USE OF ORNAMENTAL PLANTS IN THE REDUCTION OF POLLUTION IN A GHANAIAN INDUSTRIAL ENVIRONMENT- CASE STUDY, GHANA CEMENT FACTORY.

A THESIS SUBMITTED TO THE SCHOOL OF RESEARCH AND GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

AWARD OF MASTER OF SCIENCE (MSc) DEGREE LANDSCAPE STUDIES.

BY:

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SEPTEMBER, 2008.

DECLARATION

I hereby declare that the work herein now submitted as a thesis for a Master of Science degree to the School of Research and Graduate Studies, K.N.U.S.T., Kumasi is the results of my own investigation and that no previous submission for a degree has been done here or elsewhere. Works by others which served as a source of information has been duly acknowledged by reference to the authors.

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DEDICATION

This thesis work is dedicated to God and to my family, both nuclear and the church.

ACKNOWLEGMENT

I am really thankful to the Almighty God who has seen me trough this work.

I would like to thank my Supervisor Mrs. Hannah Victoria Adzraku for her encouragement, understanding and patience throughout this work.

To my dearest Aunty Irene thanks so much for all that you have done. Thanks for your encouragement, your constructive criticism of my work and fulfilling scripture (Prov. 18:24b). To Mr. and Mrs. Idun, Maame and Kofi, what could I have done without you? Thanks and I am very grateful for opening and sharing your home with me. God richly bless you and your generation. I cannot say all but God knows my heart towards you.

I owe much thanks and love to my husband Theodore Alfred Kpodonu for being there for me, looking after Nichole and Nikao all the times I was away and helping me with my work through to its completion.

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ABSTRACT

This study was conducted to identify and select plants materials that could mitigate the effects of pollutants in an industrial environment using Ghana Cement Factory (Ghacem) as a case study in Ghana. The objectives were to identify plant materials resistant to the pollutants in the Ghacem environment and review literature on other plants not found in the Ghacem environment but could reduce the effect of pollution both indoors and outdoors. To achieve objective one, a scoring scheme by Lorenze *et al.* (1997) for defoliation and discolouration was used to score plants growing in and around Ghacem while an intensive literature review was conducted on other plants to satisfy the other objectives. The study revealed that sixteen (16) plants namely *Albizia lebbeck*, *Azadirachta indica*, *Calotropis gigiantica*, *Casuarina equisetifolia*, *Cocos nucifera*, *Duranta species*, *Eucalyptus globules*, *Ipomoea carnea*, *Jatropha integerrima*, *Lagerstroemia speciosa*, *Leuceana leucocephala*, *Milletia thonningii*, *Pithecellobium dulce*, *Polyalthia longifolia*, *Punica granatum*, *Roystonea regia*, *Terminalia catappa* were able to withstand the pollution in the Ghacem environment with a defoliation class of zero (0) and a leaf loss of between 2-4 %. Seven of these plants forming about 50% were mentioned as pollution resistant plants by Sharma and Roy (1999). Two (2) of the plants sampled that is, *Millingtonia hortensis* and *Elaeis guineensis* from the Ghacem environs were however not able to withstand the pollution. Twenty-eight (28) plants were in total recommended for outdoor use and fifteen (15) plants recommended for indoor use. The use of these plants in and around Ghacem would provide a congenial and safe environment for the workers and those transacting businesses around the place which in turn will increase productivity and enhance the welfare of workers.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

The industrial revolution in the 18th century was a major shift of technological, socio-economic and cultural conditions. It began in Britain and spread throughout the world (Derry and Trevor, 1993). During that time, an economy based on manual labour was replaced by one dominated by industry and the manufacture of machines, (Hughes, 1980). It began with the mechanisation of the textile industries, the development of iron-making techniques, and the increased use of refined coal. The introduction of steam power (fuelled primarily by coal) and powered machinery (mainly in the textile manufacturing) under-pinned the dramatic increases in the production capacity (Business and Economics, 1989). Industries that sprang up in the revolution included mining, metallurgy, chemicals, steam power, textile manufacture, machine tools, gas lighting and factory sites (Mantoux, 1961).

The impact of this change on society was great. Kreis (2006) mentioned that Mary Shelly in her short story "Frankenstein" described the industrialization era as the "two-edged nature of scientific progress" due to the benefits and the side effects both on the environment and society. Nicholas Leblanc's success with the introduction of the method for the production of Sodium carbonate produced a large amount of pollution. The hydrochloric acid was initially vented into the air and Calcium sulphide was a useless waste product (Clow and Clow, 1952). The industrial revolution also led to a population increase as new industries were established and industrial workers were better paid than those in agriculture (Hartwell, 1963).

Industrialisation also led to the creation of factories (Gill, 2004) and the factory system led to the rise of the modern city, as workers migrated into the cities in search of employment in the factories. However, child labour increased and poor people lived in very small houses in cramped streets and as a result huge numbers of the working class died through diseases (Buer, 1926). Chest diseases, cholera from polluted water, typhoid and small pox were extremely common amongst the populace (Thompson, 1980).

