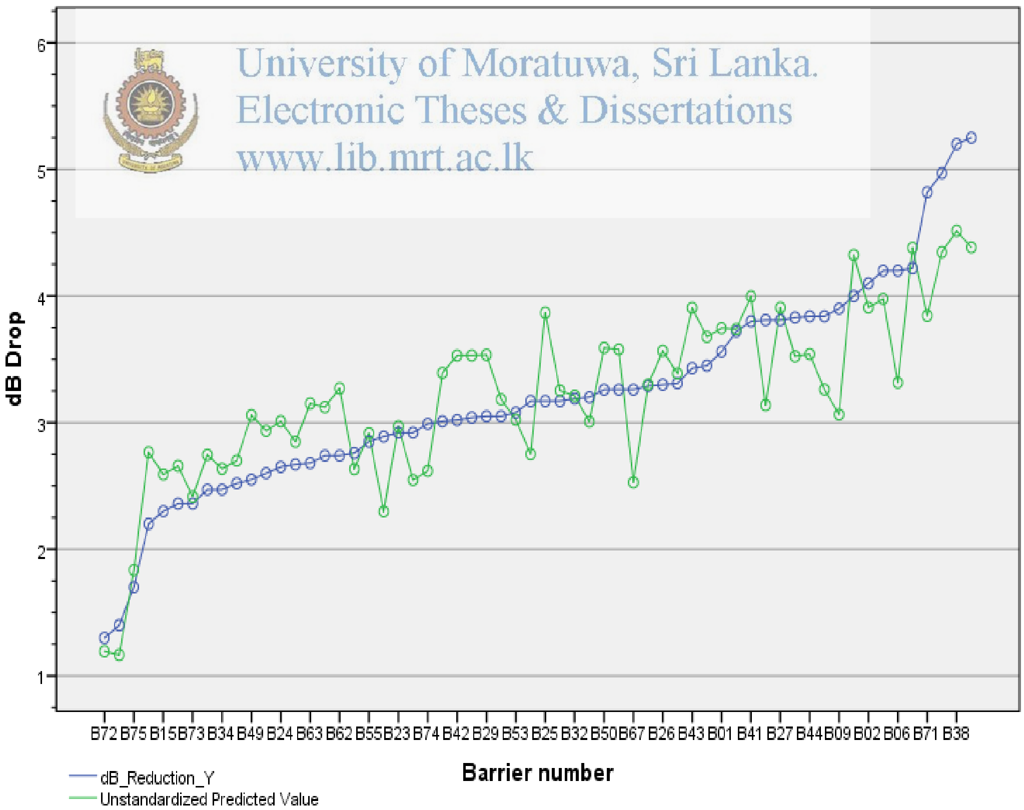


Figure 11-28 Distribution of predicted values and expected values of MLR-2A

Table 11-14 Summary of results of MLR-2A

REGRESSION EQUATION		
Least Square Method Equation	$\hat{Y} = B_0 + B_1X_{1i} + B_2X_{2i} + B_3X_{3i} + \ldots\ldots\ldots + B_nX_{ni}$	
Equation	$\hat{Y} = -3.209 + 1.231X_{1i} + 0.05X_{3i}$	
REGRESSION COEFFICENTS		
Hypothesis test		
Ho	: $B_i = 0$	
Ha	: $B_i \neq 0$	
Critical p value	: 0.05	**(two tailed test)**
Coefficents	**Condition**	**Conclusion /Result**
	Sig value	
$B_0 = -3.209$	$0.001 < p$	Significunt (reject Ho)
$B_1 = 1.231$	$0.001 < p$	Significunt (reject Ho)
$B_2 = 0$	$-$	
$B_3 = 0.05$	$0.001 < p$	Significunt (reject Ho)
Cocnclution	excluding X2 variable improved the model	
OVERAL MODEL		
	Condition	***Conclution/Result***
R^2	0.725	Good corelation
Adjusted R^2	0.716	Good corelation
Hypothesis test		
Ho	: $\beta_1 = \beta_2 = \ldots \beta_i = 0$	
Ha	: At least one of the β_i is not zero	
P value	0.05	
F statistic	75.16	Has improved since MLR-3
Significunt value	$0.001 < P$	Useful model

Residuals	Doesn’t show any pattern and scatterd
Comment	the data proivds sufficent eveidence to conclude that the model significuntly contribute to the prediction of dependent variable. t- test proves that all included variables significuntly improves the model fit.Sums of squars of errors have also being reduced.

11.8. Multiple linear regression model (MLR-3A) using X1,X3 and X4

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28.645	3	9.548	54.346	.000[b]
	Residual	9.839	56	.176		
	Total	38.484	59			

a. Dependent Variable: dB_Reduction_Y

b. Predictors: (Constant), Length_X4, GreenCover_X3, Height_X1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3.362	.531		-6.332	.000
	Height_X1	1.346	.199	.508	6.764	.000
	GreenCover_X3	.048	.006	.545	7.464	.000
	Length_X4	.017	.008	.144	2.043	.046

a. Dependent Variable: dB_Reduction_Y

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.863[a]	.744	.731	.41916	.744	54.346	3	56	.000

a. Predictors: (Constant), Length_X4, GreenCover_X3, Height_X1

b. Dependent Variable: dB_Reduction_Y

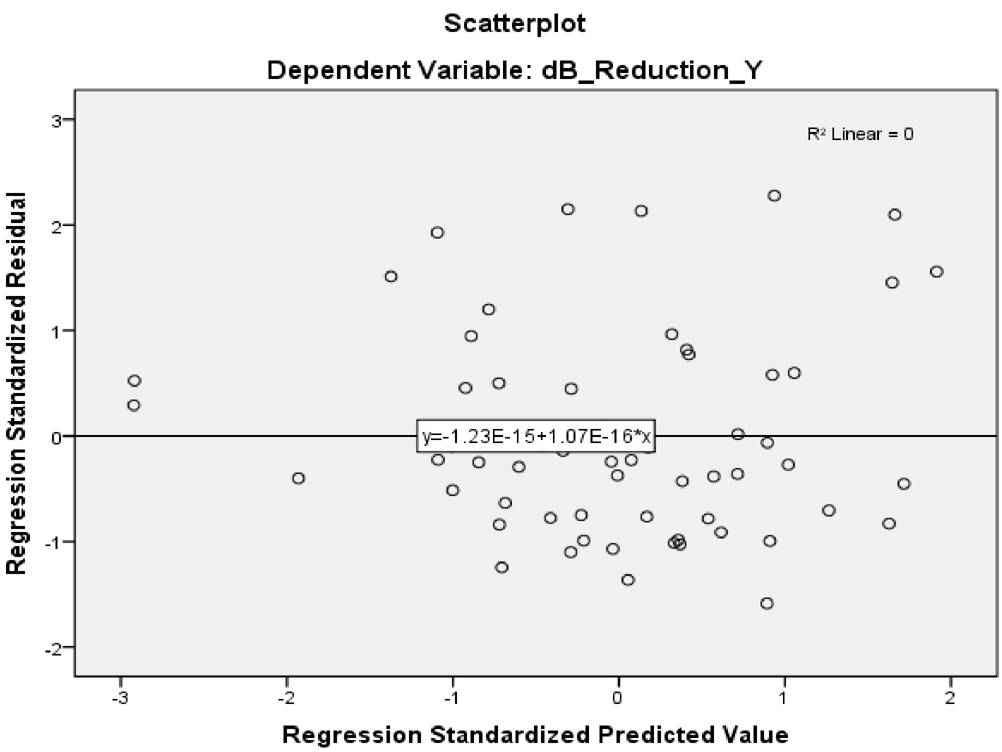


Figure 11-29 Distribution of residuals of MLR-3A

11.8.1. Distribution of desired out put and predicted output

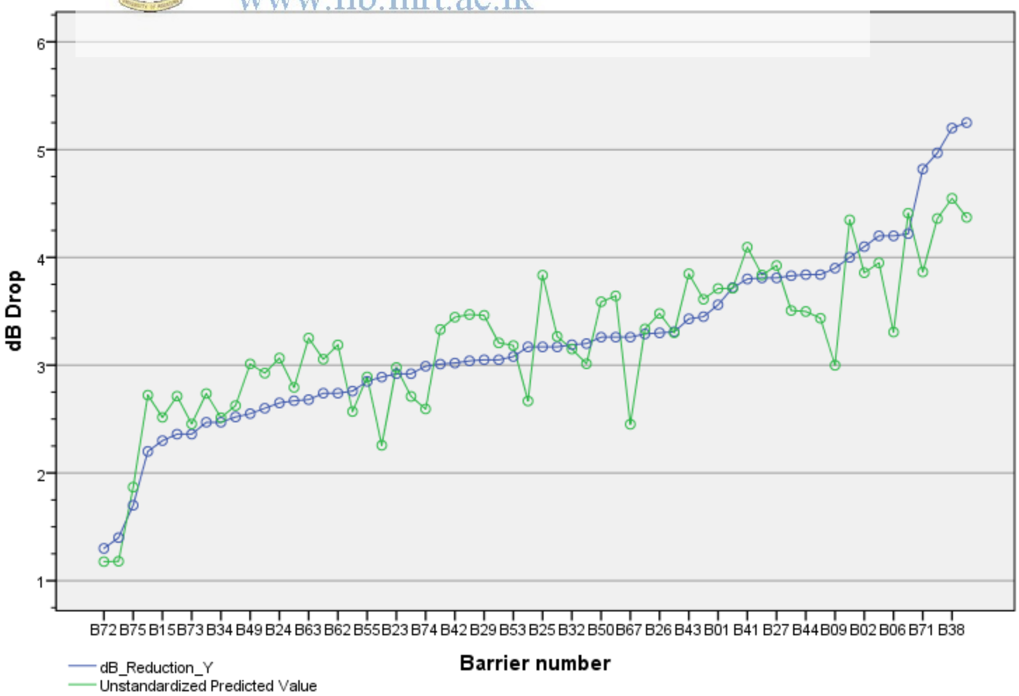


Figure 11-30 Distribution of predicted values and expected values of MLR-3A

Table 11-15 Summary of results of MLR-3A

REGRESSION EQUATION		
Least Square Method Equation	$\hat{Y} = B_0 + B_1X_{1i} + B_2X_{2i} + B_3X_{3i} + \ldots\ldots\ldots + B_nX_{ni}$	
Equation	$\hat{Y} = -3.362 + 1.346X_{1i} + 0.048X_{3i} + 0..017X_{4i}$	
REGRESSION COEFFICENTS		
Hypothesis test		
Ho	: $B_i = 0$	
Ha	: $B_i \neq 0$	
Critical p value	: 0.05	**(two tailed test)**
Coefficents	**Condition**	**Conclusion /Result**
	Sig value	
$B_0 = -3.362$	$0.001 < p$	Significunt (reject Ho)
$B_1 = 1.346$	$0.001 < p$	Significunt (reject Ho)
$B_2 = 0$	$-$	
$B_3 = 0.048$	$0.001 < p$	Significunt (reject Ho)
$B_4 = 0.017$	$0.046 < p$	Significunt (reject Ho)
Cocnclution	Including X4 variable would improve the model	
OVERAL MODEL		
	Condition	***Conclution/Result***
R^2	0.744	Good corelation
Adjusted R^2	0.731	Good corelation
Hypothesis test		
Ho	: $\beta_1 = \beta_2 = \ldots \beta_i = 0$	
Ha	: At least one of the β_i is not zero	
P value	0.05	
F statistic	54.35	Has not improved since MLR-2A

Significunt value	0.001< *P*	Useful model
Residuals	Doesn't show any pattern or relationship	
Comment	the data proivds sufficent eveidence to conclude that the model significuntly contribute to the prediction of dependent variable. R2 value has inproved how ever the improvement is not very large as a result of introducsing X4 variable to the model. t- test proves that all included variables significuntly improves the model fit.Sums of squars of errors have also being reduced.	

11.9. Multiple linear regression model (MLR-5) using X1,X3,X4,X5.and X6

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	29.228	5	5.846	34.104	.000[b]
	Residual	9.256	54	.171		
	Total	38.484	59			

a. Dependent Variable: dB_Reduction_Y

b. Predictors: (Constant), GreenCover_X3, Temp_X5, Height_X1, Length_X4, Humidity_X6

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-5.505	2.013		-2.735	.008
	Length_X4	.020	.009	.166	2.195	.032
	Height_X1	1.373	.197	.519	6.958	.000
	Temp_X5	.015	.041	.031	.364	.717
	Humidity_X6	.023	.013	.141	1.731	.089
	GreenCover_X3	.049	.006	.561	7.683	.000

a. Dependent Variable: dB_Reduction_Y

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.871[a]	.759	.737	.41401	.759	34.104	5	54	.000

a. Predictors: (Constant), GreenCover_X3, Temp_X5, Height_X1, Length_X4, Humidity_X6

b. Dependent Variable: dB_Reduction_Y

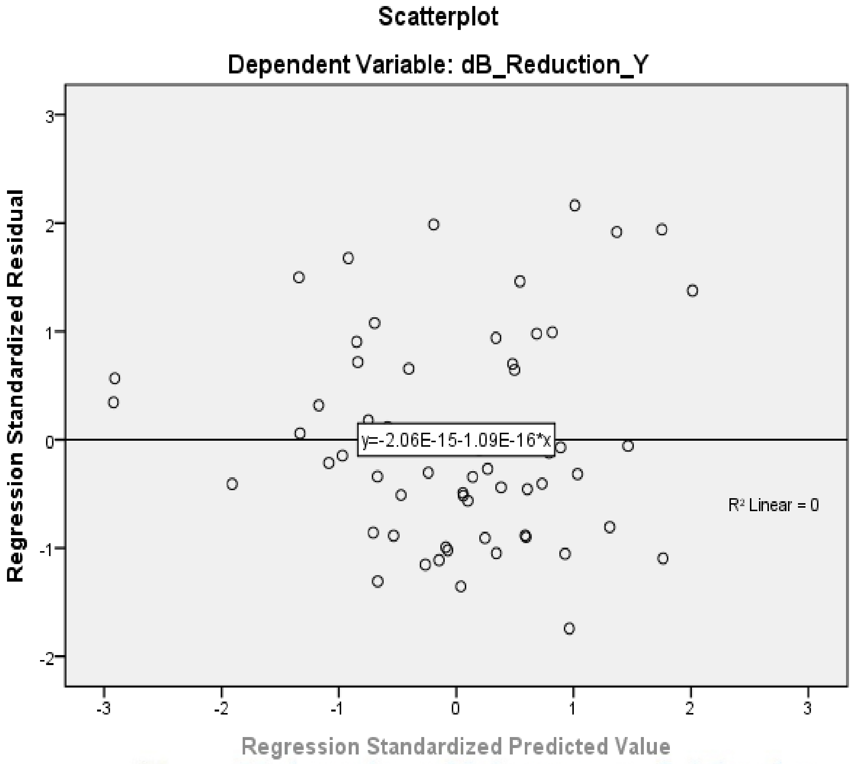


Figure 11-31 Distribution of residuals of MLR-5

11.9.1. Distribution of desired output and predicted output

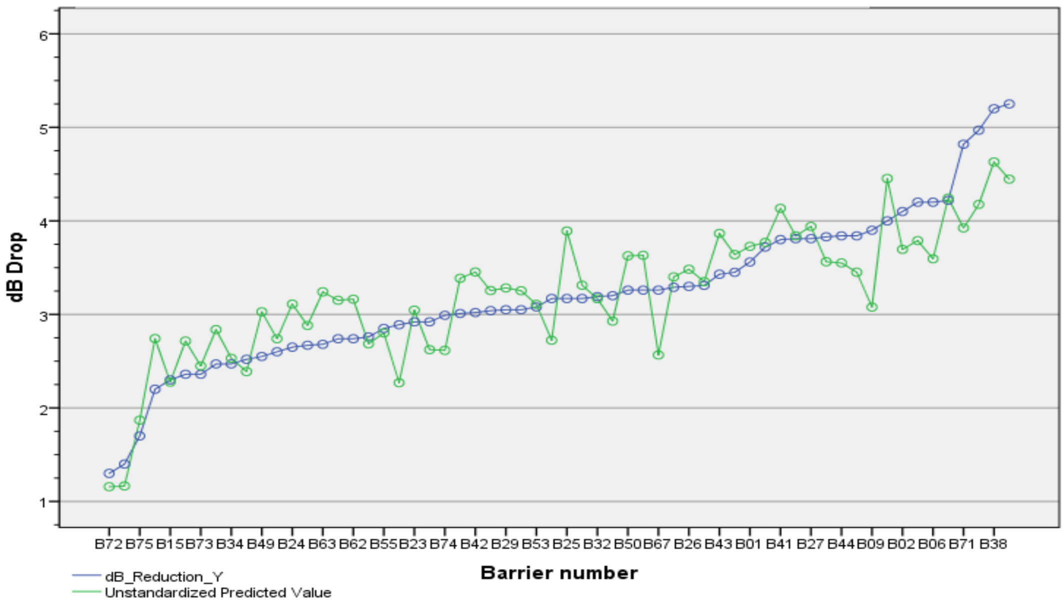


Figure 11-32 Distribution of predicted values and expected values of MLR-5

Table 11-16 Summary of results of MLR-5

REGRESSION EQUATION		
Least Square Method Equation	$\hat{Y} = B_0 + B_1X_{1i} + B_2X_{2i} + B_3X_{3i} + \dots\dots\dots + B_nX_{ni}$	
Equation	$\hat{Y} = -5.505 + 1.373X_{1i} + 0.049X_{3i} + 0.020X_{4i} + 0.015X_{5i} + 0.023X_{6i}$	
REGRESSION COEFFICENTS		
Hypothesis test		
Ho	: $B_i = 0$	
Ha	: $B_i \neq 0$	
Critical p value	: 0.05	**(two tailed test)**
Coefficents	**Condition**	**Conclusion /Result**
	Sig value	
$B_0 = -5.505$	$0.008 < p$	Significunt (reject Ho)
$B_1 = 1.373$	$0.001 < p$	Significunt (reject Ho)
$B_2 = 0$	–	
$B_3 = 0.049$	$0.001 < p$	Significunt (reject Ho)
$B_4 = 0.020$	$0.032 < p$	Significunt (reject Ho)
$B_5 = 0.015$	$0.717 > p$	Fail to reject Ho
$B_6 = 0.023$	$0.089 > p$	Fail to reject Ho
Cocnclution	Including X6 variable would improve the model	
OVERAL MODEL		
	Condition	***Conclution/Result***
R^2	0.759	Good corelation
Adjusted R^2	0.737	Good corelation
Hypothesis test		
Ho	: $\beta_1 = \beta_2 = \dots \beta_i = 0$	
Ha	: At least one of the β_i is not zero	

P value	0.05	
F statistic	34.00	Has not improved since MLR-3A
Significunt value	0.001 < P	Useful model
Residuals	Doesn’t show any pattern or relationship	
Comment	the data proivds sufficent eveidence to conclude that the model significuntly contribute to the prediction of dependent variable. R^2 value has inproved how ever the improvement is not very large as a result of introducsing X5 and X6 variable to the model. Even though X5 and X6 variables improves the model slightly, significunt of X5 and X6 variables in the models do not agree according to t- test	

11.10. MULTIPLE LINEAR REGRESSION MODEL (MLR-4) USING X1,X3,X4 AND X6.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	30.580	4	7.645	47.596	.000[b]
	Residual	8.834	55	.161		
	Total	39.414	59			

a. Dependent Variable: pro_dB reduction_Y

b. Predictors: (Constant), Humidity_X6, Height_X1, Length_X4, GreenCover_X3

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4.306	.991		-4.344	.000
	Height_X1	1.323	.191	.493	6.909	.000
	GreenCover_X3	.050	.006	.592	8.412	.000
	Length_X4	.019	.008	.161	2.349	.022
	Humidity_X6	.012	.011	.072	1.072	.288

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.881[a]	.776	.760	.40077	.776	47.596	4	55	.000

a. Predictors: (Constant), Humidity_X6, Height_X1, Length_X4, GreenCover_X3

b. Dependent Variable: dB reduction_Y

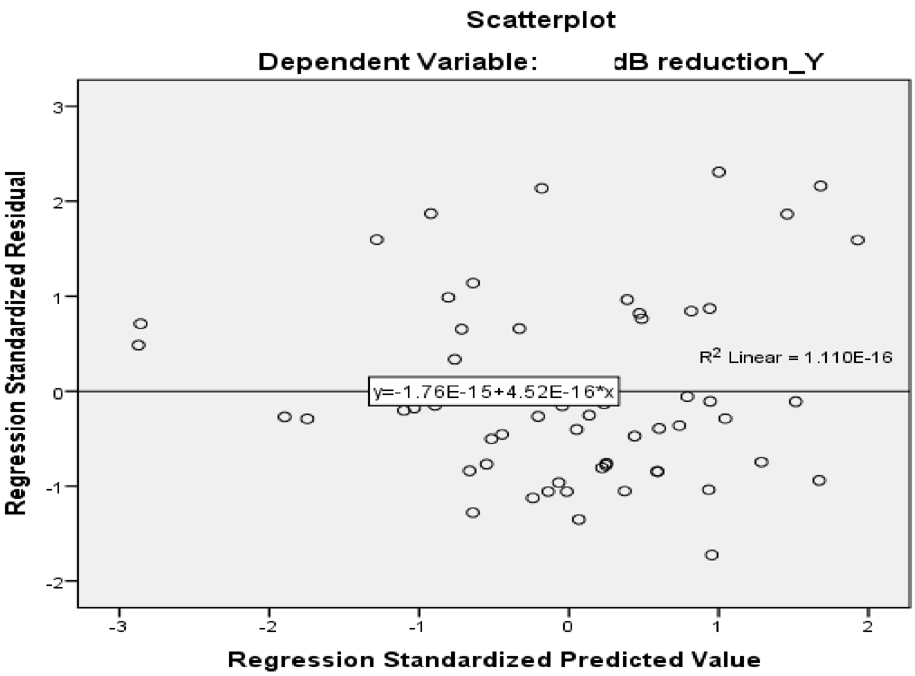


Figure 11-33 Distribution of residuals of MLR-4

11.10.1. Distribution of desired output and predicted output.

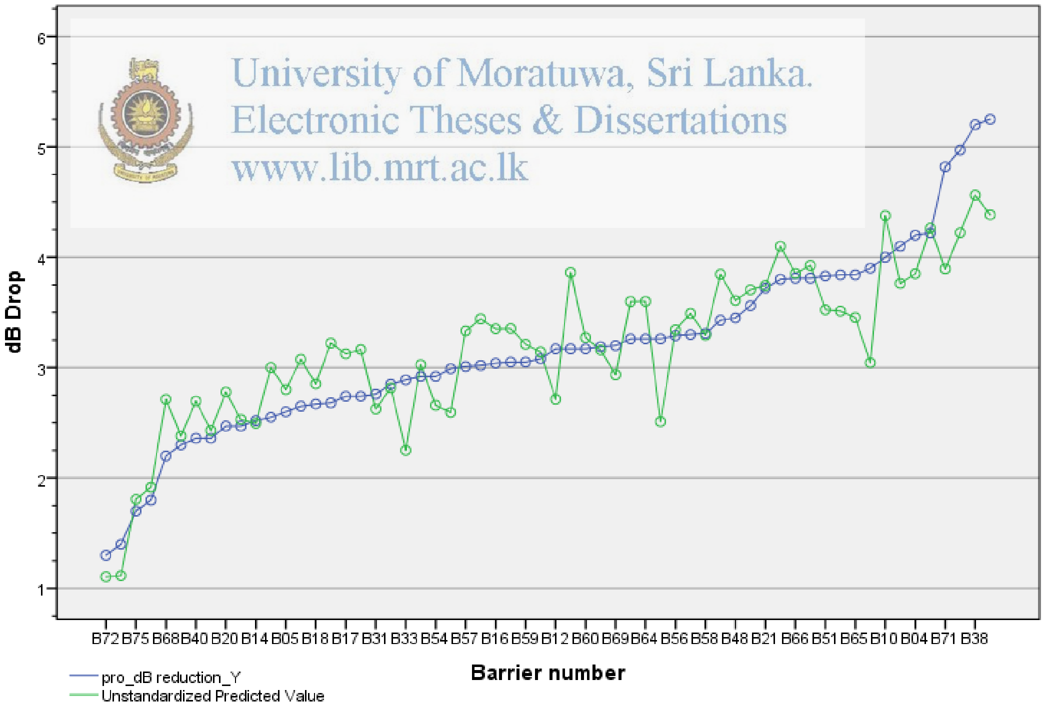


Figure 11-34 Distribution of predicted values and expected values of MLR-4

Table 11-17 Summary of results of MLR-4

REGRESSION EQUATION		
Least Square Method Equation	$\hat{Y} = B_0 + B_1X_{1i} + B_2X_{2i} + B_3X_{3i} + \ldots\ldots\ldots + B_nX_{ni}$	
Equation	$\hat{Y} = -4.306 + 1.323X_{1i} + 0.050X_{3i} + 0.019X_{4i} + 0.012X_{6i}$	
REGRESSION COEFFICENTS		
Hypothesis test		
Ho	: $B_i = 0$	
Ha	: $B_i \neq 0$	
Critical p value	: 0.05	**(two tailed test)**
Coefficents	**Condition**	**Conclusion /Result**
	Sig value	
$B_0 = -4.306$	$0.001 < p$	Significunt (reject Ho)
$B_1 = 1.323$	$0.001 < p$	Significunt (reject Ho)
$B_2 = 0$	$-$	
$B_3 = 0.050$	$0.001 < p$	Significunt (reject Ho)
$B_4 = 0.019$	$0.022 < p$	Significunt (reject Ho)
$B_5 = -$	$-$	
$B_6 = 0.012$	$0.288 > p$	Fail to reject Ho
Cocnclution	excluding X5 variable would improve the model	
OVERAL MODEL		
	Condition	***Conclution/Result***
R^2	0.776	Good corelation
Adjusted R^2	0.760	Good corelation
Hypothesis test		
Ho	: $\beta_1 = \beta_2 = \ldots \beta_i = 0$	
Ha	: At least one of the β_i is not zero	

P value	0.05	
F statistic	47.59	Has imporved since MLR-5
Significunt value	0.001< *P*	Useful model
Residuals	Doesn’t show any pattern or relationship	
Comment	the data proivds sufficent eveidence to conclude that the model significuntly contribute to the prediction of dependent variable. R^2 value has inproved how ever the improvement is not very large as a result of introducsing X6 and removing X5 variable from the model. Even though X5 and X6 variables improves the model slightly, significunt of X5 and X6 variables in the models do not agree according to t- test	

11.11. MULTIPLE LINEAR REGRESSION MODEL (MLR-4A) USING X1,X3,X4 AND X5

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	30.430	4	7.608	46.576	.000[b]
	Residual	8.983	55	.163		
	Total	39.414	59			

a. Dependent Variable: pro_dB reduction_Y

b. Predictors: (Constant), Temp_X5, GreenCover_X3, Height_X1, Length_X4

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2.917	1.110		-2.628	.011
	Height_X1	1.304	.192	.486	6.775	.000
	GreenCover_X3	.049	.006	.579	8.284	.000
	Length_X4	.019	.009	.157	2.159	.035
	Temp_X5	-.016	.034	-.033	-.464	.644

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.879[a]	.772	.755	.40415	.772	46.576	4	55	.000

a. Predictors: (Constant), Temp_X5, GreenCover_X3, Height_X1, Length_X4

b. Dependent Variable: pro_dB reduction_Y

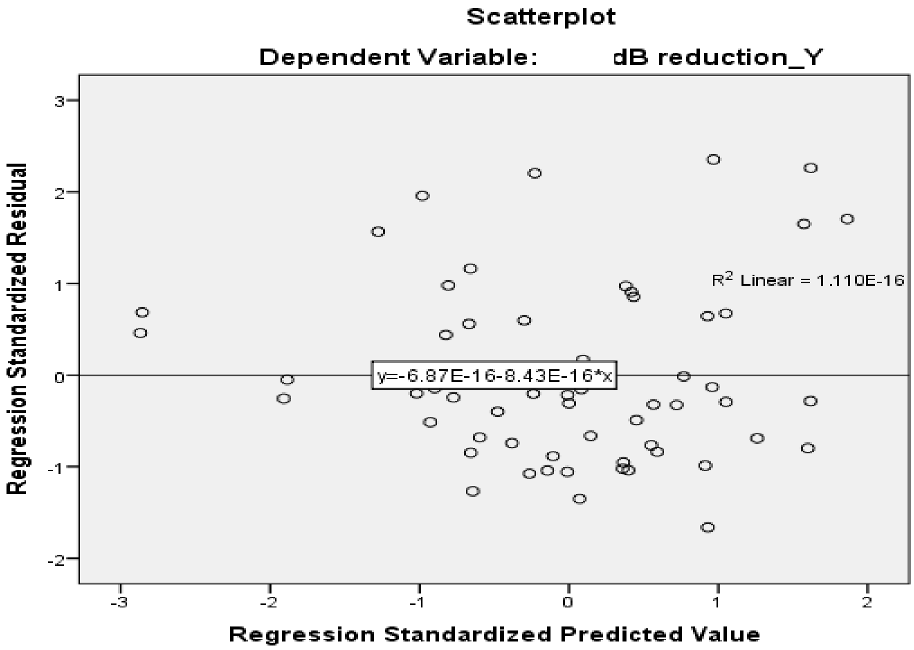


Figure 11-35 Distribution of residuals of MLR-4A

11.11.1. Distribution of desired output and predicted value.

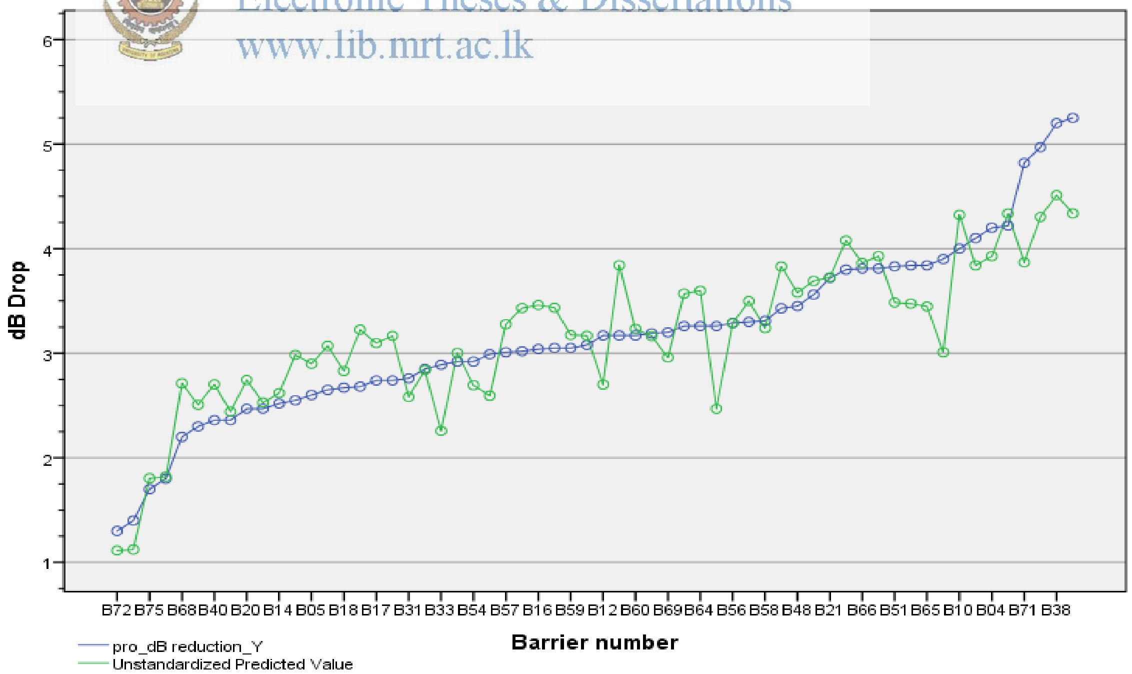


Figure 11-36 Distribution of predicted values and expected values of MLR-4A

Table 11-18 Summary of results of MLR-4A

REGRESSION EQUATION		
Least Square Method Equation	$\hat{Y} = B_0 + B_1X_{1i} + B_2X_{2i} + B_3X_{3i} + \ldots\ldots\ldots + B_nX_{ni}$	
Equation	$\hat{Y} = -2.917 + 1.304X_{1i} + 0.049X_{3i} + 0.019X_{4i} - 0.016X_{5i}$	
REGRESSION COEFFICENTS		
Hypothesis test		
Ho	$: B_i = 0$	
Ha	$: B_i \neq 0$	
Critical p value	: 0.05	**(two tailed test)**
Coefficents	**Condition**	**Conclusion /Result**
	Sig value	
$B_0 = -2.917$	$0.001 < p$	Significunt (reject Ho)
$B_1 = 1.304$	$0.001 < p$	Significunt (reject Ho)
$B_2 = 0$	$-$	
$B_3 = 0.049$	$0.001 < p$	Significunt (reject Ho)
$B_4 = 0.019$	$0.022 < p$	Significunt (reject Ho)
$B_5 = -0.016$	$0.644 > p$	Fail to reject Ho
$B_6 = -$	$-$	
Cocnclution	excluding X6 variable would improve the model	
OVERAL MODEL		
	Condition	***Conclution/Result***
R^2	0.772	Good corelation
Adjusted R^2	0.755	Good corelation
Hypothesis test		
Ho	$: \beta_1 = \beta_2 = \ldots \beta_i = 0$	
Ha	: At least one of the β_i is not zero	

P value	0.05	
F statistic	46.57	No significunt change since MLR-4.
Significunt value	0.001< *P*	Useful model
Residuals	Doesn't show any pattern or relationship	
Comment	the data proivds sufficent eveidence to conclude that the model significuntly contribute to the prediction of dependent variable. R^2 value has inproved how ever the improvement is not very large as a result of introducsing X5 and removing X6 variable from the model. Even though X5 and X6 variables improves the model slightly, significunt of X5 and X6 variables in the models do not agree according to t- test .	

11.12. SUMMARY OF MLR MODELS

Table 11-19 Summary of MLR models

Model	Equation	Significant variables	R2	R_a^2 (Adjusted R^2)	Standard Error of the Estimate
MLR-2	$\hat{Y} = 1.943 + 0.503X_{1i} + 0.526X_{2i}$	X1	0.119	0.095	0.93915
MLR-3	$\hat{Y} = -3.481 + 1.341X_{1i} - 0.256X_{2i} + 0.053X_{3i}$	X1, X3	0.705	0.690	0.47331
MLR-2A	$\hat{Y} = -3.209 + 1.231X_{1i} + 0.05X_{3i}$	X1, X3	0.725	0.716	0.43068
MLR-3A	$\hat{Y} = -3.362 + 1.346X_{1i} + 0.048X_{3i} + 0..017X_{4i}$	X1,X3,X4	0.744	0.731	0.41916
MLR-5	$\hat{Y} = -5.505 + 1.373X_{1i} + 0.049X_{3i} + 0.020X_{4i} + 0.015X_{5i} + 0.023X_{6i}$	X1,X3,X4	0.759	0.737	0.41401
MLR-4	$\hat{Y} = -4.306 + 1.323X_{1i} + 0.050X_{3i} + 0.019X_{4i} + 0.012X_{6i}$	X1,X3,X4	0.776	0.760	0.40077
MLR-4A	$\hat{Y} = -2.917 + 1.304X_{1i} + 0.049X_{3i} + 0.019X_{4i} - 0.016X_{5i}$	X1,X3,X4	0.772	0.755	0.40415

According to the results of multiple linear regression analysis most promising models are MLR-5, MLR-4, and MLR-4A. According to MLR models variable X1,X3,X4 significantly contribute in describing the variability of dependent variable in the models. Model MLR-5,MLR-4A and MLR-4 shows R^2 values greater than 0.75 and Adjusted R^2 value decreases when X5 and X6 variables introduced to the model together where as MLR-4 model shows the highest adjusted R^2 value when X6 variable is introduced.

12.ARTIFICIAL NEURAL NETWORK ANALYSIS RESULTS

Fully connected artificial neural networks were trained and tested for the given data set. Firstly ANNs were created using single hidden layer then another set of ANNs were created using two hidden layers.

Network architecture was defined for the research increasing number of predictor variables from 3 to 6. Number of hidden layers were increased from one to two. Activation functions were assigned with appropriate re-scaling methods. Batch training, Mini batch training and online training was carried out for each model. The model architectures used for the research are summarized in Table 12-2,Table 12-3,Table 12-6,Table 12-8 and Table 12-10.

In the network architecture the first hidden layer possess number of perceptrons at least equal to the number of input variables. Then the network architecture was modified and tested while incrementing and adjusting the number of perceptrons in each hidden layers to find out the best model.

The ANNs are analyses and trained using SPSS version 23 software package.

12.1. EVALUATION OF PERFORMANCE OF ANN

The networks are evaluated using the following criterions to find out the best model explaining the problem.

1. The Sums of Square Error (SSE) and Root Mean Square Error (RMSE) to evaluate the predictive accuracy of the model.
2. Predicted value Vs actual value plot to evaluate the prediction accuracy and R^2 value (Coefficient of determination) to measure the variance interpreted by the model. Using predicted value Vs actual value plot, best model should give the highest R^2 values.
3. Residuals Vs predicted value plot to evaluate that the variance of residuals are constant throughout the model. If the residuals are scattered without showing any pattern model is considered as non-bias and to generalize the error.

12.2. ANNOTATION FOR ANN MODELS

Annotation method was developed to name the Different types of networks

Table 12-1 Annotation for ANN models

Annotation	Description
ANN3 , ANN6	Artificial Neural Network with three input variables , Artificial Neural Network with six input variables
MLP	Multi-Layer Perceptron

ON , ONLINE	Online trained
BT, BATCH	Batch Trained
BT10, BATCH10	Mini Batch Trained where Mini Batch size is ten
L1 , L2	Number of hidden layers.
S6S3	In a two hidden layer network first hidden layer contains six perceptrons and second hidden layer contains three perceptrons
SIG,SIGMOID	Sigmoid function as the activation function
HYP,HYP TAN	Hyperbolic tangent function as the activation function
ID	Identity function as the activation function
Stand	Standardizing as rescaling method
Norm	Normalizing as rescaling method
Adj Norm	Adjusted Normalizing as rescaling method

12.3. ANN3 MODELS

In MLR models it was observed that three variables were effective at determining the relationship between predictors and the expected output.

ANN3 models consists with main three input variables Height X1, Thickness X2 and Green cover X3.

12.3.1. ANN3 Single hidden layer networks

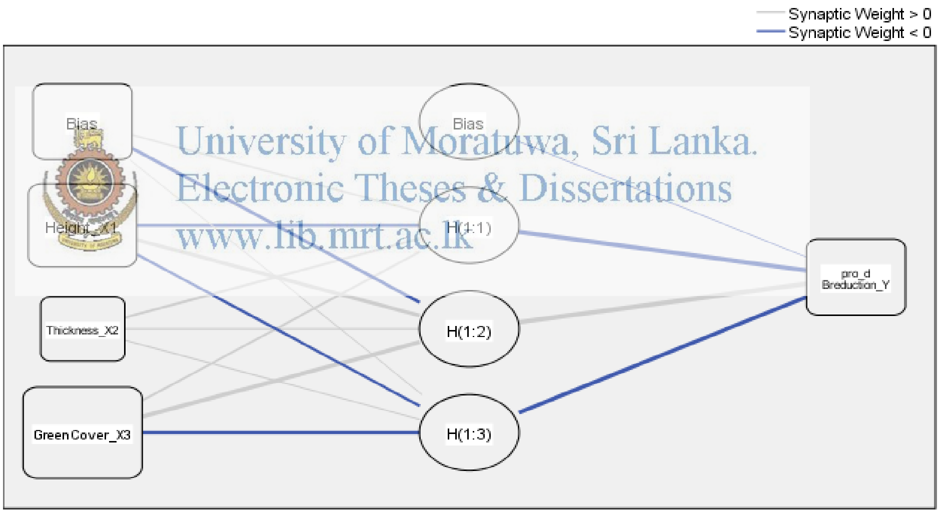
The network architecture is shown in Table 12-2

Table 12-2 Network architecture for ANN3 single hidden layer models

Model Architecture							
	Variables	**MLP-a**	**MLP-b**	**MLP-c**	**MLP-d**	**MLP-e**	**MLP-f**
Independent	**x1**	✓	✓	✓	✓	✓	✓
	x2	✓	✓	✓	✓	✓	✓
	x3	✓	✓	✓	✓	✓	✓
	x4	-	-	-	-	-	-
	x5	-	-	-	-	-	-
	x6	-	-	-	-	-	-
Dependent	**Y**	✓	✓	✓	✓	✓	✓
Network Architecture							
Num of hidden layers		1	1	1	1	1	1
Synaptic	**Layers**						
	input	3	3	3	3	3	3

	Hidden 1	3	3	3	3	3	3
	Hidden 2	0	0	0	0	0	0
	output	1	1	1	1	1	1
Rescaling	**Layers**						
	input	stand	norm	stand	norm	-	-
	output	norm	norm	Adj-norm	norm	-	-
Activation function	**Layers**						
	Hidden	sigmoid	sigmoid	hyp tan	hyp tan	sigmoid	hyp tan
	Output	sigmoid	sigmoid	hyp tan	hyp tan	sigmoid	hyp tan
Training type		batch	batch	batch	batch	batch	batch
Algorithm		Gradient decent	Gradient decent	Gradient decent	Gradient decent	Gradient decent	Gradient decent
R^2		0.676	0.575	0.670	0.598	0.402	0.401
(R^2 value of the relationship between predicted output Vs the actual)							

12.3.2. Model details of ANN3 ON L1 S3-MLP-b



Hidden layer activation function: Sigmoid

Output layer activation function: Sigmoid

Model Summary

Training	Sum of Squares Error	.566
	Relative Error	.466
	Stopping Rule Used	5 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.02
Testing	Sum of Squares Error	.224

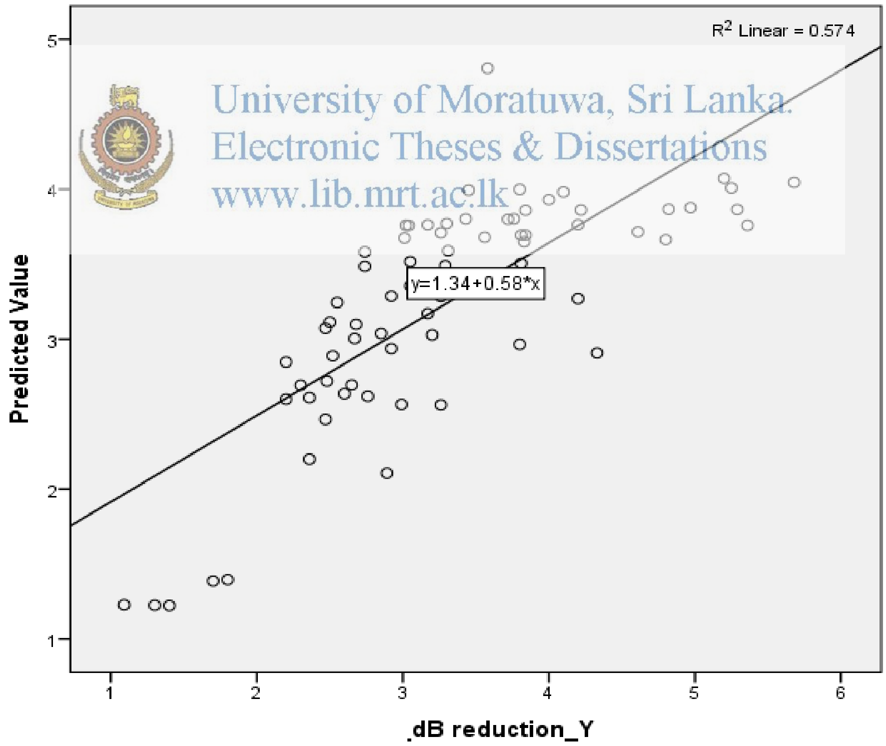
Relative Error	.385

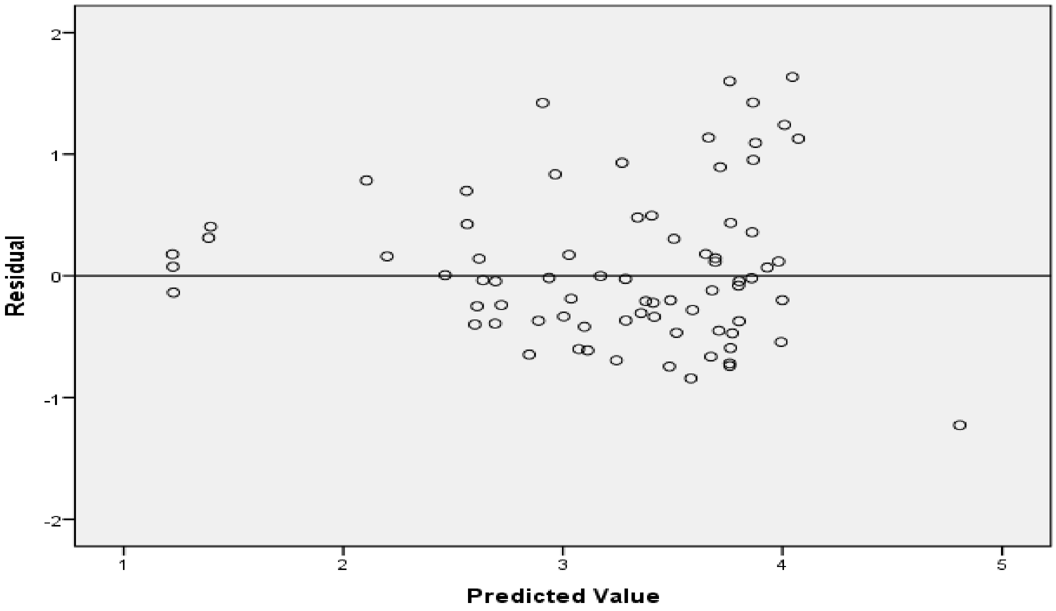
Dependent Variable: dB reduction_Y

a. Error computations are based on the testing sample.

Parameter Estimates

Predictor		Predicted			
		Hidden Layer 1			Output Layer
		H(1:1)	H(1:2)	H(1:3)	pro_dBreduction_Y
Input Layer	(Bias)	.589	-1.542	.022	
	Height_X1	-1.018	1.938	-.785	
	Thickness_X2	.719	.459	.172	
	GreenCover_X3	.619	3.340	-1.585	
Hidden Layer 1	(Bias)				-.020
	H(1:1)				-5.188
	H(1:2)				5.709
	H(1:3)				-2.023





Dependent Variable: dB reduction_Y

12.3.3. ANN3 Two hidden layer networks

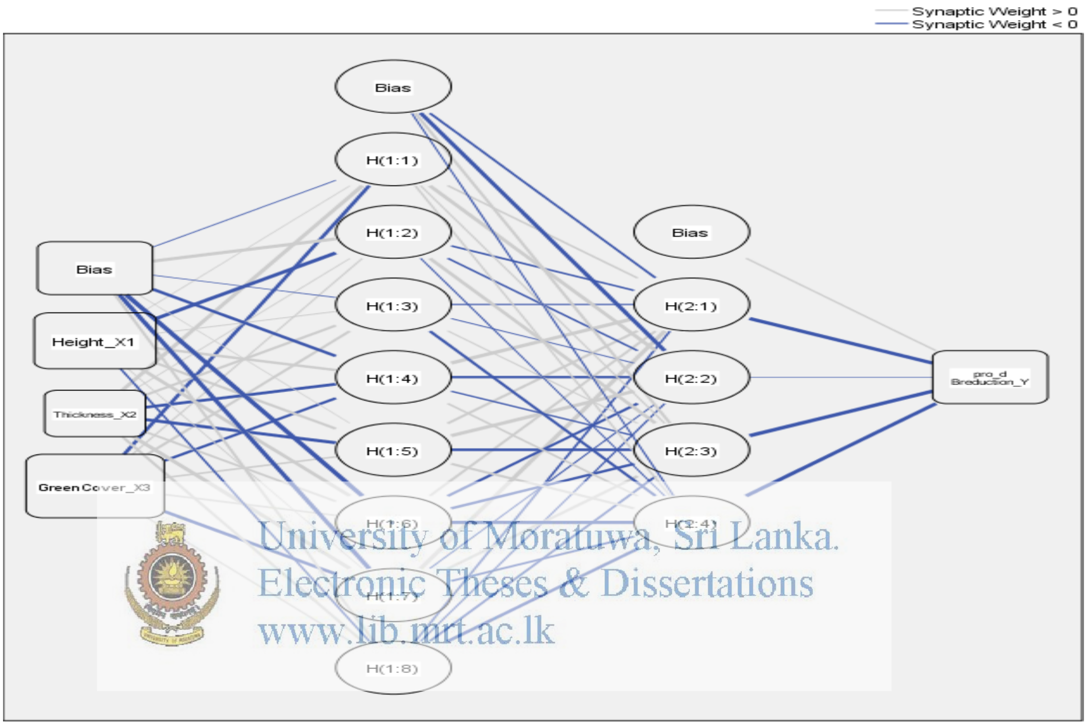
The ANN3 architecture for two hidden layer networks are shown in Table 12-3

Table 12-3 Network architecture for ANN3 two hidden layer models

Model architecture							
	Variables	MLP3-a	MLP3-b	MLP3-c	MLP-d	MLP3-e	MLP3-f
Independent	x1	✓	✓	✓	✓	✓	✓
	x2	✓	✓	✓	✓	✓	✓
	x3	✓	✓	✓	✓	✓	✓
	x4						
	x5						
	x6						
Dependent	Y	✓	✓	✓	✓	✓	✓
Network Architecture							
Num of hidden layers		2	2	2	2	2	2
Synaptic	Layers						
	input	3	3	3	3	3	3
	Hidden1	3	3	3	3	3	3
	Hidden 2	3	3	3	3	3	3
	output	1	1	1	1	1	1
Rescaling	Layers						
	input	stand	norm	stand	norm	-	-
	output	norm	norm	adj norm	adj-norm	norm	-
Activation function	Layers						
	Hidden	sigmoid	sigmoid	hyp tan	hyp tan	sigmoid	hyp tan

	Output	sigmoid	sigmoid	hyp tan	hyp tan	sigmoid	hyp tan
Training Type	*Type*	online	online	online	online	online	online
Algorithm		Gradient decent	Gradient decent	Gradient decent	Gradient decent	Gradient decent	Gradient decent
R^2		0.592	0.59	0.588	0.611	0.252	0.068
(R^2 value of the relationship between predicted output Vs actual value)							

12.3.4. Model details of ANN3 ON L2 S8S4-MLP-c



Hidden layer activation function: Hyperbolic tangent

Output layer activation function: Hyperbolic tangent

Model Summary

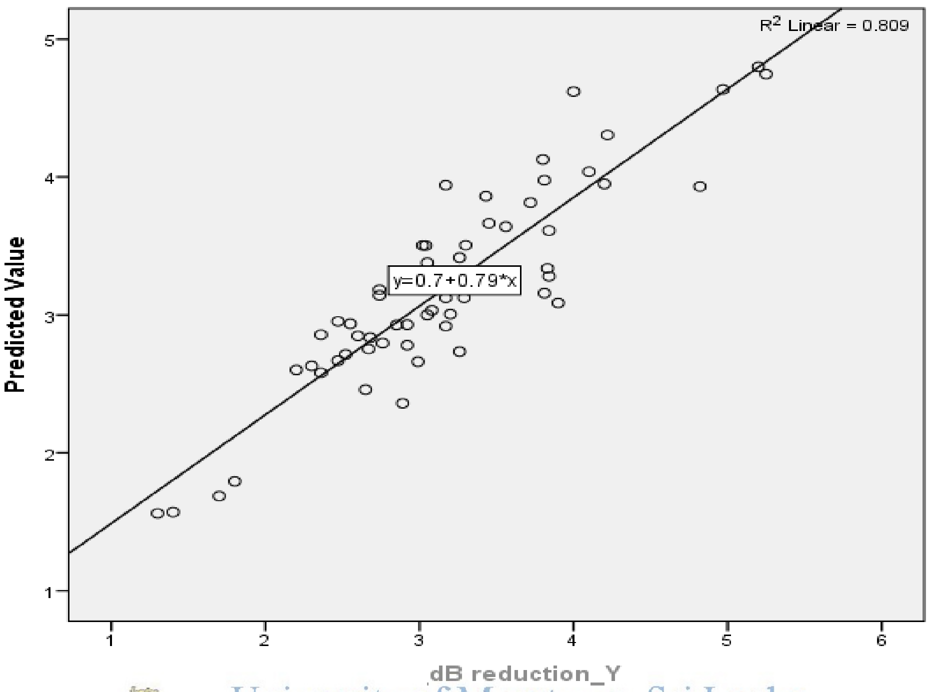
Training	Sum of Squares Error	.612
	Relative Error	.137
	Stopping Rule Used	5 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.84
Testing	Sum of Squares Error	.344
	Relative Error	.859

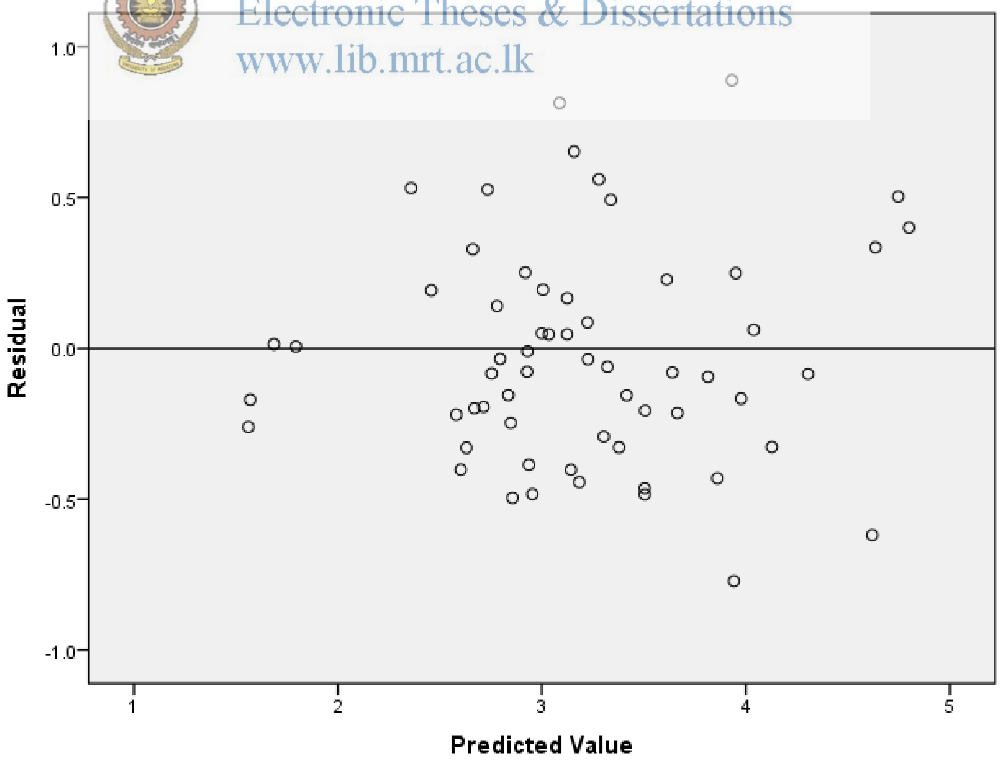
Dependent Variable: dB reduction_Y

a. Error computations are based on the testing sample.

Parameter Estimates														
Predictor		Predicted												
		Hidden Layer 1								Hidden Layer 2				Output Layer
		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	H(1:6)	H(1:7)	H(1:8)	H(2:1)	H(2:2)	H(2:3)	H(2:4)	dB reduction_Y
Input Layer	(Bias)	-.021	.636	-.019	-.440	7.982E-5	-.961	-.552	.225					
	Height_X1	.014	-.652	.048	.399	.308	.455	.021	-.141					
	Thickness_X2	.480	.027	.294	-.494	-.624	.226	.527	.243					
	GreenCover_X3	-.372	.100	.245	-.341	.194	.213	-.486	.130					
Hidden Layer 1	(Bias)									-.199	-.500	.234	-.095	
	H(1:1)									.170	.476	.117	.131	
	H(1:2)									-.185	-.157	.407	-.051	
	H(1:3)									-.130	-.046	.089	-.249	
	H(1:4)									.674	-.368	-.135	.180	
	H(1:5)									.255	.660	-.416	.262	
	H(1:6)									.226	-.257	-.365	-.724	
	H(1:7)									.511	-.071	.340	-.239	
	H(1:8)									-.146	-.118	-.212	-.413	
Hidde	(Bias)													.136
	H(2:1)													-.683

	H(2:2)													-.008
	H(2:3)													-1.192
	H(2:4)													-.553





Dependent Variable: dB reduction_Y

12.3.5. ANN3 Results Summery

Table 12-4 R^2 Values of ANN3

	Model	MLP-a	MLP-b	MLP-c	MLP-d	MLP-e	MLP-f
1	ANN3 BT L1 S3	0.602	0.596	0.678	0.588	-	-
2	ANN3 ON L1 S3	0.676	**0.574**	0.670	0.598	0.402	0.401
3	ANN3 ON L2 S3	**0.592**	0.590	**0.588**	0.611	0.252	0.068
4	ANN3 ON L2 S4	0.645	0.606	0.669	**0.557**	-	-
5	ANN3 BT L2 S4	0.623	0.583	0.685	0.601	-	-
6	ANN3 ON L2 S6	0.743	0.653	0.789	0.754	-	-
7	ANN3 BT L2 S6	0.659	0.742	0.803	0.749	-	-
8	ANN3 ON L2 S8	0.760	0.754	0.668	0.743	-	-
9	ANN3 BT L2 S8	0.740	0.694	0.770	0.731	-	-
10	ANN3 ON L2 S12	**0.793**	0.756	0.779	0.733	-	-
11	ANN3 BT L2 S12	0.771	0.750	0.793	0.735	-	-
12	ANN3 ON L2 S16	0.750	0.751	0.764	0.718	-	-
13	ANN3 BT L2 S16	0.736	0.682	0.733	0.735	-	-
14	ANN3 ON L2 S6S3	0.781	**0.780**	0.805	0.745	-	-
15	ANN3 BT L2 S6S3	0.776	0.708	0.807	0.730	-	-
16	ANN3 ON L2 S8S4	0.738	0.751	**0.809**	**0.786**	-	-
17	ANN3 BT L2 S8S4	0.766	0.664	0.774	0.739	-	-

Table 12-5 Model annotation of ANN3

Model annotation	ANN3 ON L2 S8S4		
ANN3	ON	L2	S8S4
Artificail Neural network with 3 inputs	Training method,	Number of hidden layers	Number of perceptrons in each hidden layers

It was observed that the MLP-e and MLP-f models resulting in lower R^2 values compared to the others and it was decided to omit the particular architecture in further testing. Two hidden layer models has shown to produce improved R^2 values. According to the Table 12-4 most promising model is ANN3 ON L2 S8S4-MLP-c.

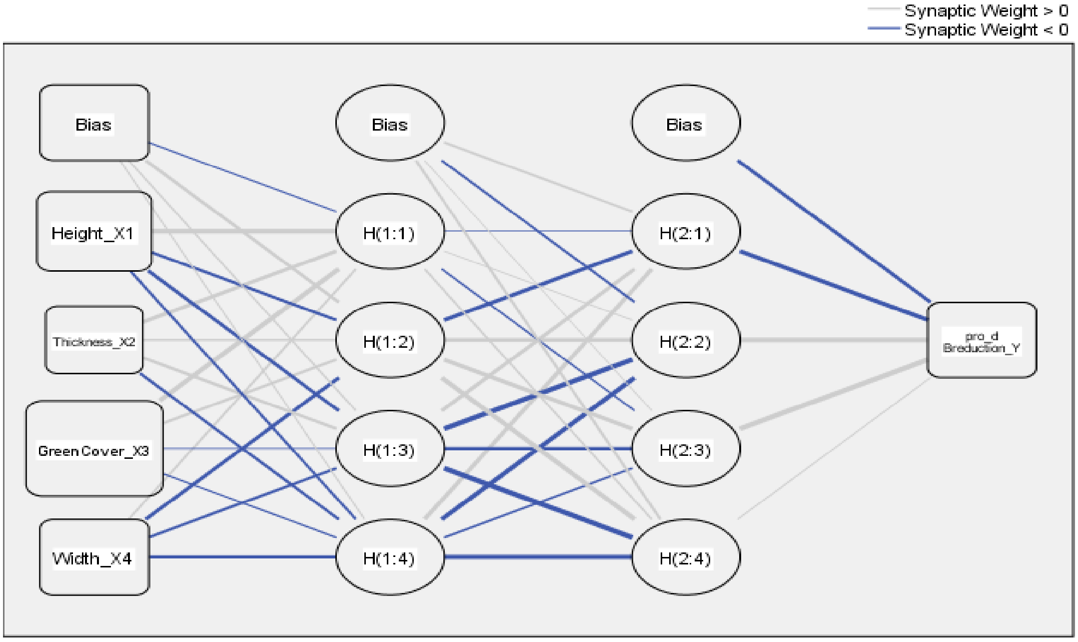
12.4. ANN4 MODELS

12.4.1. ANN4 Two hidden layer networks

Table 12-6 Network architecture for ANN4 two hidden layer models

Model Architecture					
	Variables	**MLP4-a**	**MLP4-b**	**MLP4-c**	**MLP4-d**
Independent	**x1**	✓	✓	✓	✓
	x2	✓	✓	✓	✓
	x3	✓	✓	✓	✓
	x4	✓	✓	✓	✓
	x5				
	x6				
Dependent	**Y**				
Network Architecture					
Num of hidden layers		2	2	2	2
Synaptic	**Layers**				
	input	4	4	4	4
	Hidden 1	6	6	6	6
	Hidden 2	3	3	3	3
	output	1	1	1	1
Rescaling	**Layers**				
	input	stand	norm	stand	norm
	output	norm	norm	adj norm	adj norm
Activation	**Layers**				
	Hidden	sigmoid	sigmoid	hyp tan	hyp tan
	Output	sigmoid	sigmoid	hyp tan	hyp tan
Training	*Type*	Batch10	Batch10	Batch10	Batch10
Type	*Algorithm*	Gradient decent	Gradient decent	Gradient decent	Gradient decent
R^2		0.811	0.755	0.807	0.774
(R^2 value of the relationship between predicted Vs Target value)					

12.4.2. Model details of ANN4 ON L2 S4-MLP-a



Hidden layer activation function: Sigmoid

Output layer activation function: Sigmoid

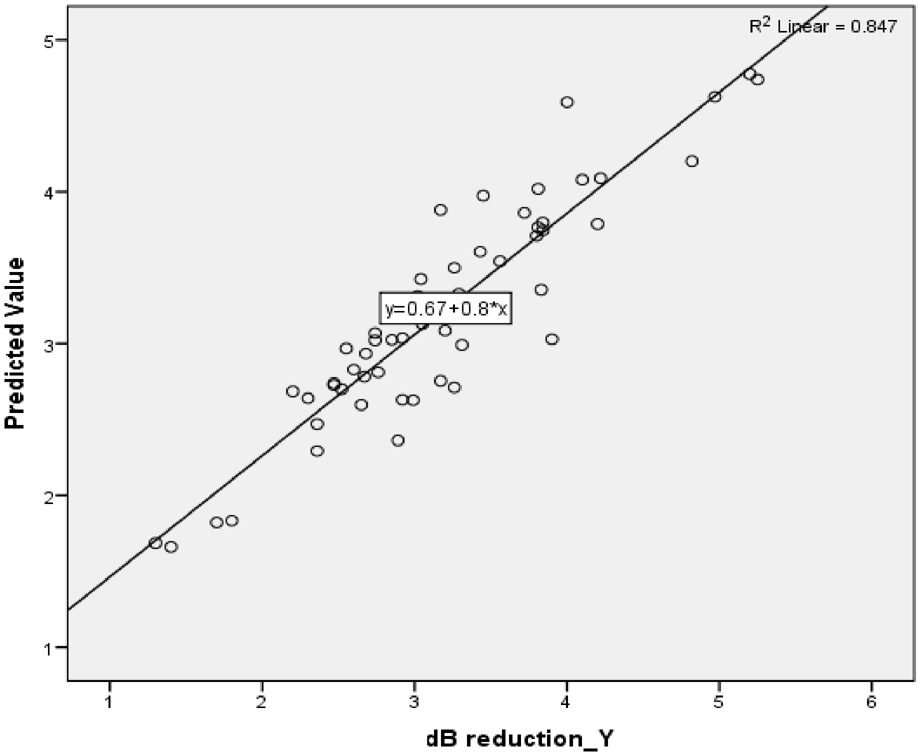
Model Summary

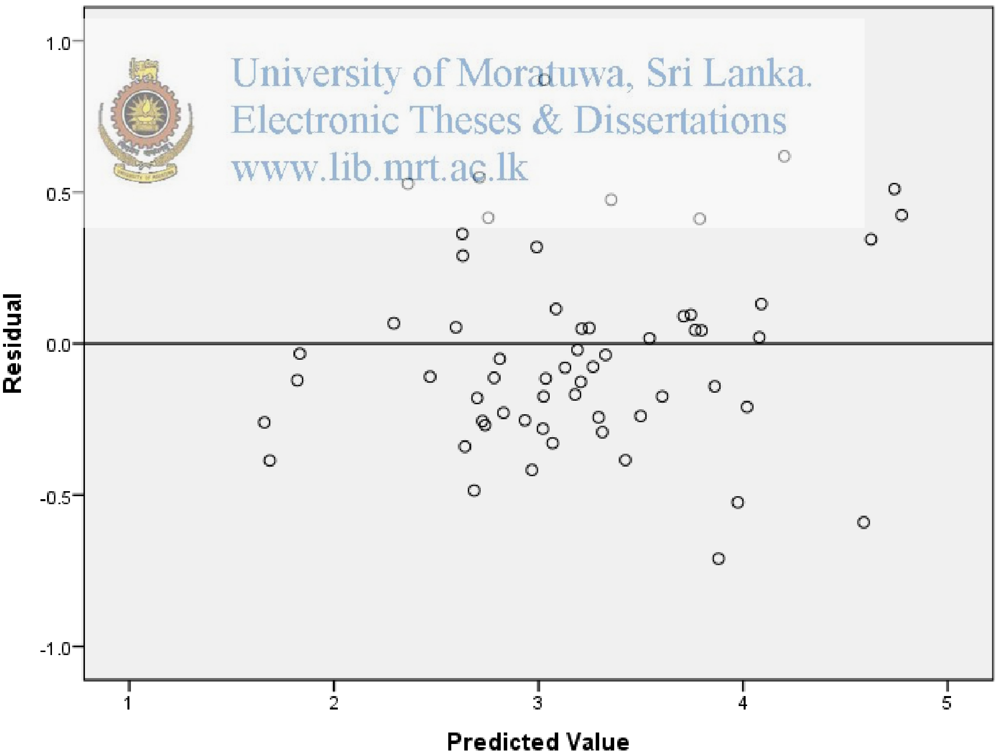
Training	Sum of Squares Error	.119
	Relative Error	.124
	Stopping Rule Used	5 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.03
Testing	Sum of Squares Error	.074
	Relative Error	.279

Dependent Variable: dB reduction_Y

a. Error computations are based on the testing sample.

Parameter Estimates										
		Predicted								
		Hidden Layer 1				Hidden Layer 2				Output Layer
Predictor		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(2:1)	H(2:2)	H(2:3)	H(2:4)	dB reduction_Y
Input Layer	(Bias)	-.217	1.118	.272	.187					
	Height_X1	3.148	-.972	-1.237	-.577					
	Thickness_X2	1.481	.442	.988	-.830					
	GreenCover_X3	2.840	.926	-.142	-.254					
	Length_X4	.497	-1.341	-.775	-1.036					
Hidden Layer 1	(Bias)					.540	-.505	.053	.598	
	H(1:1)					-.005	.135	-.298	.315	
	H(1:2)					-1.558	1.958	2.153	2.777	
	H(1:3)					1.468	-3.741	-1.349	-3.851	
	H(1:4)					1.634	-2.407	-.461	-2.397	
Hidden Layer 2	(Bias)									-1.247
	H(2:1)									-2.335
	H(2:2)									3.333
	H(2:3)									4.031
	H(2:4)									.185





Dependent Variable: dB reduction_Y

12.4.3. ANN4 result summery

Table 12-7 R^2 values of ANN4

	Model	MLP-a	MLP-b	MLP-c	MLP-d
18	ANN4 ON L2 S4	**0.847**	0.741	0.807	0.767
19	ANN4 BT L2 S4	0.813	0.766	0.761	0.701
20	ANN4 ON L2 S6	0.780	0.773	0.821	0.710
21	ANN4 BT L2 S6	0.670	0.704	0.753	0.759
22	ANN4 ON L2 S8	0.754	**0.793**	**0.849**	0.759
23	ANN4 BT L2 S8	0.763	0.769	0.836	0.763
24	ANN4 ON L2 S12	0.809	0.771	0.759	0.788
25	ANN4 BT L2 S12	0.776	0.741	0.810	0.753
26	ANN4 ON L2 S16	0.792	0.761	0.835	0.768
27	ANN4 BT L2 S16	0.791	0.758	0.783	0.764
28	ANN4 ON L2 S4S2	0.693	0.775	0.825	0.756
29	ANN4 BT L2 S4S2	0.695	0.750	0.800	0.766
30	ANN4 ON L2 S6S3	0.812	0.762	0.786	0.683
31	ANN4 BT L2 S6S3	0.811	0.755	0.807	0.774
32	ANN4 ON L2 S8S4	0.812	0.762	0.786	0.683
33	ANN4 BT L2 S8S4	0.811	0.755	0.807	0.774
34	ANN4 ON L2 S12S6	0.781	0.744	0.726	**0.805**
35	ANN4 BT L2 S12S6	0.778	0.775	0.789	0.672

The most promising model from ANN4 is ANN4 ON L2 S4-MLP-a which shows a R2 value of 0.847.

12.5. ANN6 MODELS

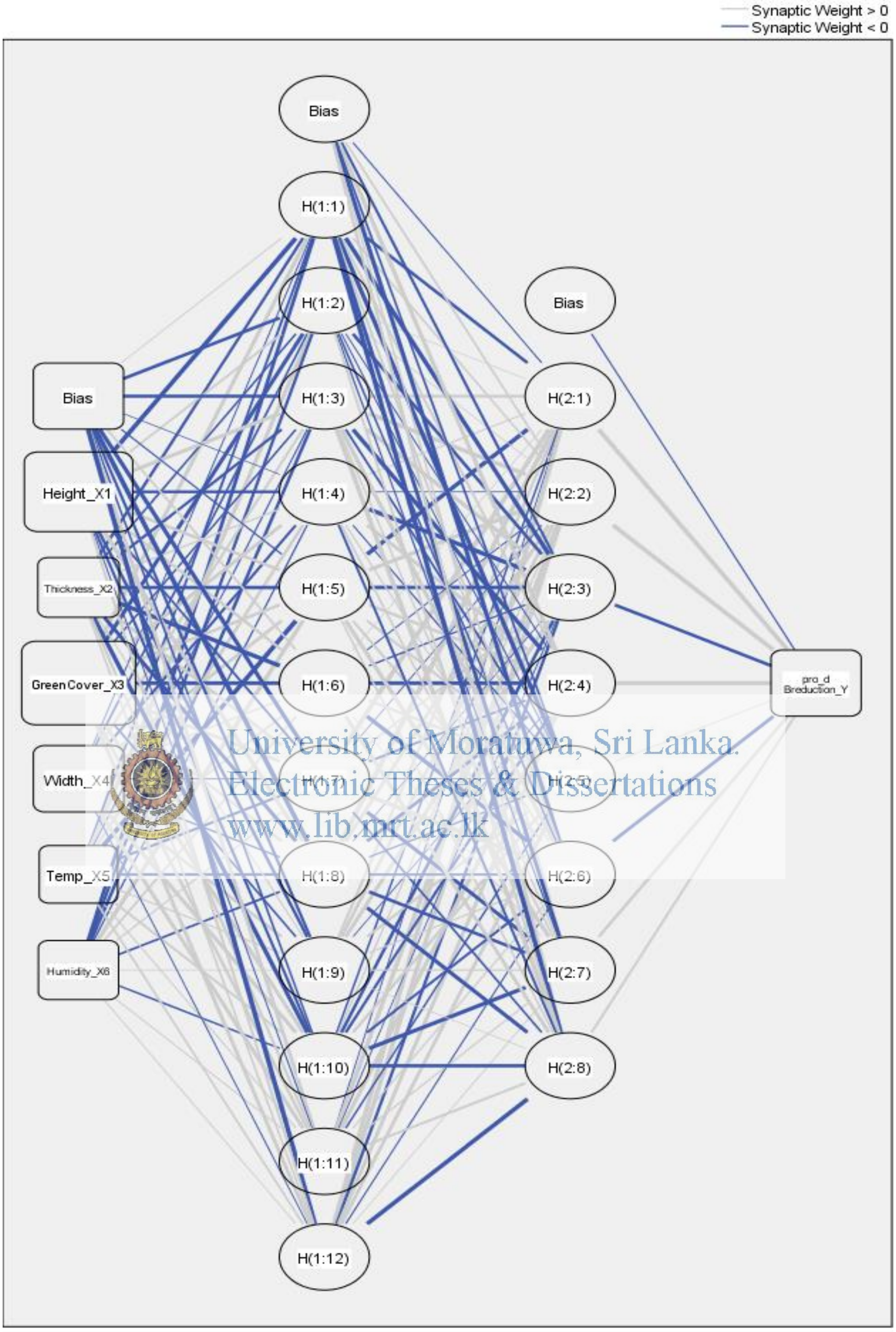
12.5.1. ANN6 Two hidden layer networks

Table 12-8 Network architecture for ANN6 two hidden layer models.

Model Architecture.					
	Variables	**MLP-a**	**MLP-b**	**MLP-c**	**MLP-d**
Independent	**x1**	✓	✓	✓	✓
	x2	✓	✓	✓	✓
	x3	✓	✓	✓	✓
	x4	✓	✓	✓	✓
	x5	✓	✓	✓	✓
	x6	✓	✓	✓	✓
Dependent	**Y**	✓	✓	✓	✓
Network Architecture					
Num of hidden layers		2	2	2	2
Synaptics	**Layers**				
	input	6	6	6	6

	Hidden 1	12	12	12	12
	Hidden 2	6	6	6	6
	output	1	1	1	1
Rescaling	**Layers**				
	input	stand	norm	stand	norm
	output	norm	norm	adj norm	adj norm
Activation	**Layers**				
	Hidden	sigmoid	sigmoid	hyp tan	hyp tan
	Output	sigmoid	sigmoid	hyp tan	hyp tan
Training	*Type*	Batch10	Batch10	Batch10	Batch10
	Algorithm	Gradient decent	Gradient decent	Gradient decent	Gradient decent
R^2		0.760	0.737	0.896	0.735
(R^2 value of the relationship between predicted Vs Target value)					

12.5.2. Model details of ANN6 BT L2 S12S6-MLP-c



Hidden layer activation function: Hyperbolic tangent

Output layer activation function: Hyperbolic tangent

Model Summary

Training	Sum of Squares Error	.313
	Relative Error	.092
	Stopping Rule Used	5 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.07
Testing	Sum of Squares Error	.257
	Relative Error	.133

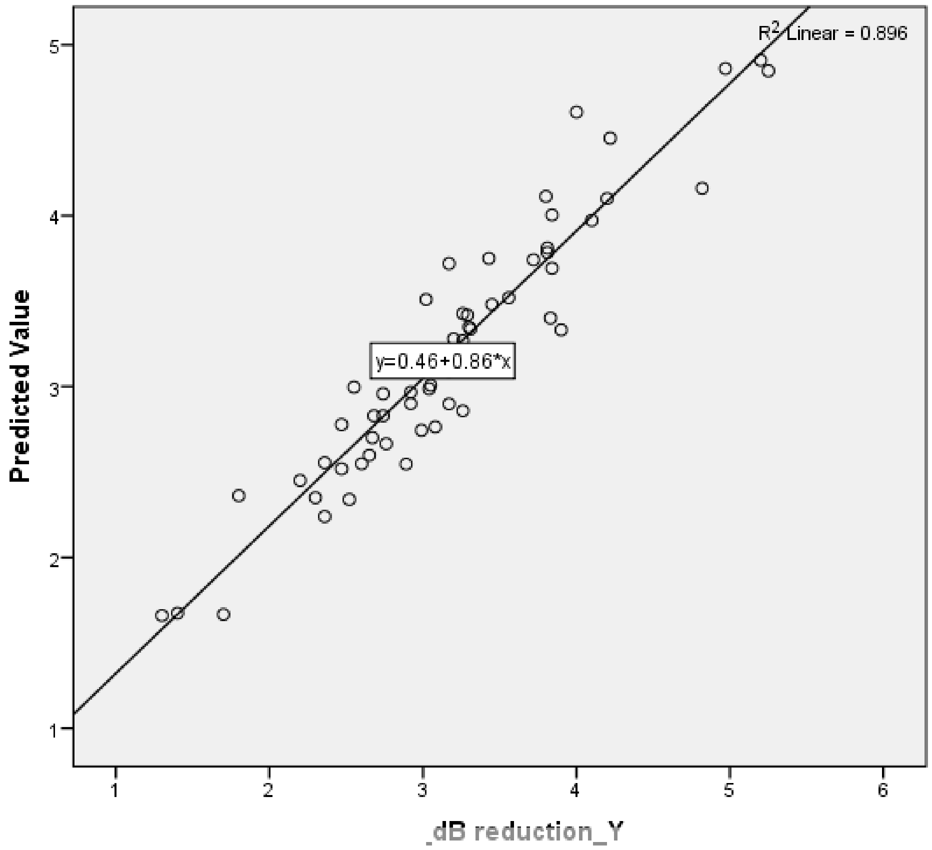
Dependent Variable: dB reduction_Y

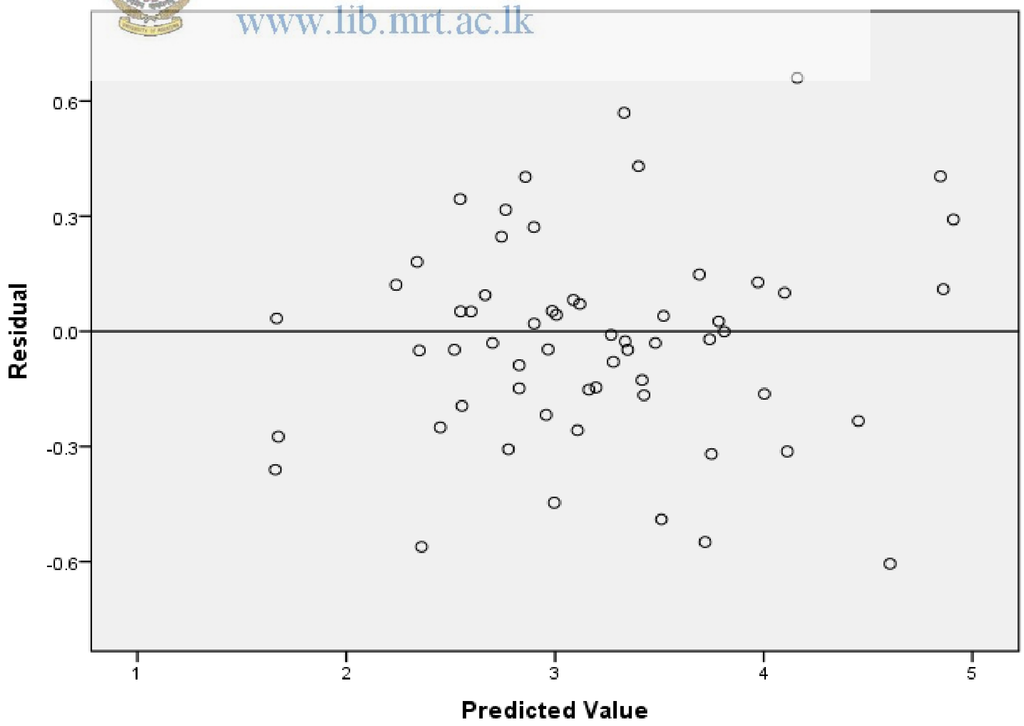
a. Error computations are based on the testing sample.

Parameter Estimates

Predictor		Predicted																				
		Hidden Layer 1												Hidden Layer 2								Output Layer
		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	H(1:6)	H(1:7)	H(1:8)	H(1:9)	H(1:10)	H(1:11)	H(1:12)	H(2:1)	H(2:2)	H(2:3)	H(2:4)	H(2:5)	H(2:6)	H(2:7)	H(2:8)	dB reduction_Y
Input Layer	(Bias)	.035	-.357	-.366	-.009	-.091	-.177	-.492	-.820	-.272	-.143	.373	-.861									
	Height_X1	-.697	.187	.410	-.317	.334	.305	-.184	.426	-.307	-.262	-.053	.235									
	Thickness_X2	-.289	-.144	-.278	.118	-.385	-.652	.297	-.406	.072	-.554	.261	.137									
	GreenCover_X3	.409	-.441	-.130	.395	.314	-.471	.343	.280	-.147	.377	.299	.381									
	Length_X4	-.048	-.147	.233	-.259	.362	.121	-.062	-.115	.292	.424	.409	-.047									
	Temp_X5	-.191	.452	-.071	.312	-.782	.221	-.269	-.282	.090	.208	.067	.174									
	Humidity_X6	-.369	-.290	-.317	-.096	.550	.186	.091	-.177	.017	-.126	.054	.037									

Hidden Layer 1	(Bias)													-.057	.166	-.267	.467	-.170	-.506	.114	.283	
	H(1:1)													-.324	.140	-.591	.200	-.580	.199	-.395	-.742	
	H(1:2)													.001	.020	-.337	-.053	-.057	-.127	-.083	.187	
	H(1:3)													.308	.603	.538	-.534	-.180	.474	.115	.687	
	H(1:4)													.063	-.019	-.645	.394	-.088	.091	.153	-.228	
	H(1:5)													-.588	.486	-.409	.308	.239	.251	.544	.132	
	H(1:6)													.009	-.040	-.112	-.477	.285	-.531	.013	.364	
	H(1:7)													.638	-.024	.175	-.215	-.024	.638	-.400	-.152	
	H(1:8)													.874	.360	-.016	-.337	-.105	-.230	-.338	-.455	
	H(1:9)													.274	.350	.407	-.029	.262	.108	.103	.010	
	H(1:10)													-.229	.117	-.330	-.270	.295	-.246	-.516	-.373	
	H(1:11)													-.039	.576	-.028	.464	-.118	.100	.097	.240	
	H(1:12)													.637	.601	-	.388	.357	-	.026	-	
Hidden Layer 2	(Bias)																					-.077
	H(2:1)																					.735
	H(2:2)																					.669
	H(2:3)																					-.344
	H(2:4)																					.604
	H(2:5)																					.033
	H(2:6)																					-.367
	H(2:7)																					.310
	H(2:8)																					.215





Dependent Variable: dB reduction_Y

12.5.3. ANN6 Result Summery

Table 12-9 R^2 values for ANN6

	Model	MLP-a	MLP-b	MLP-c	MLP-d
36	ANN6 ON L2 S6	0.770	0.723	0.824	0.674
37	ANN6 BT L2 S6	0.731	0.737	0.805	0.725
38	ANN6 ON L2 S9	0.804	0.754	0.851	0.753
39	ANN6 BT L2 S9	0.793	0.759	0.812	0.764
40	ANN6 ON L2 S12	0.683	0.757	0.822	0.754
41	ANN6 BT L2 S12	0.807	0.770	0.770	0.727
42	ANN6 ON L2 S18	0.692	0.736	0.810	0.733
43	ANN6 BT L2 S18	0.812	**0.784**	0.597	0.777
44	ANN6 ON L2 S6S3	0.731	0.706	0.808	0.688
45	ANN6 BT L2 S6S3	0.787	0.677	0.822	0.761
46	ANN6 ON L2 S9S6	**0.821**	0.728	0.794	0.772
47	ANN6 BT L2 S9S6	0.819	0.767	0.749	0.774
48	ANN6 ON L2 S12S6	0.806	0.767	0.696	0.771
49	ANN6 BT L2 S12S6	0.760	0.737	**0.886**	0.735
50	ANN6 ON L2 S18S9	0.783	0.756	0.812	**0.815**
51	ANN6 BT L2 S18S9	0.820	0.764	0.827	0.747

Best out come from ANN6 models were from ANN6 BT L2 S12S6 –MLP-c, where the R^2 value is close to 0.900.

12.6. ANN6 MODELS WITH IDENTITY FUNCTION AS OUTPUT LAYER ACTIVATION FUNCTION.

Identity function is commonly used as output layer activation function in case of a scale dependent variable as output

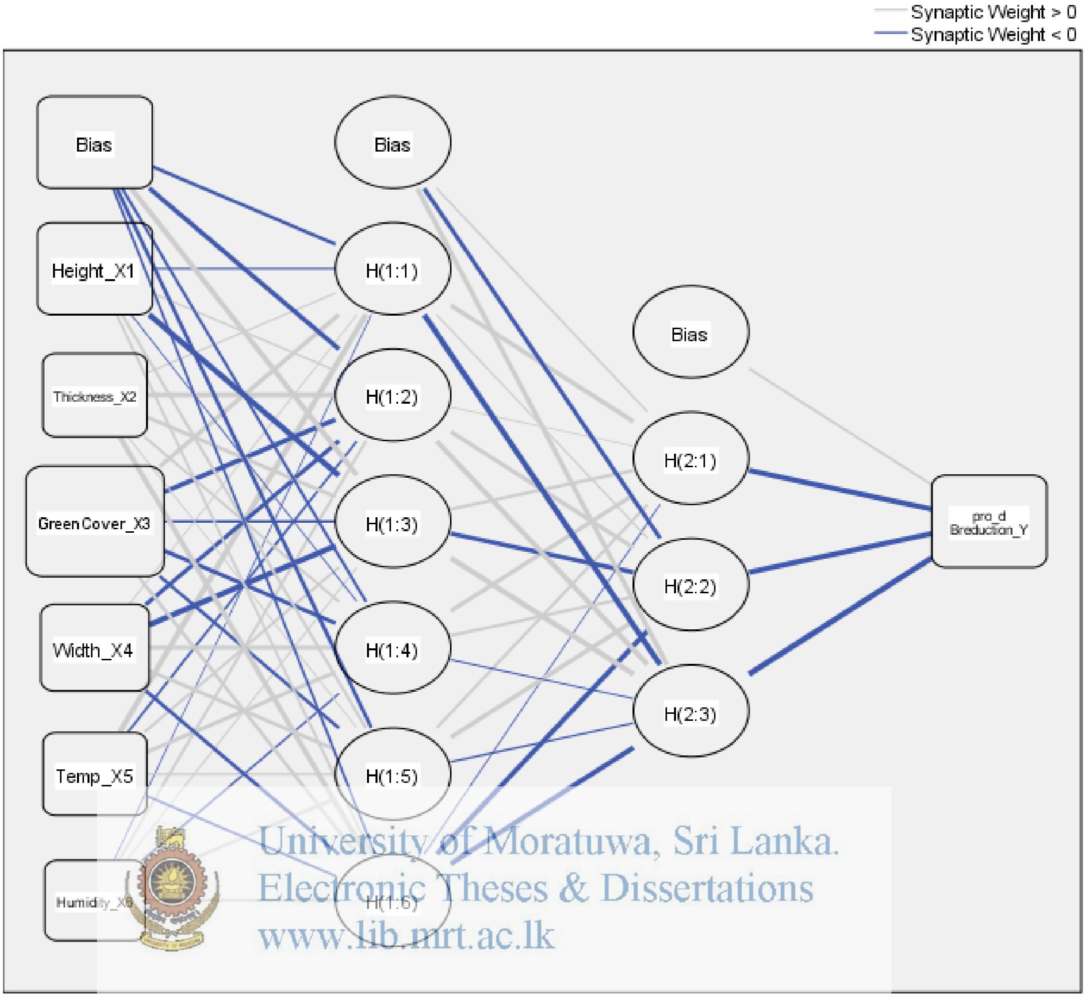
12.6.1. ANN6 -ID Two hidden layer networks

Table 12-10 Network architecture for ANN6-ID two hidden layer models

Model Architecture									
	Variables	MLP-a	MLP-b	MLP-c	MLP-d	MLP-e	MLP-f	MLP-g	MLP-h
Independent	x1	✓	✓	✓	✓	✓	✓	✓	✓
	x2	✓	✓	✓	✓	✓	✓	✓	✓
	x3	✓	✓	✓	✓	✓	✓	✓	✓
	x4	✓	✓	✓	✓	✓	✓	✓	✓
	x5	✓	✓	✓	✓	✓	✓	✓	✓
	x6	✓	✓	✓	✓	✓	✓	✓	✓
Dependent	Y	✓	✓	✓	✓	✓	✓	✓	✓

Network Architecture									
Num of hidden layers		1	1	1	1	1	1	1	1
Synaptics	**Layers**								
	input	6	6	6	6	6	6	6	6
	Hidden1	6	6	6	6	6	6	6	6
	Hidden2	3	3	3	3	3	3	3	3
	output	1	1	1	1	1	1	1	1
Rescaling	**Layers**								
	input	stand	norm	stand	norm	stand	norm	stand	norm
	output	norm	norm	non	non	stand	adj norm	non	adj norm
Activation	**Layers**								
	Hidden	sigmoid	sigmoid	sigmoid	sigmoid	hyp tan	hyp tan	hyp tan	hyp tan
	output	identity	identity	identity	identity	identity	identity	identity	identity
Training	*Type*	BT	BT	BT	BT	BT	BT	BT	BT
Type	*Algorithm*	Gradient decent	Gradient decent	Gradient decent	Gradient decent	Gradient decent	Gradient decent	Gradient decent	Gradient decent
R^2		0.763	0.661	0.709	0.767	0.900	0.776	0.826	0.721
(R^2 value of the relationship between predicted Vs Target value)									

12.6.2. Model details of ANN6 BT L2 S6S3ID-MLP-e



Hidden layer activation function: Hyperbolic tangent

Output layer activation function: Identity

Model Summary

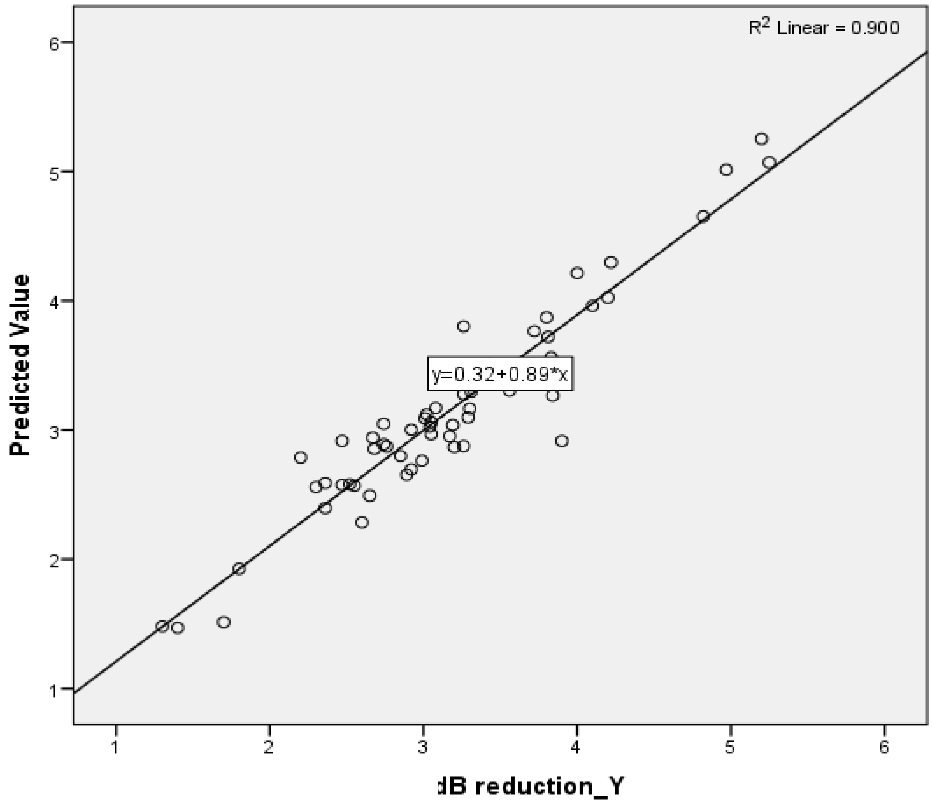
Training	Sum of Squares Error	1.165
	Relative Error	.057
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.02
Testing	Sum of Squares Error	1.772
	Relative Error	.203

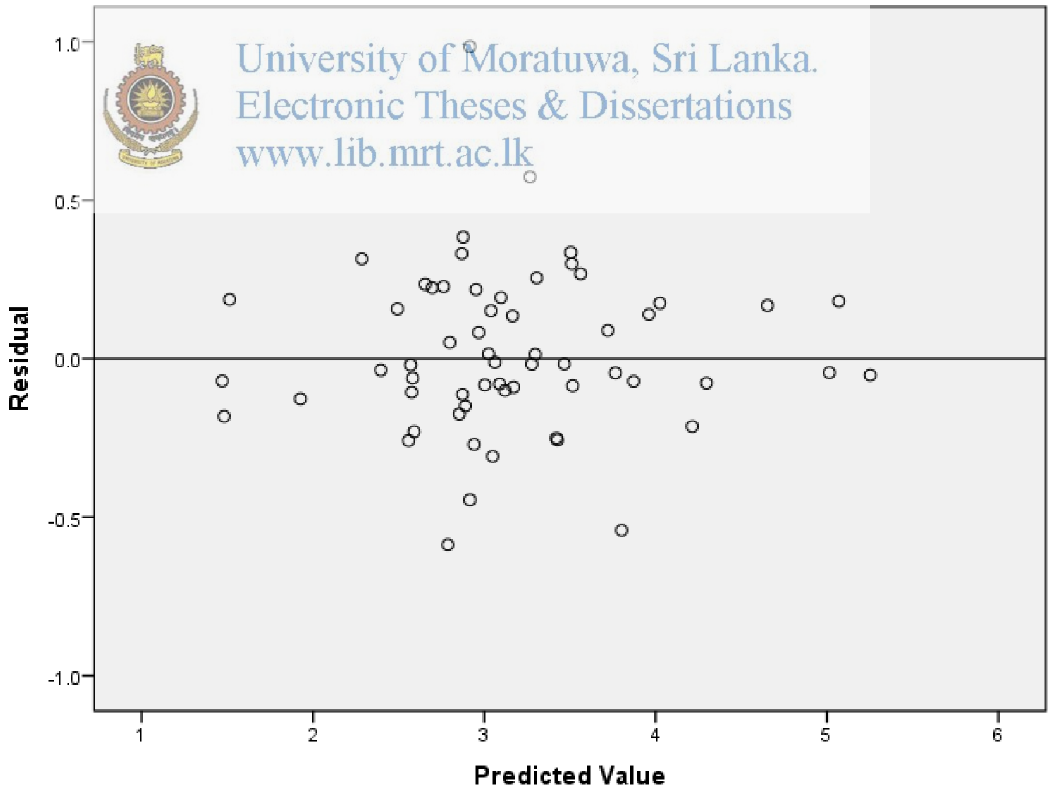
Dependent Variable: dB reduction_Y

a. Error computations are based on the testing sample.

Parameter Estimates

Predictor		Predicted									
		Hidden Layer 1						Hidden Layer 2			Output Layer
		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	H(1:6)	H(2:1)	H(2:2)	H(2:3)	dBreduction_Y
Input Layer	(Bias)	-.377	-.604	.717	-.303	-.425	-.236				
	Height_X1	-.103	.198	-1.345	-.017	.307	.252				
	Thickness_X2	.117	.665	.460	.293	.033	.709				
	GreenCover_X3	.580	-.660	-.232	-.527	-.356	.385				
	Length_X4	.063	-.528	-.838	.466	.410	-.407				
	Temp_X5	.773	-.230	.296	.517	.199	-.208				
	Humidity_X6	-.001	.295	.091	-.122	.382	.340				
Hidden Layer 1	(Bias)							.205	-.563	.622	
	H(1:1)							.617	.119	-.913	
	H(1:2)							.023	.576	.712	
	H(1:3)							.366	-.594	.768	
	H(1:4)							.574	.344	-.072	
	H(1:5)							.315	.594	-.125	
	H(1:6)							-.015	-.699	-.708	
Hidden Layer 2	(Bias)										.247
	H(2:1)										-.762
	H(2:2)										-.761
	H(2:3)										-1.750





Dependent Variable: dB reduction_Y

12.6.3. ANN6ID Result summery

Table 12-11 R^2 values for ANN6 ID

	Model	MLP-a	MLP-b	MLP-c	MLP-d	MLP-e	MLP-f	MLP-g	MLP-h
52	ANN6 ON L1 S6ID	0.830	0.772	0.812	0.800	0.802	0.775	0.845	0.726
53	ANN6 BT L1 S6ID	0.699	0.738	0.830	0.787	0.763	0.740	**0.872**	0.779
54	ANN6 BT10 L1 S6ID	0.839	0.770	0.757	0.731	0.826	0.745	0.828	**0.816**
55	ANN6 ON L1 S9ID	0.804	0.705	0.813	0.804	0.842	0.778	0.831	0.776
56	ANN6 BT L1 S9ID	0.790	0.574	0.704	0.757	0.791	0.774	0.868	0.698
57	ANN6 BT10 L1 S9ID	0.831	0.762	0.820	0.800	0.824	0.762	0.817	0.767
58	ANN6 ON L1 S12ID	0.810	0.760	0.794	0.775	0.820	0.756	0.817	0.731
59	ANN6 BT L1 S12ID	0.775	0.771	0.812	0.762	0.816	0.787	0.804	0.761
60	ANN6 BT10 L1 S12ID	0.836	0.768	0.732	0.773	0.758	0.772	0.822	0.755
61	ANN6 ON L2 S6S3ID	0.769	0.763	0.825	0.785	0.762	0.796	0.791	0.664
62	**ANN6 BT L2 S6S3ID**	0.763	0.661	0.709	0.767	**0.900**	0.776	0.826	0.721
63	ANN6 BT10 L2 S6S3ID	0.761	0.708	0.803	0.803	0.852	0.759	0.766	0.792
64	ANN6 ON L2 S6ID	0.755	0.757	0.743	0.788	0.738	0.724	0.823	0.697
65	ANN6 BT L2 S6ID	0.780	0.757	0.827	0.784	0.847	0.776	0.773	0.595
66	ANN6 BT10 L2 S6ID	0.796	0.765	0.677	0.736	0.738	**0.801**	0.828	0.767
67	ANN6 ON L2 S6S9ID	0.813	0.733	0.761	**0.816**	0.843	0.755	0.752	0.788
68	ANN6 BT L2 S6S9ID	0.760	0.577	0.714	0.768	0.824	0.780	0.817	0.737
69	ANN6 BT10 L2 S6S9ID	0.781	0.754	0.819	0.746	0.808	0.708	0.839	0.766

12.7. COMPARISON OF ANN RESULTS

Using the performance evaluation method explained in 12.1 neural networks which gives most promising results were identified and further modified.

It was observed that the models with hyperbolic tan function as activation function yields better results. From the training methods it was observed that the batch training methods yielding better results for the particular scenario. Table 12-9,Table 12-11,Table 12-7. Models mentioned in Table 12-12 has shown better performance.

Table 12-12 Comparison of ANN results

	Model	R^2	Sums of Square Error (SSE)		Root Mean Square Error (RMSE)		Relative Error	
			Training	Testing	Training	Testing	Training	Testing
01	ANN4 ON L2 S8-MLP-c	0.849	0.405	0.372	0.082	0.079	0.128	0.283
02	ANN6 BT L2 S6S3-MLP-c	0.835	0.647	0.221	0.104	0.061	0.186	0.172
03	ANN6 BT L2 S6S4-MLP-c	0.840	0.653	0.194	0.104	0.057	0.162	0.245

04	ANN6 BT L2 S12S6-MLP-c	0.841	0.525	0.138	0.094	0.048	0.313	0.255
05	ANN6 BT L2 S12S8-MLP-c	0.904	0.207	0.299	0.059	0.071	0.066	0.155
06	ANN6 BT L1 S6 ID-MLP-g	0.872	1.906	0.643	0.178	0.104	0.129	0.135
07	ANN6 BT L1 S9 ID-MLP-g	0.868	1.063	1.317	0.133	0.148	0.094	0.275
08	ANN6 BT10 L2 S6S3 ID-MLP-e	0.900	1.165	1.772	0.139	0.172	0.057	0.203
09	ANN6 BT10 L2 S12S6 ID-MLP-e	0.882	1.947	1.502	0.180	0.158	0.091	0.211

12.7.1. Residual plots of ANN models

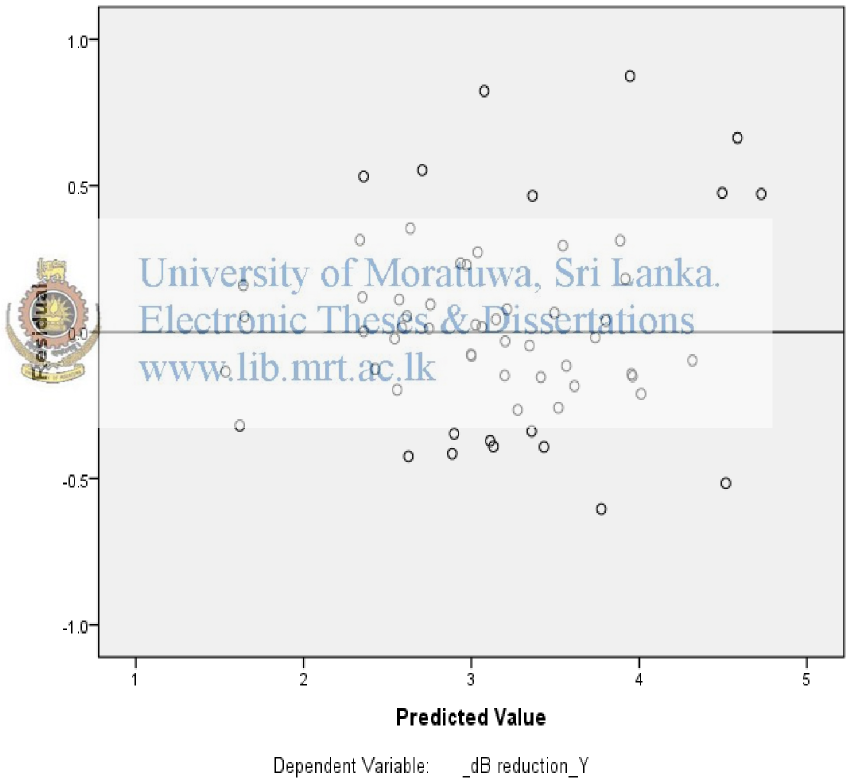


Figure 12-1. Residual plot of ANN4 ON L2 S8-MLP-c

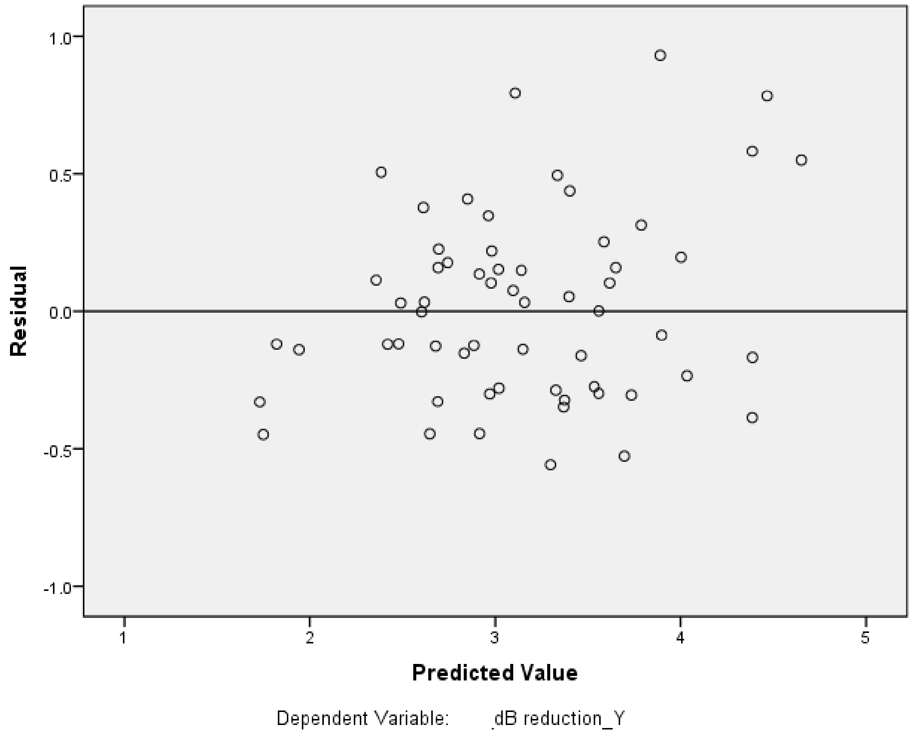


Figure 12-2. Residual plot of ANN6 BT L2 S6S3-MLP-c

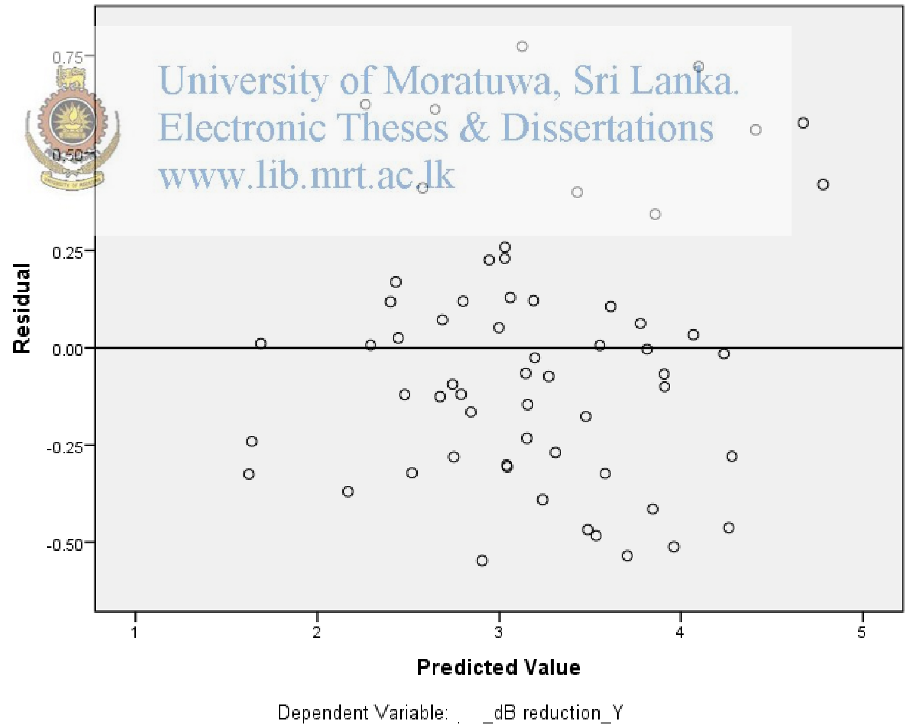


Figure 12-3 Residual plot of ANN6 BT S2 S6S4-MLP-c

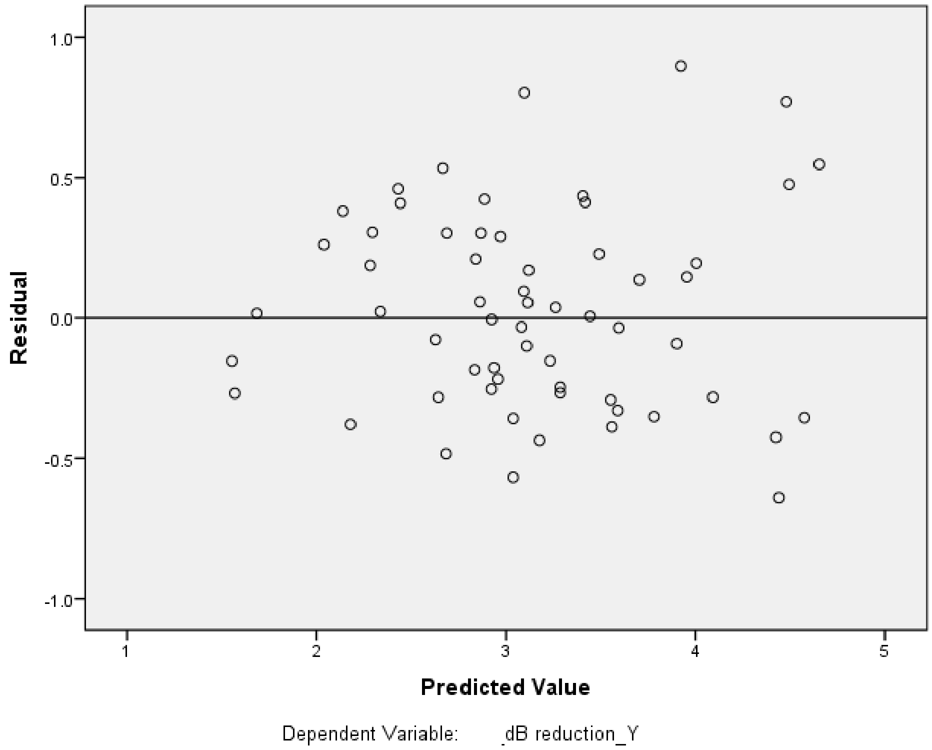


Figure 12-4 Residual plot of ANN6 BT10 L2 S12S6-MLP-c

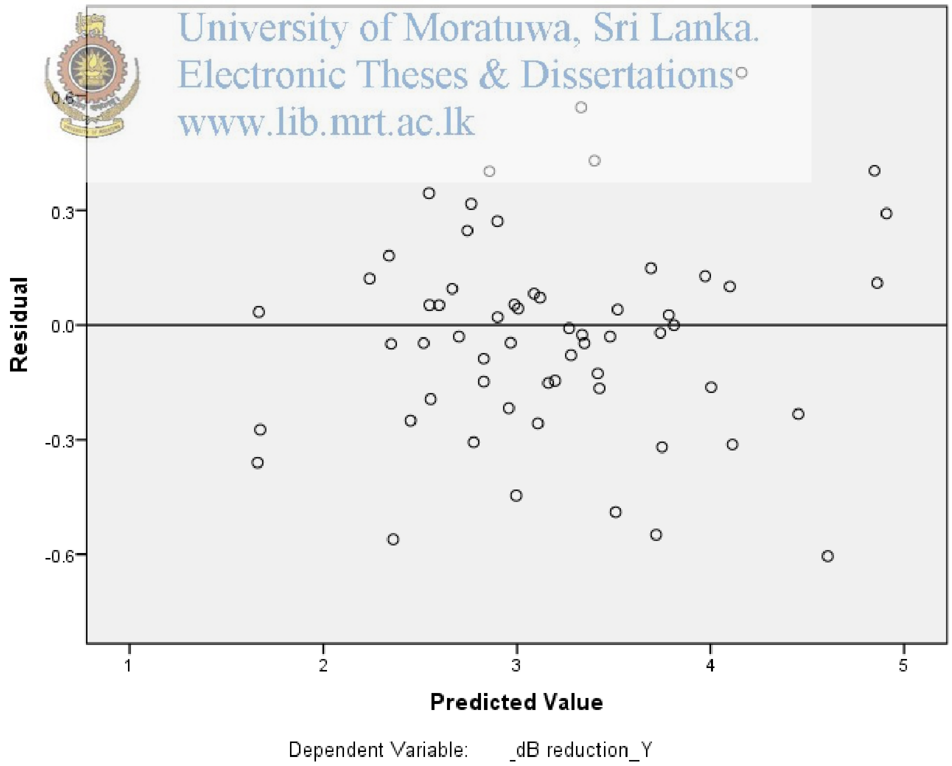


Figure 12-5 Residual plot of ANN6 BT L2 S12S8-MLP-c

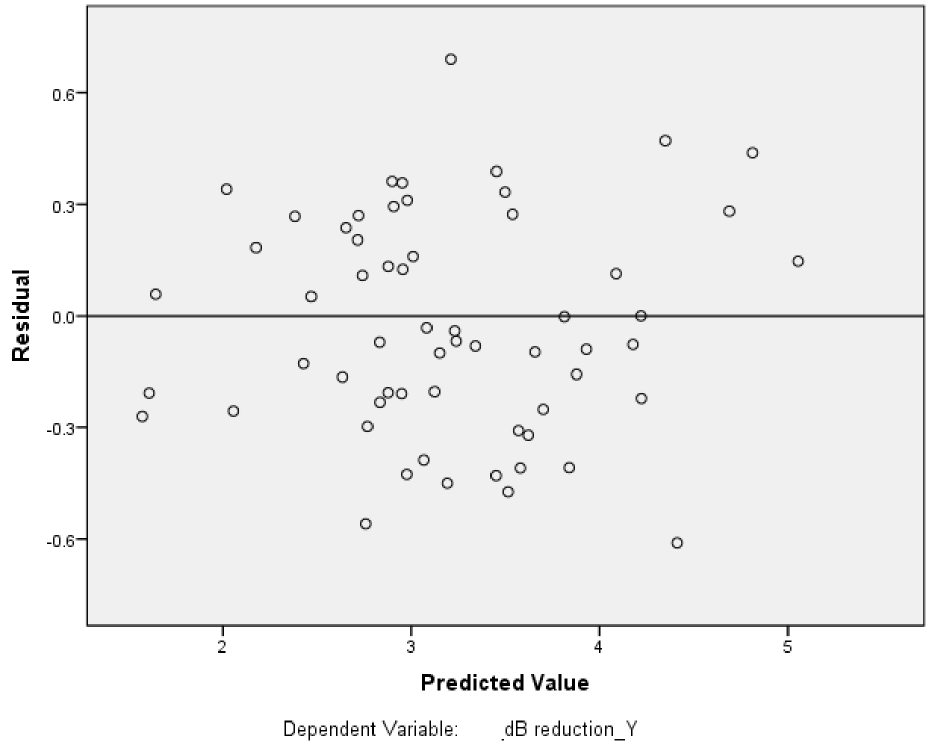


Figure 12-6 Residual plot of ANN6 BT L1 S6 ID-MLP-g

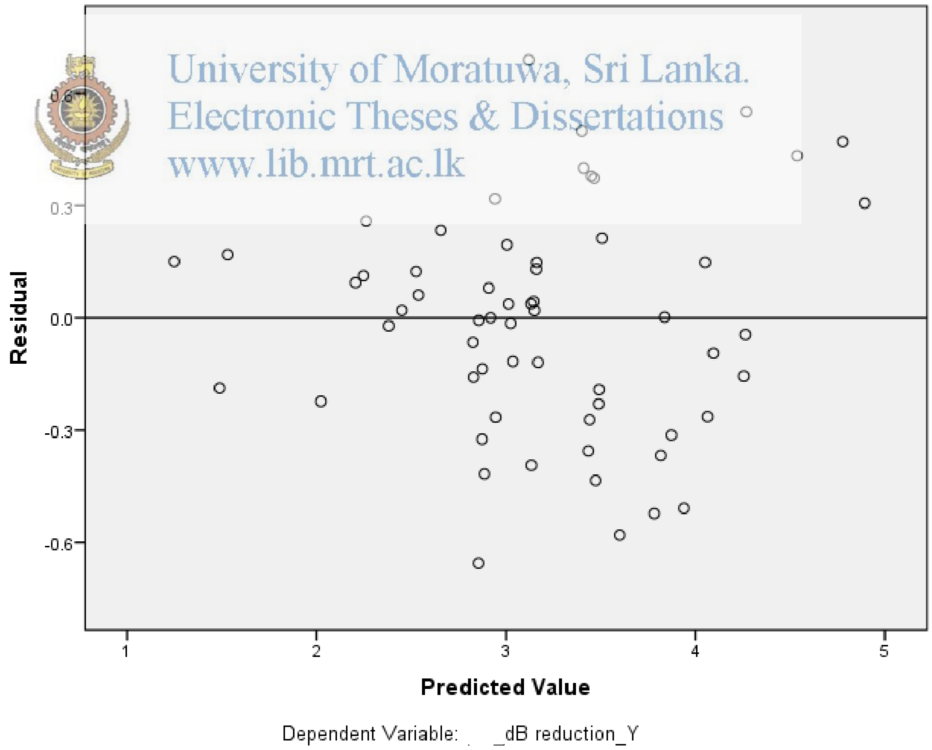


Figure 12-7 Residual plot of ANN6 BT L1 S9 ID-MLP-g

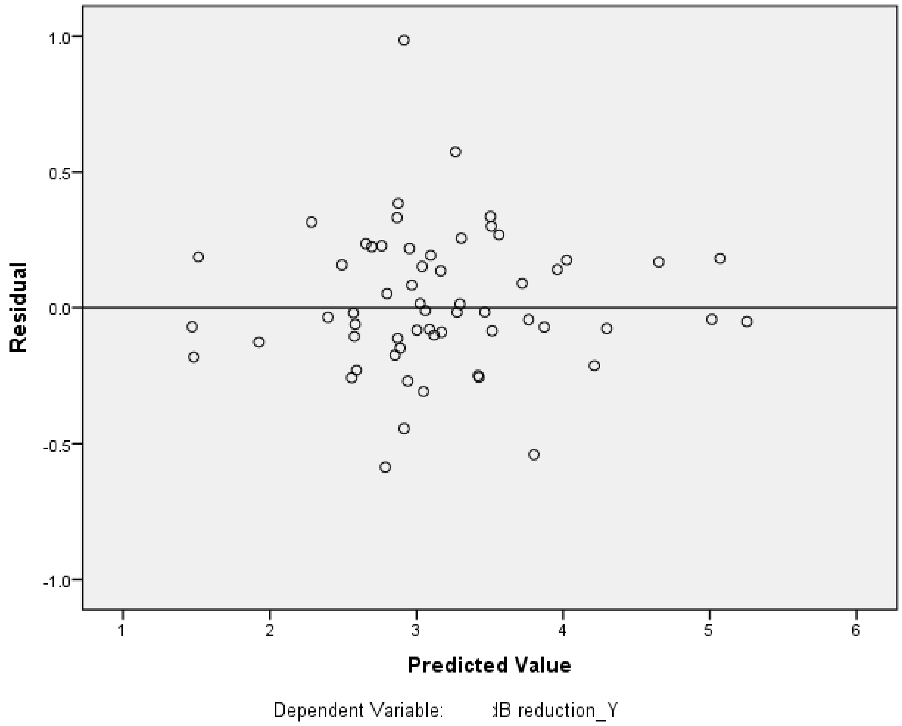


Figure 12-8 Residual plot of ANN6 BT10 L2 S6S3 ID-MLP-e

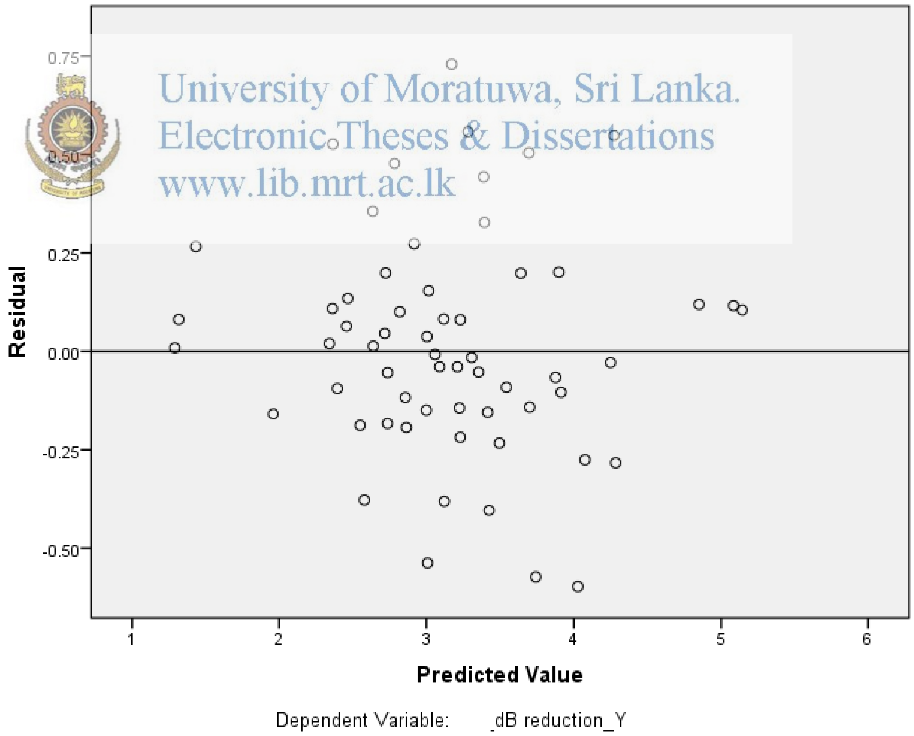


Figure 12-9 Residual plot of ANN6 BT10 L2 S12S6 ID-MLP-e

12.7.2. Conclusion of comparison of models

All the residual plots are not showing any pattern hence residual plots shows that the selected models are not bias.

From the results promising R^2 are given by the **ANN6 BT10 L2 S6S3 ID-MLP-e** and **ANN6 BT L2 S12S8-MLP-c** explaining about 90%of the variance in the model .The RMSE and SSE of the above two models are smaller and shows a higher predictive accuracy. Comparatively increasing the number of synaptic weights in the model **ANN6 BT10 L2 S6S3 ID-MLP-e** to constitute **ANN6 BT10 L2 S12S6 ID-MLP-e** has not proved significant improvement in the model. Hence considering the complexness of the two models, **ANN6 BT10 L2 S6S3 ID-MLP-e** can be considered to be the economical one.

However even with a single hidden layer **ANN6 BT L1 S6 ID-MLP-g** model has proven to be effective and match the performance of the **ANN6 BT10 L2 S6S3 ID-MLP-e** model closely.

We can conclude that model **ANN6 BT L2 S12S8-MLP-c** or **ANN6 BT10 L2 S6S3 ID-MLP-e** would yield better predictions. The **ANN6 BT L2 S12S8-MLP-c** model has a good overall performance with respect to R^2, SSE and RMSE. This models shows the highest R^2 value of 0.904 and lowest RMSE.

Table 12-13. Details of best ANN6 models

	Variables	ANN6 BT10 L2 S12S8-MLP-c	ANN6 BT L2 S6S3 ID-MLP-e	ANN6 BT10 L2 S12S6 ID-MLP-e	ANN6 BT L1 S6 ID-MLP-g
Independent	x1	✓	✓	✓	✓
	x2	✓	✓	✓	✓
	x3	✓	✓	✓	✓
	x4	✓	✓	✓	✓
	x5	✓	✓	✓	✓
	x6	✓	✓	✓	✓
Dependent	**Y**	✓	✓	✓	✓
Network Architecture					
Num of hidden layers		1	1	1	1
Synaptics	**Layers**				
	input	6	6	6	6
	layer1	12	6	12	6
	layer2	8	3	6	0
	output	1	1	1	1
Rescaling	**Layers**				
	input	stand	stand	stand	stan
	output	adj norm	stand	stand	non

Activation	**Layers**				
	Hidden	hyp tan	hyp tan	hyp tan	hyp tan
	output	hyp tan	identity	identity	identity
Training	*Type*	BT10	BT	BT10	BT
Type	*Algorithm*	Gradient decent	Gradient decent	Gradient decent	Gradient decent
model ID		***ANN6 -A***	***ANN6 -B***	***ANN6-C***	***ANN6-D***
R^2 Filtered		0.904	0.900	0.882	0.872
(R^2 value of the relationship between predicted Vs Target value)					

13.COMPARISON OF ACTUAL AND PREDICTED RESULTS FROM VARIOUS MODELS

Comparison is done to reveal the prediction capability of MLR and ANN models.

The best MLR model is MLR-4 shown in Table 11-19. The best two ANN models are **ANN6 BT L2 S12S8-MLP-c** and **ANN6 BT10 L2 S6S3 ID-MLP-e.** Comparison of models are shown in Figure 13-1.

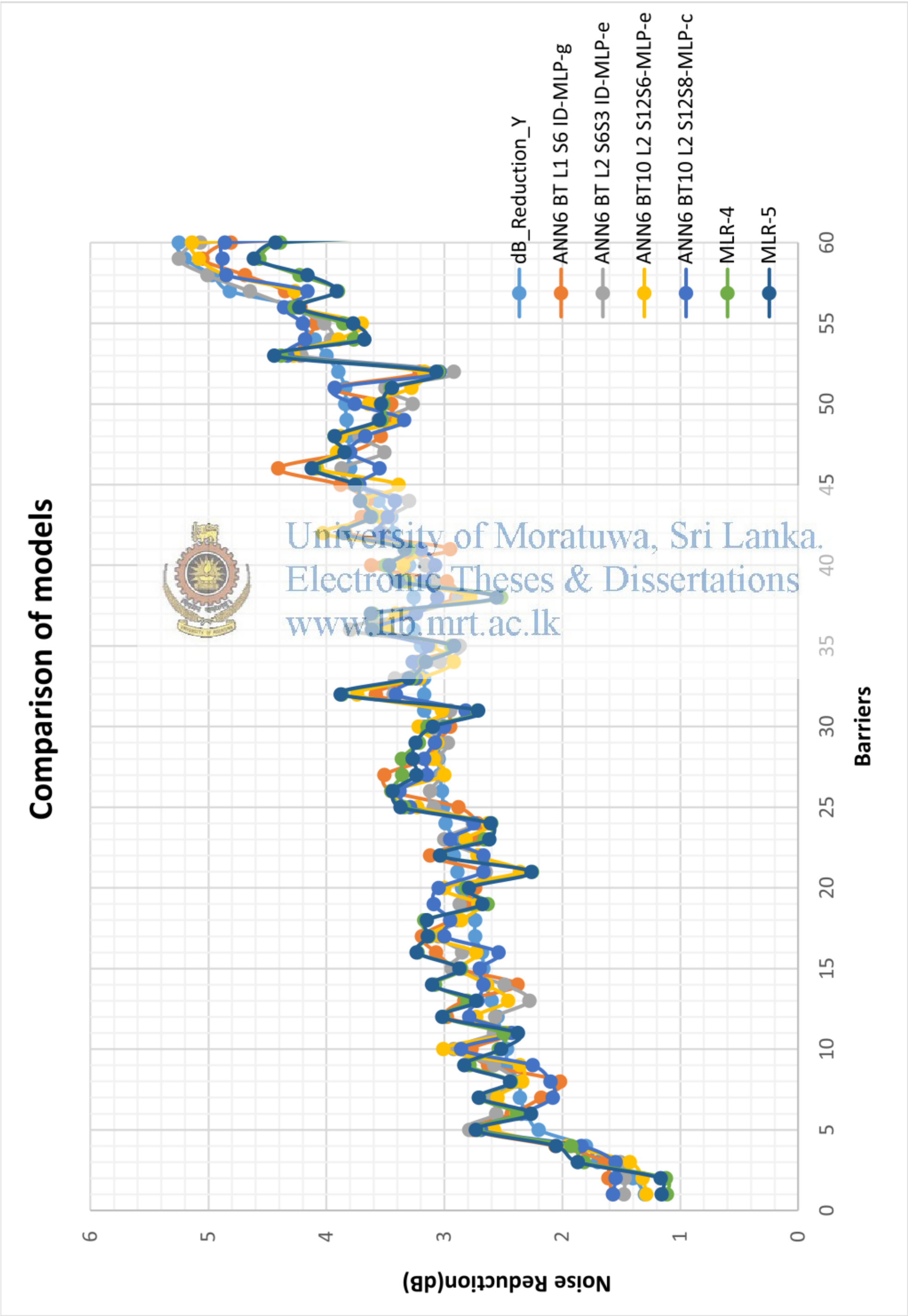


Figure 13-1Comparison of models results with actual

14.DESIGNING TREE BARRIERS FOR NOISE ATTENUATION

From using the created ANN models and MLR models, performance of trail barriers can be evaluated. Configuration of proposed trail barriers are shown in Table 14-1.

Table 14-1 Proposed trail barriers

No	Barrier	Length_ X4 (m)	Height_ X1 (m)	Thickness_ X2 (m)	Temp_ X5 (C°)	Humidity_ X6	GreenCover_ X3 (%)
1	B01	5.00	0.5	0.30	30	50.00	80.00
2	B02	5.00	1	0.60	30	50.00	80.00
3	B03	5.00	1.5	0.90	30	50.00	80.00
4	B04	5.00	2	1.20	30	50.00	80.00
5	B05	5.00	2.5	1.50	30	50.00	80.00
6	B06	10.00	0.5	0.30	30	50.00	90.00
7	B07	10.00	1	0.60	30	50.00	90.00
8	B08	10.00	1.5	0.90	30	50.00	90.00
9	B09	10.00	2	1.20	30	50.00	90.00
10	B10	10.00	2.5	1.50	30	50.00	90.00

Evaluated performance of proposed trail barriers are shown in Figure 14-1.

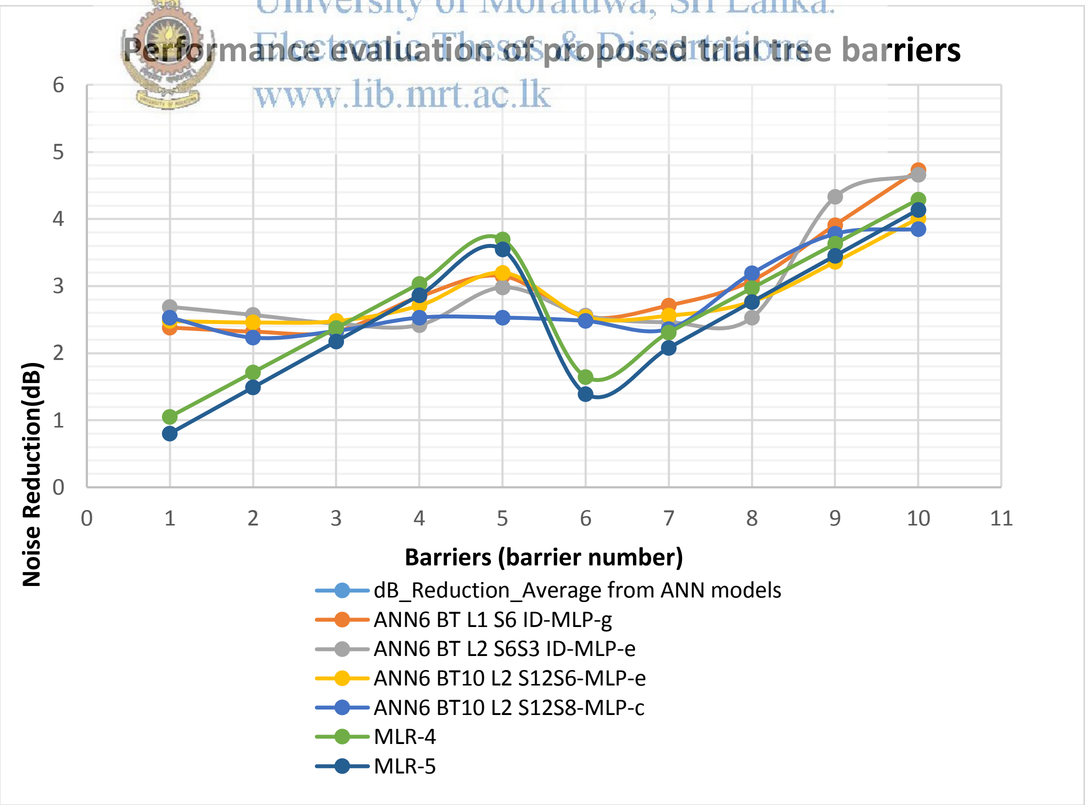


Figure 14-1 . Performance of trail tree barriers

To make an influence which is sensible to the human hearing in reducing sound levels, sound levels should be at least reduced by 3 dB. The hearing pattern of human ear is sensitive in a pattern equal to decibel scale. The goal should be to propose tree belts which at least capable of reducing noise level by 3dB. However according to the methodology of this research this minimum decibel reduction is expected beyond 1.5m away from the barrier. Since the aim is to provide a barrier which is suitable for urban condition the dimensions of the barrier should be carefully selected.

Both MLR and ANN models suggest that to exceed the target attenuation level and ensure the performance of tree belts a tree belt should be at least close to 2m of height or more. When considering the Green cover of the tree belt it should be close to 90% or more. Further analysis was done using different configuration of trail barriers. The main focus is to rectify the effect of green cover and height of the proposed barrier. The thickness of the barrier has kept to 1m. (it is considered that due to practical reasons in planting trees and land scarcity of the urban society 1m thickness allocation for the barrier should be the maximum thickness allocation which can be reasonably given for .It was assumed that the 1m thickness would facilitate the growing medium and maintaining tree barrier, watering, providing any artificial structure if required to support the barrier and would provide better separation from other structures near the barrier. Hence following barrier configurations were suggested. Temperature and humidity levels in the design was kept constant throughout.

Table 14-2 Configuration for proposed trail natural barriers

No	Sheet_ X7	Length_ X4 (m)	Height_ X1 (m)	Thickness_ X2 (m)	Temp_ X5 (C°)	Humidity_ X6	GreenCover_ X3 (%)
1	B01	5.00	0.5	1.00	27	70	75.00
2	B02	5.00	1	1.00	27	70	75.00
3	B03	5.00	1.5	1.00	27	70	75.00
4	B04	5.00	2	1.00	27	70	75.00
5	B05	5.00	2.5	1.00	27	70	75.00
6	B06	5.00	3	1.00	27	70	75.00
7	B07	5.00	0.5	1.00	27	70	80.00
8	B08	5.00	1	1.00	27	70	80.00
9	B09	5.00	1.5	1.00	27	70	80.00
10	B10	5.00	2	1.00	27	70	80.00
11	B11	5.00	2.5	1.00	27	70	80.00
12	B12	5.00	3	1.00	27	70	80.00
13	B13	5.00	0.5	1.00	27	70	85.00

No	Sheet_ X7	Length_ X4 (m)	Height_ X1 (m)	Thickness_ X2 (m)	Temp_ X5 (Cº)	Humidity_ X6	GreenCover_ X3 (%)
14	B14	5.00	1	1.00	27	70	85.00
15	B15	5.00	1.5	1.00	27	70	85.00
16	B16	5.00	2	1.00	27	70	85.00
17	B17	5.00	2.5	1.00	27	70	85.00
18	B18	5.00	3	1.00	27	70	85.00
19	B19	5.00	0.5	1.00	27	70	90.00
20	B20	5.00	1	1.00	27	70	90.00
21	B21	5.00	1.5	1.00	27	70	90.00
22	B22	5.00	2	1.00	27	70	90.00
23	B23	5.00	2.5	1.00	27	70	90.00
24	B24	5.00	3	1.00	27	70	90.00
25	B25	5.00	0.5	1.00	27	70	95.00
26	B26	5.00	1	1.00	27	70	95.00
27	B27	5.00	1.5	1.00	27	70	95.00
28	B28	5.00	2	1.00	27	70	95.00
29	B29	5.00	2.5	1.00	27	70	95.00
30	B30	5.00	3	1.00	27	70	95.00
31	B31	5.00	0.5	1.00	27	70	100.00
32	B32	5.00	1	1.00	27	70	100.00
33	B33	5.00	1.5	1.00	27	70	100.00
34	B34	5.00	2	1.00	27	70	100.00
35	B35	5.00	2.5	1.00	27	70	100.00
36	B36	5.00	3	1.00	27	70	100.00
37	B37	10.00	0.5	1.00	27	70	75.00
38	B38	10.00	1	1.00	27	70	75.00
39	B39	10.00	1.5	1.00	27	70	75.00
40	B40	10.00	2	1.00	27	70	75.00
41	B41	10.00	2.5	1.00	27	70	75.00
42	B42	10.00	3	1.00	27	70	75.00
43	B43	10.00	0.5	1.00	27	70	80.00
44	B44	10.00	1	1.00	27	70	80.00
45	B45	10.00	1.5	1.00	27	70	80.00
46	B46	10.00	2	1.00	27	70	80.00

No	Sheet_ X7	Length_ X4 (m)	Height_ X1 (m)	Thickness_ X2 (m)	Temp_ X5 (Cº)	Humidity_ X6	GreenCover_ X3 (%)
47	B47	10.00	2.5	1.00	27	70	80.00
48	B48	10.00	3	1.00	27	70	80.00
49	B49	10.00	0.5	1.00	27	70	85.00
50	B50	10.00	1	1.00	27	70	85.00
51	B51	10.00	1.5	1.00	27	70	85.00
52	B52	10.00	2	1.00	27	70	85.00
53	B53	10.00	2.5	1.00	27	70	85.00
54	B54	10.00	3	1.00	27	70	85.00
55	B55	10.00	0.5	1.00	27	70	90.00
56	B56	10.00	1	1.00	27	70	90.00
57	B57	10.00	1.5	1.00	27	70	90.00
58	B58	10.00	2	1.00	27	70	90.00
59	B59	10.00	2.5	1.00	27	70	90.00
60	B60	10.00	3	1.00	27	70	90.00
61	B61	10.00	0.5	1.00	27	70	95.00
62	B62	10.00	1	1.00	27	70	95.00
63	B63	10.00	1.5	1.00	27	70	95.00
64	B64	10.00	2	1.00	27	70	95.00
65	B65	10.00	2.5	1.00	27	70	95.00
66	B66	10.00	3	1.00	27	70	95.00
67	B67	10.00	0.5	1.00	27	70	100.00
68	B68	10.00	1	1.00	27	70	100.00
69	B69	10.00	1.5	1.00	27	70	100.00
70	B70	10.00	2	1.00	27	70	100.00
71	B71	10.00	2.5	1.00	27	70	100.00
72	B72	10.00	3	1.00	27	70	100.00

14.1. ACOUSTIC PERFORMANCE EVALUATION OF PROPOSED TRAIL BARRIERS USING ANN6 MODEL

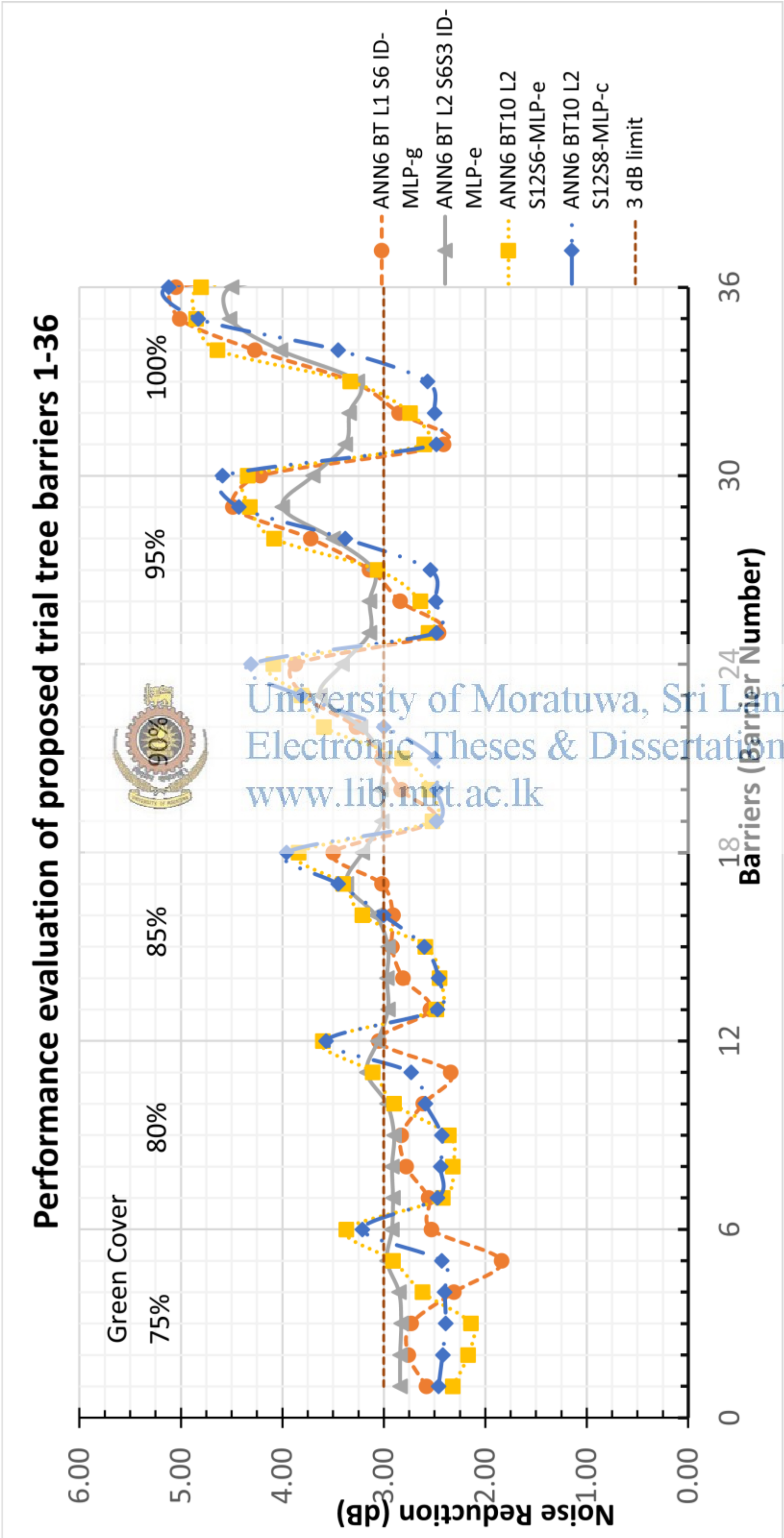


Figure 14-2. Performance evaluation of trail barrier 1-36

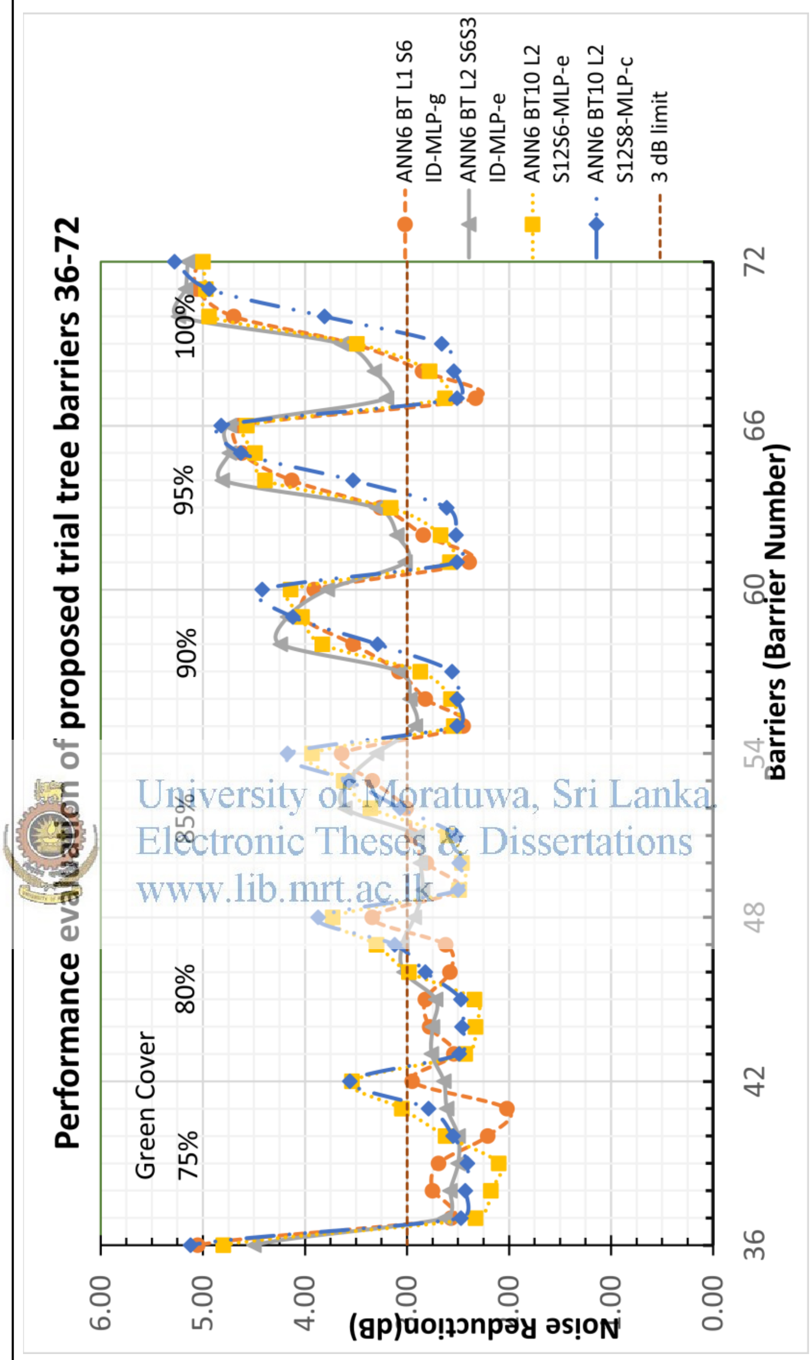


Figure 14-3 Performance evaluation of trail barrier 37-72

According to the performance evaluation ANN6-A model can be recommended as a useful model to evaluate the acoustic performance of natural barriers. ANN6-B model even with a good R^2 value and low RMSE value doesn't seems to be constant in predicting natural barrier acoustic performance.

ANN6-C and ANN6-D models show a similar pattern of prediction with respect to ANN6-A model, hence can be used to validate the ANN6-A model. Green cover act as a very vital factor deciding the acoustic performance of a natural barrier. Below green cover 85% , ANN6 models predictions seems to be in consistent and only ANN6-A model seems to keep a general pattern of prediction below 85% of green cover.

The target was to achieve at least 3dB reduction from a natural barrier while controlling it dimensions to suit the urban conditions.

Trial results suggest that use of barrier height close to 2m or more could provide the required 3dB reduction or more.(human preference for the barrier heights lays in this range).Trail results concludes that to ensure the proper performance levels the natural barrier, green cover should be equal or more than 85%.

The trail barrier results shows that there's a possibility of reaching equal or more than 5dB reduction from a natural barrier close to 100% of green cover and height exceeding 2m.

14.2. ENERGY REDUCTION EVALUATION FOR DROP OF DECIBEL

Sound intensity (I) is defined as the sound power (P) per unit area. Hence ($I \propto P$).

A situation where sound level dB1 is dropped to dB2 and the sound level drop is indicated as $(dB1 - dB2) = \Delta dB$.power of sound will be reduced from P_1 to P_2 and theoretical reduction in sound energy can be calculated as follows. Sound energy reduction as a percentage is shown in Eq: 22

$$dB1 = 10\log(\frac{P_1}{P_o})$$

$$dB2 = 10\log(\frac{P_2}{P_o})$$

$$(dB1 - dB2) = \Delta dB = 10\log\left(\frac{P_1}{P_2}\right)$$

$$10^{\frac{\Delta dB}{10}} = \frac{P_1}{P_2} = k$$

$$sound\ energy\ reduction\ \% = \left(\frac{P_1 - P_2}{P_1}\right)\% = \left(1 - \frac{1}{k}\right)\%$$

Eq: 22

Table 14-3 .Sound energy reduction and decibel reduction chart

	Decibel reduction from initial noise level (dB)	Sound energy reduction from initial level as a percentage (%)
01	1	20.57%
02	2	36.90%
03	3	49.88%
04	4	60.19%
05	5	68.38%

15.RESULTS FROM TESTING ARTIFICIAL BARRIERS FOR ACOUSTIC PERFORMANCE

Same procedure which has been used to evaluate natural barriers was carried out for evaluating acoustic performance of artificial barriers by omitting the green cover measurement. In this case commonly used boundary walls made out of brick or blocks were defined in artificial barriers.

Table 15-1 Artificial barrier test results

No	Sheet	Length (m)	Height (m)	Thickness (m)	Temp (°C)	Humidity (%)	Type	dB reduction
76	B76	8	2.25	0.2	30	71	Artificial	6.19
77	B77	10	1.5	0.15	31	71	Artificial	4.41
78	B78	5	1.4	0.1	31	71	Artificial	4.02
79	B79	7	1.1	0.1	31	70	Artificial	3.08
80	B80	11	1.6	0.1	31	70	Artificial	4.87
81	B81	6	1.35	0.12	29	70	Artificial	3.2
82	B82	12	2	0.25	30	72	Artificial	7.2
83	B83	21	1.9	0.2	30	72	Artificial	7.45
84	B84	15	1.45	0.15	30	72	Artificial	3.91
85	B85	12	1.9	0.1	30	72	Artificial	5.02
86	B86	8	1.65	0.1	31	71	Artificial	5.12
87	B87	10	1.9	0.2	30	71	Artificial	6.56
88	B88	10	1.5	0.15	30	72	Artificial	3.41
89	B89	12	2	0.1	30	72	Artificial	5.8

No	Sheet	Length (m)	Height (m)	Thickness (m)	Temp (°C)	Humidity (%)	Type	dB reduction
90	B90	7	1.55	0.1	30	71	Artificial	4.31
91	B91	10	2	0.18	30	71	Artificial	7.79
92	B92	10	1.25	0.15	31	70	Artificial	3.58
93	B93	10	2	0.15	30	71	Artificial	6.44
94	B94	7	1.45	0.15	30	70	Artificial	4.92
95	B95	6	1.35	0.12	29	70	Artificial	3.59
96	B96	15	1.8	0.2	30	71	Artificial	7.14
97	B97	10	1.85	0.2	30	71	Artificial	7.55
98	B98	11	1.75	0.15	31	71	Artificial	5.32
99	B99	8	1.65	0.2	30	71	Artificial	4.55
100	B100	9	1.65	0.15	30	71	Artificial	5.36

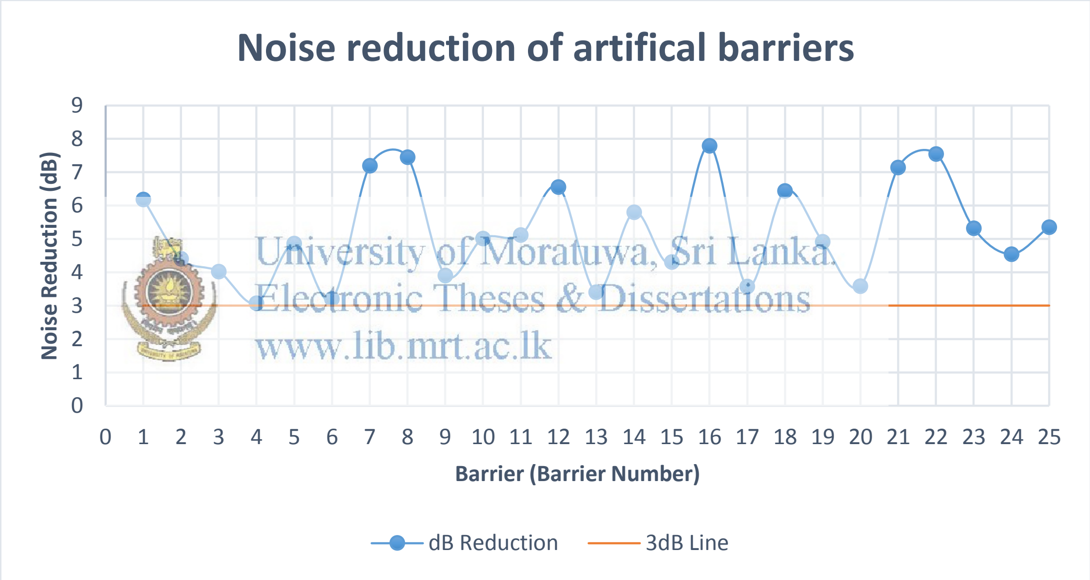


Figure 15-1 Noise Reduction from artificial barriers

16.DISCUSSION.

The findings form the research mainly divide in to two areas. The results and findings from the questionnaire survey and the results and findings from field testing conducted on natural barriers.

16.1. QUESTIONNAIRE SURVEY RESULTS AND ACTUAL NOISE MEASUREMENTS IN URBAN AREAS.

Human perception regarding the level of noise disturbance was revealed from the research in selected urban areas. Residents living within the 2.5 km radius from the main city are the most disturbed by the sound levels. As evidence by a 64% of residents who live within 1 km radius have indicated exposure to high sound levels. Totally, 44% of moderate to high sound level disturbance ratings are from the respondents living in the radius of 5 km from the city area. Closer to the city more severe the sound problem according to human perspective. If distance from the main closest city considered as a measurement of urbanization, noise level ratings increases with the urbanization. This may be the reason where nearly 70% of respondents, rate noise level in the nearest city to be disturbing.

Occurrence of excessive sound levels are in line with the time and durations of traffic pattern in the Western province. Morning peak hours from 7.00-9.00 A.M was claimed as the noisiest period. This can be clearly proven by comparing the responses for starting time of high sound level occurrence with trip generation pattern in Western province in Figure 5-3.

Evening peak 5.00-7.00 P.M and intermediate peak 1.00-3.00 P.M indicates the durations of noisy periods which are not critical as morning peak. According to actual noise levels measured in urban areas mentioned in Table 7-1 it is evident that the actual noise levels are well above the permissible noise levels recommended by the Sri Lankan government regulations mentioned in Table 1-1. It can be concluded that traffic is the most critical factor for excessive sound levels in urban areas in Western province. The Above conclusion is supported by the respondents reasoning for the source of noise disturbance in Figure 5-6. Where 78% respondents have pointed out traffic noise to be the source of noise pollution.

Considering the duration of exposure to high sound levels in Figure 5-4, 70% of respondents have claimed they are exposed to high sounds 0-4 hours per day in urban context whereas 15% claims they are exposed more than 6 hours daily. These lengthy hours of exposure can affect their health conditions and increase stress levels. The information regarding the number of hours where the respondents continuously exposed to adverse noise was not revealed in this research and further study should be done to find out the details of the exposure durations to confidently comment on the adverse effect faced by the respondents. However the actual noise levels in the study areas during peak hours are in the range of 75- 82 dB as in Table 7-1. Only 10% of respondents have declared the exposure duration to be more than 7 hours per day as in

Figure 5-4. It is evident that the noise pollution levels are within the recommended exposure limits by (NIOSH) standards.

Table 16-1 Cross comparison of questionnaire survey results.

% Values	**02 .Sound level >= rating 3**	**03 .Disturbed by the sound levels**	**04 .Require a solution**	**05 .Already taken a solution**	**06. Prefer a natural barrier**	**07. Experience in planting >= rating 3**	**08 .Security rating of natural walls>= rating 3**	**09 .Security rating of artificial walls>=rating 3**	**10. Aesthetic appeal of natural barriers >= rating 3**
01 .Living distance from main city <=5 km	44%	57%	51.5%	6.5%	68.5%	22%	36.5%	79.5%	78%
02. Sound level >= rating 3		38%	38%	5%	43%	16.5%	23.5%	50%	49.5%
03. Disturbed by the sound			53.5%	7%	61%	16.5%	28%	67.5%	66.5%
04. Require a solution				7.5%	54.5%	15%	26%	60%	59.5%
05. Already taken a solution					7.5%	3%	2%	8%	8%
06 .Prefer a natural barrier						26.5%	37%	83.5%	83%
07. Experience in planting >= Rating 3							16.5%	27.5%	28%
08. Security rating of natural walls>= Rating 3								40.5%	40.5%
09. Security rating of artificial walls>=rating 3									94.5%

From the respondents who have rated the noise disturbance equal or above moderate, only 38% have declared that they need a solution for the excessive sound levels. This may be due to an adaptation to high sound levels by people, even though they think noise levels are un-bearable for them. Among the respondents who have identified and answered positive that they are clearly disturbed by noise, 53% has agreed for the need of a solution. Nearly half of the respondents who are clearly disturbed by noise, reject a solution for high sound levels. Responses rejecting a solution, may be due to the human behavior of pressing on more important matters in surviving urban life. The other possible reasons are unawareness of harmful effects from the prolong exposure to high noise levels, lack of knowledge regarding remedial actions and unavailability of solutions.

The lack of knowledge and unavailability of a proper solutions to noise problem is reflected through the percentage of respondents who have already taken remedial actions to prevent excessive noise levels, which is 8%. Percentage of respondents who have taken remedial actions and who also claims they need a solution is 7%. This indicates that whatever the solution respondents have already taken is not satisfactory enough. Common responses for remedial actions were, use of thick curtains, boundary walls and keeping windows and doors closed during noisy time etc. Noticeably, most of the respondents who have gone through the trouble of finding a remedy are within the 5 km radius from a main city. Which is 6% from the total respondents, which is 75% from the total respondents who have taken remedial actions for noise problem.

Even though the respondents were alien to the concept of natural barriers, they appreciated the concept of natural barriers upon receiving information. Respondent's enthusiasm in the concept is evident by their responses, where 86% respondents were in favor of using natural barrier at their own gardens. According to Figure 6-1, 87% respondents expressed the willingness to go through the course of maintaining a natural barrier. The preference for a natural barrier over a conventional boundary wall is significant where 74% responses are in favor of natural barriers. This is evidence for the likely hood of urban society accepting natural barriers over artificial, if introduced as proper solution. Hence, a high degree of acceptance from the urban society for a natural barrier solution can be anticipated.

Research result revealed a need of an awareness program to enhance the ability and knowledge of the people regarding plantation and maintenance, if a natural barrier solution to be implemented. Respondents have shown lack of confidence in the experience and knowledge regarding tree plantation and maintenance, as only 30% of respondents indicating high levels of experience and knowledge rating for tree plantation and maintenance. According to Table 16-1, only 26% of respondents are positive on the required tree plantation experience level and also have the desire to plant a tree barrier in their garden.

People tend to pay a considerable attention to security levels provided by a barrier. However they are not very convinced about the protection level provided by a natural barrier. Nearly 60% of respondents indicated the self-evaluated security level provided by a natural barrier to be bellow moderate, as in Figure 6-3. Human belief on the expected security level provided by an artificial barrier is high whereas 97% of respondents have indicated security rating more than moderate level for artificial barriers in Figure 6-4. Hence it can be concluded that the solution of natural barrier will be highly compromised by the people with regard to security levels. Practical and convincing way of enhancing the security levels provided by types of natural barriers should be extensively investigated. A 40% of respondent who have rated security level of artificial barriers equal or more than moderate has responded that the security level of a natural barrier could be equal or more than moderate in Table 16-1. Hence it can be assumed that, if natural barrier security level can be increased convincingly, people would be satisfied with the security level provided. Introducing hybrid barriers where natural barriers are supported by artificial structure such as conventional walls, steel or wood frames etc. can be suggested as a highly viable remedy for lack of security aspects of natural barriers.

Human preference lies within the range of 5-7 feet of height considering the desired height of a barrier where nearly 50% of responses are in favor as shown in Fig 5.12.

Barriers with the height of more than 12 ft are very likely to be rejected by the people where only 2% of responses are in the favor of barriers above 12 ft of height**.**

It can be reasonably assumed that the level of privacy provided by a boundary wall is decided by its transparent and opaque qualities. According to human perception, a significant consideration has been given to the level of privacy provided by a boundary wall types. Only 3% of responses are in favor of transparent barriers and 57% of responses are in favor of Opaque barriers as in Figure 6-7. Hence for a viable solution a natural barrier should be providing adequate privacy level. In order to achieve the level of privacy demanded, a natural barrier should be thick and dense enough. The tree types such as ever green trees will be capable to act as natural barrier to maintain its denseness throughout the year without impairment of its performances.

Natural barriers are highly accepted considering the aesthetic appeal. 90% of respondents have declared the aesthetic appeal of a natural barrier would be equal or higher than moderate level according to their expectations. Noticeably 51% of respondents have rated natural barriers in very highly aesthetically appealing category as in Figure 6-8**.** Human concern regarding aesthetic appeal of green solutions is highlighted in these responses.

Street plantation has been introduced in Sri Lanka and has been incorporated with road development projects. Moderate to very high suitability rate was assigned by more than 95% of the respondents to concept of urban street plantations. Where only 1% of respondents have rejected street plantation as in Figure 6-9. This indicated that the concept of street plantation has become popular and appreciated by the people.

Disturbance level of the street plantations to motorists and pedestrians were evaluated and revealed where 67% of respondents from motorist category voted for negligible to low disturbance ratings as in Figure 6-10. In pedestrian’s perspective, 75% voted for negligible to low rating of disturbance from street plantation as in Figure 6-11. From above facts it can be predicted that disturbance occurred from street plantation is negligible asper the human perspective and its positive qualities have been highly appreciated. However visibility of road signs and traffic signals should not be disturbed by the street plantations to ensure road safety.

In terms of aesthetic appeal generated by street plantation, 58% of respondents have rated it as very highly aesthetically appealing. Totally, 97% of respondents have rated street plantation as moderate to very high aesthetically appealing category. This indicated that in urban context, aesthetic appeal of the street plantation is highly demanded.

16.1.1. Actual noise levels in the urban areas.

According to the field test carried on selected urban areas it was identified that most of the peak hours the noise levels exceeding the recommended noise levels by Sri Lankan standards shown in Table 1-1. Situation in the sub urban areas also just at the margin of exceeding the allowable sound limits.

Form the sound data collected it was evident that the majority of noise levels in the above mentioned areas are due to low to mid frequency sound. Hence a noise barrier implemented in this area should be able to address those sound frequency ranges. The captured actual noise levels during peak hour duration shows 70-80 dB output in mid-range frequencies. Noise barriers made out of vegetation has proven to be effective at attenuating the low to mid frequency noise levels. According to the gathered results as in Table 7-3 the noise levels during peak levels at selected urban locations have exceeded the allowed noise levels in Sri Lankan regulations in Table 1-1

16.2. FIELD TESTING RESULTS AND FINDINGS ON NATURAL BARRIER PERFORMANCE.

Field testing was carried out to reveal the performance of natural barrier in reducing noise levels. The data gathered was analyzed and Multiple Linear Regression (MLR) models and Artificial Neural Network (ANN) s were created. The aim was to create a mathematical model which will be able to predict the noise reduction of a natural green barrier explained in 1.7.

16.2.1. MLR models

According to MLR models natural barrier acoustic performance was highly dependent on the Height (X1), Green cover(X3) and Length (X4) of the barrier. From the results of linear regression models (Table 11-19) it was identified that independent variable Green cover has a highly positive correlation with the dependent variable decibel reduction where R^2 value is 0.741.Likewise Height independent variable also shows a moderate good correlation to dependent variable decibel reduction where R^2 value is 0.533.

Among the MLR models the best R^2 value is shown in MLR-4 where the Height (X1), Green cover(X3), Length (X4) and Humidity (X6) act as predictor variables. The residual plot of MLR-4 shows that the model is unbiased. Minimum standard error of the estimate of 0.40077 is given by the MLR-4 model. Hence MLR-4 model is the best among MLR models with a best prediction accuracy. However only 76% of variability of the dependent variable is explained by MLR-4 indicating that the MLR-4 model is not the best solution to make accurate predictions of green barrier performance.

16.2.2. ANN models

More than 70 network models were tested to find a better combination for the problem. Since the data set gathered in the research is not a large data set batch training and mini-batch training method yielded better results in creating ANN models. Also models with hyperbolic tangent function as the activation function for hidden layers yielded better results.

The created models are fully connected models and it was ensured that minimum number of synaptics in hidden layer 1 should be equal to the number of inputs. The performance of the models were evaluated using RMSE and R^2 values respectively to evaluate prediction accuracy and the amount of variability predicted by the models. It was observed that the models with two hidden layers providing lower RMSE values compared to the single hidden layer models.

An approach of increasing the number of synaptic was carried out to improve the models which showed good results. It was observed that ANNs with the number of synaptic in hidden layer 2 is equal to 1/2 or 2/3 times of the number of synaptic in hidden layer 1, performing better.

The best R^2 is given by the ANN6 BT10 L2 S6S3 ID-MLP-e (ANN6-B) and ANN6 BT L2 S12S8-MLP-c (ANN6-A) explaining about 90%of the variance in the model .The RMSE and SSE of the above two models are smaller and shows a higher predictive accuracy. Reduction of R^2 value and RMSE was observed in increasing the number of synaptic weights in the model ANN6 BT10 L2 S6S3 ID-MLP-e (ANN6-B) to constitute ANN6 BT10 L2 S12S6 ID-MLP-e (ANN6-C). However even with a single hidden layer ANN6 BT L1 S6 ID-MLP-g (ANN6-D) model has proven to be effective and match the performance of the ANN6-B model closely. However the model's RMSE value is unfavorable.

It was earlier conclude that model ANN6 BT L2 S12S8-MLP-c or ANN6 BT10 L2 S6S3 ID-MLP-e would yield better predictions. However when testing the four ANN6 models it was found out that the consistency of prediction of ANN6-B model is problematic with respect to other three ANN6 models. The ANN6-A model has a good overall performance with respect to R^2, SSE and RMSE. This models shows the highest R^2 value of 0.904 and lowest RMSE. It was observed in the design trail barriers ANN6-A model is providing rational and acceptable predictions as shown in Figure 14-2 and Figure 14-3. The ANN6-A model pattern of prediction can be validated by the other two ANN models (ANN6-C and ANN6-D). Hence it can be concluded that the ANN6-A model is useful and can be effectively used in prediction of performance of natural barriers explained in this research.

16.3. NATURAL BARRIER DESIGN FOR URBAN AREAS.

According to the findings in the research through questionnaire survey and the field testing, following design consideration can be suggested in designing natural barriers for urban areas as acoustic barriers.

1. Should be able to accommodate the limited space.

    Length, height and thickness of barrier will be critical design criteria. It was found out in the research that the most preferred height of the barriers are from 6-7 ft. at the same time the barrier should be tall enough to effectively attenuate the noise. Hence a barrier with a height not more than 3 meters will have a greater chance of being accepted in urban conditions. Since the barriers are made of vegetation, thickness of barrier should be considered as at least 0.3 m (1 feet) due to practical considerations. Length of the barrier can be vary, however it is recommended to consider 2.5 m as the minimum Length of a barrier if the results from this research to be used (the minimum Length of tree barriers came across in the field testing was 2.5m).

2. Natural barrier should be ever green and should have the characteristics explained in section 1.7.

   Evergreen plantation should be used to preserve the performance of the natural barriers throughout the year. Overall barrier shape would be a cuboid.
3. The barrier should at least attenuate 3dB

   This is due to the fact that the human ear sensitivity pattern is similar to decibel scale and it requires at least 3dB reduction to perceive a considerable reduction in noise levels.
4. Natural barrier should have enough green coverage.

   According to the results of the research it is evident that the green cover of the species in the barrier plays a vital role it deciding its acoustic performance
5. Natural barrier should be able to preserve privacy and convince the level of security given.

   According to the results it's evident that the privacy and security level given by a barrier is given a lot of concern by the users. As a solution hybrid natural barriers half artificial structure and half vegetation can be a good approach to provide the privacy levels and security levels required by the users.
6. The designed natural barriers should be easy to implement and maintain in urban conditions.

   Species should be able to withstand the conditions in the urban environment. Fast spreading and growing species may induce unnecessary problems in maintaining. Taller natural barriers would be problematic in pruning and maintaining.

Configurations of natural barriers shown in Table 14-2 can be suggested for urban areas. These natural barrier performance are evaluated using the ANN6 models.

It was found out that to ensure a natural barrier to reduce noise level by at least 3dB the green cover should be more than or closely equal to 85%. Height requirement of the barrier should be closely equal to 2m or more to provide the appropriate noise reduction.

17.CONCLUSION

From the questionnaire survey and the study on actual noise measurements in selected urban and suburban areas in the western province, it was possible to summarize very important details about the public perception on noise levels and natural barriers. Comparison of actual noise levels and public perception was also made possible by the results.

According to the summarized facts, motor traffic noise is the main reason for noise pollution in urban areas. Hence it can be argued that controlling and reducing motor traffic noise will contribute significantly to solve the excessive noise problem in urban areas. High noise durations are in line with traffic patterns. Even though people experience high sound levels in the urban environment, there is a significant lack of awareness and un-availability of remedies to solve the problem. There exist a possible risk of human adaptation to excessive noise levels in urban areas. Considering actual noise levels in urban areas investigated by the study conducted during the peak hours, the allowable noise levels asper Sri Lankan regulations are violated irrespective of the location being urban or suburban. Within the study area, noise exposure limits are below the recommended noise exposure limits by (NIOSH) even though actual noise levels are considerably high. The actual noise levels in the study areas during peak hours are in the range of 75- 82 dB.

Even with the fever details collected in this research regarding the duration of continuous exposure to excessive noise levels in urban and suburban areas, it can be concluded that the durations and the amount of noise level can cause tension, unease, stress and influence negative social behaviors. The long term effect of this kind of condition can bring about more harmful effect to individuals and society.

Overall responses for the natural barriers clearly reflects that there is a high demand for aesthetic appeal provided by natural barriers in the urban context. Urban population is eager to adopt the natural barrier concept. So it is evident that urban society expects more from a natural barriers which is also in line with the findings of previous research (Bailey & Grossardt, 2006). In order to successfully implement natural barrier solutions, raising the awareness of the urban community on tree plantation and maintenance is vital. A natural barrier solution should convincingly and effectively perform in providing adequate security level, adequate privacy and ease of maintainability without impairment of performance throughout the year. Furthermore people should be well supported with technical and practical knowledge in applying natural barriers in urban areas. A proper monitoring and maintenance mechanism to mitigate any adverse effects by street plantation is vital upon implementation in order to preserve the public favor for the concept of natural barriers in urban area.

Mathematical models developed using Multiple Linear Regression (MLR) analysis and Artificial Neural Networks (ANN) has proven to yield a method to evaluate the type natural barriers explained in the research of their performance in noise attenuation. MLR models were able to explain 75% of the variability of the model using 4 variables. The natural barrier acoustic performance was highly dependent on the Height (X1), Green cover(X3) and Length (X4) of the barrier.

In the research it was evident that the foliage area or the green cover has a positive relationship towards deciding the noise reduction of the natural barrier. This finding agrees with the results from previous researches where the importance of foliage cover in natural noise barriers has being emphasized (Bullen & Fricke, 1982; Watanabe & Yamada, 1996). According to research findings Length of the natural barrier is also a driving factor of deciding the noise reduction capability of the barrier which also agrees with the previous research findings (Kragh, 1981)

ANN6-A model developed in the research proven to be useful in determining and designing a natural barrier with required noise attenuation for urban areas. According to the ANN6-A model, to ensure an noise attenuation equal or more than 3dBs, the green cover of the natural barrier should be closely equal or more than 85% and the height of the natural barrier should be closely equal or more than 2m.the design barrier heights to obtain desirable noise attenuation from the natural barriers proposed is within the barrier height range preferred by the urban society (1.5m to 3.0 m). The ANN6-A model also shows that a natural barrier can be designed with the above criterion with a green cover close to 100% to achieve 5.0dB or more.

Field testing concluded that the cuboid shaped closely grown tree belts (where foliage cover dominates the vegetation) would act as an effective natural noise barrier. Overly the natural barriers which is described in 1.7 has shown a mean reduction of 3.3 dB in a confidence level of 95% and confidence interval of ±1.92 .The maximum noise attenuation by the natural barrier recorded as 5.68 dB. However all the tested artificial barriers has shown noise reduction above 3.0dBs where the average reduction is 5.23dB reducing 68% of acoustic energy. But the facts from the research proves that a natural barrier can be developed to match the performance of an artificial barrier.

In addition to the noise attenuation provided by a natural barrier, it can provide more benefits over an artificial barrier. Natural barrier types are generating high aesthetical appeal and proven to effect positively on good mental health while providing pleasing and pleasant environments in urban conditions.

Natural barriers go along with green building concept while providing means to develop carbon neutral cities. In addition to acting as a noise barrier natural barrier would reduce all most any kind of air pollution, provide thermal insulation, air quality improvement, reduction of heat island effect around the vicinity, reduction of dust and smoke intrusion in to road side buildings and act as a sustainable solution which felicitous and highly in demand.

18.FUTURE DEVELOPMENTS & POSSIBILITIES

Following future developments can be suggested according to the findings at the end of the research.

1. Field testing was carried under the influence of lot of variabilities and disturbances it is suggested to perform the same testing procedure or better in a controlled environment to evaluate the effects and results more accurately.
2. Green cover measurement was used to satisfy the requirement of using a nondestructive method to evaluate barriers physical properties, however obtaining actual density of the natural barriers would have a probability of improving the results.
3. Variation of two predictors, temperature and humidity with respect to the range of variation of other predictors, were limited in the research. There is a possibility of evaluating the effect of temperature and humidity in deciding the noise reduction qualities of natural barriers in a better way by conducting the testing in a controlled environment.
4. Further extensive research can be useful to identify the contribution of physical properties of leaves such as their thickness, shape, surface area etc. towards the acoustic performance of natural barriers.

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20.APPENDICES

APPENDIX A.

Pictures of few tested natural barriers

APPENDIX B

Green Cover Measurement

A photographic method was used to calculate the green cover of the barrier.

Assumption.

Spread and distribution of foliage are constant throughout the barrier

Method

Following methodology was adopted to evaluate green cover

1. Photograph of the front elevation of the foliage area of the barrier surface is taken.
2. Square area of the photograph was marked and total number of pixels in the marked area is measured.
3. Pixels representing the foliage area in the selection on the photograph was classified and given a color code (color code used #00ff00), Pixels representing the color code #00ff00 now represents the number of pixels representing to foliage area of the selection.

   Total number of pixels in the selection = N_1
   Total number of pixels in classified selection for foliage area = N2
   Green cover = GC %

$$GC = \left({}^{N_2}/_{N_1} \right) x\,100\%$$

Eq: 23

At least three photographs were analyzed to arrive at an average green cover value. This analysis was carried for all the 75 natural barriers.

Software used for classification was Adobe Photoshop CS6 (64bit).

Eg: Barrier 53 (B53)

Table 20-1 Green Cover measurement example

Green cover measurement B53			
Photo	N1	N2	GC (N_2/N_1)%
P1	312481	279866	**89.56**
P2	326041	299774	**91.94**
P3	373321	330471	**88.52**
Average GC	**337281**	**303370.3**	**89.95**

Table 20-2. Classified photo example for green cover measurement

Barrier	**B53**		
Classified photo (color code #00ff00)			
Photo Number	B53-P1	B53-P2	B53-P3

APPENDIX C

Sample dB reduction measurement. B53

01. Ambient Noise calculation (preparation for testing)

Ambient noise calculation						
	amb1		amb2		Average amb	
Hz	**dB**	**A weight**	**dB**	**A weight**	**dB**	**A weight**
31.5	52.64	13.24	58.58	19.18	55.61	16.21
63	54.23	28.03	53.52	27.32	53.88	27.68
125	42.67	26.57	43.24	27.14	42.96	26.86
250	31.76	23.16	36.1	27.5	33.93	25.33
500	33.24	30.04	37.6	34.4	35.42	32.22
1000	38.48	38.48	39.21	39.21	38.85	38.85
2000	34.44	35.64	40.62	41.82	37.53	38.73
4000	45.05	46.05	40.37	41.37	42.71	43.71
8000	27.69	26.59	29.67	28.57	28.68	27.58
16000	24.75	18.15	25.39	18.79	25.07	18.47
L_{Aeq}		46.97		46.08		46.53

02. Barrier properties and environment conditions

Location	Gampaha	Unit
Temp	33	°C
Humidity	60	%
Green cover	90	%
Thickness	1.0	m
Length	20	m
Height	1.4	m

03. Noise measurement with the barrier

With the barrier						
Distance from source	**1.5m** **Reading 01**		**5.5m** **Reading 02**		**ΔdB**	**ΔdB A**
		A Weighted		**A Weighted**		
Freq Hz	dB	dB	dB	dB		
31.5	55.37	15.97	53.96	14.56	1.41	1.41
63	60.69	34.49	58.78	32.58	1.91	1.91
125	55.65	39.55	51.49	35.39	4.16	4.16
250	57.15	48.55	51.06	42.46	6.09	6.09
500	67.42	64.22	53.61	50.41	13.81	13.81
1000	58.35	58.35	55.69	55.69	2.66	2.66
2000	69.7	70.9	56.98	58.18	12.72	12.72
4000	74.79	75.79	58.35	59.35	16.44	16.44
8000	64.83	63.73	48.24	47.14	16.59	16.59
16000	60.8	54.2	34.02	27.42	26.78	26.78
L_{Aeq}		77.17		64.95		**12.22**

04. Noise measurements without the barrier.

Without the barrier						
Distance from source	**1.5 m** **Reading 03**		**5.5m** **Reading 04**		**ΔdB**	**ΔdB A**
		A Weighted		**A Weighted**		
Freq Hz	dB	dB	dB	dB		
31.5	53.76	14.36	53.7	14.3	0.06	0.06
63	55.08	28.88	58.95	32.75	-3.87	-3.87
125	50.55	34.45	54.03	37.93	-3.48	-3.48
250	55.71	47.11	50.38	41.78	5.33	5.33
500	66.41	63.21	56.96	53.76	9.45	9.45
1000	62.1	62.1	52.21	52.21	9.89	9.89
2000	68.03	69.23	57.78	58.98	10.25	10.25
4000	72.5	73.5	61.03	62.03	11.47	11.47
8000	66.6	65.5	55.88	54.78	10.72	10.72
16000	64.04	57.44	50.41	43.81	13.63	13.63
L_{Aeq}		75.54		65.4		**10.14**

Noise reduction as an effect of the barrier =12.22-10.14 = 2.08 dB L_{Aeq}

APPENDIX D

INDEX

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V