The industrialisation era also gave rise to the need for more shelter to house both workers in the industry as well as the machines which were used in the industry. Cement, which is an inorganic substance with binding property that can be used in materials such as concrete consequently, became an essential commodity (Pearce, 2002).

Like in the era of the industrial revolution the Ghanaian government's industrialization policies initiated since independence led to the establishment of a wide range of manufacturing industries (Britannica, 2007) including the cement producing factory (Ghacem) in 1967 (Ghacem Tema Works, 2001). Ghana being a third world country is still developing in terms of infrastructure that includes a lot of constructional activity and the need therefore of cement, cannot be over emphasised.

Cement is a very important product in the world. It is a key component in nearly all construction. It is estimated that about 2.7 billion tonnes of cement is produced worldwide annually as at 2007 (US Geological Survey, 2008) with Ghana producing

1.2 million tonnes per year (Ghacem Tema Works, 2001). This was before the setting up of the new cement plant in Aflao.

Despite the importance of cement, its production process impacts heavily on the environment. The manufacture of cement gives rise to two major environmental concerns namely dust pollution of the atmosphere and the emission of green house gases, besides the ecological concern arising from the degradation of mined-out areas (Cleantechindia, 2005).

1.2 PROBLEM STATEMENT AND JUSTIFICATION

Man probably first experienced harm from air pollution when he built fires in poorly ventilated caves and since then has gone on to pollute more of the earth's surface. Until recently, environmental pollution problems have been local and minor because of the Earth's own ability to absorb and purify minor quantities of pollutants (Wolverton, 1996). The industrialization of society, the introduction of motorized vehicles, and the explosion of the population, are factors contributing toward the growing air pollution problem (Socha, 2007). Socha, 2007 also mentioned the two main sources of pollutants in urban areas as transportation (predominantly automobiles) and fuel combustion in stationary sources, including residential, commercial and industrial heating and cooling and coal-burning power plants. The primary air pollutants found in most urban areas are Carbon monoxide (CO), 8u oxides (NO_X), Sulphur oxides (SO_X), Hydrocarbons and particulate matter (both solid and liquid). Serious health problems can occur quickly when air pollutants are concentrated, such as when massive injections of SO_2 and suspended particulate matter are emitted (Socha, 2007). Mudd and Kozlowski (1975) mentioned that rapid the industrialisation and the addition of toxic substances to the environment are responsible for the altering of the ecosystem. Stern (1976) also attested to the fact that the cement industry plays a vital role in the imbalances of the environment and produces air pollution hazards. It is therefore urgent that we find methods to clean up the air.

The Ghana Cement Factory (Ghacem Ltd.) is the largest cement manufacturer in Ghana and operates two clinker grinding plants located in the heavy industrial area of Tema and Takoradi harbours (Ghacem Tema Works, 2001). Like all cement producers, Ghacem also releases some pollutants into the atmosphere. The environmental impact statement of the company indicates that release of dust (airborne particles) into the atmosphere is the major source of shock resulting from Ghacem activities (Ghacem Tema Works, 2001). Efforts made by the company to manage the issue of dust release into the atmosphere include the installation of filters in the processing unit to trap dust (Ghacem Tema Works, 2001). However, a reconnaissance survey conducted as part of this study has revealed that a lot of dust is still being released by Ghacem. This is evident by the pile of dust found on some plants outside the factory, visible dust in and around the factory during processing, loading and off-loading. In an interview with the workers, the two closest neighbours of the Ghacem; Enyedado cold store and AFKO Fisheries, and those who buy and sell from the cold stores revealed that large amounts of dust is released.

One cannot escape air pollution, not even indoors as was initially thought of as the safes haven from the evils of air pollution (Wolverton, 1996). Indoor air pollution has been associated with allergies and other chronic illnesses and according to the

US EPA, ranked as one of the top five threats to public health (Wolverton, 1996). Sources include off-gassing building materials, pollution from electro-mechanical equipment and appliances, combustion and cleaning and maintenance compounds (Gunderson and Farms, 2007).

In weighing the options for dust management, the use of plants are often ignored but Socha (2007) suggested the planting of trees for controlling air pollution. Innes (1990) also suggested planting of greens in the control of pollution as open spaces planted with trees, shrubs and herbaceous plants especially grasses, alter the local climate, and thus alter the dispersion of pollutants. Innes (1990) mentioned that grasses absorb twice as much of some pollutants than the bare soil and this scavenging effect reduces with the inclusion of shrubs and trees. Thus, the average concentration of a pollutant in the atmosphere declines with increasing proportion of well planted open space in industrial areas. Also, evaluation for trees for the landscaped areas around cement factories have revealed that neem tree leaves have a very high dust retention capacity and the Bambun Cement Ltd. in India has achieved some success with this (Moses, 1996). As noted by Wolverton (1990), increasing ventilation in a room does not offer solution to the problem of indoor pollution but rather an inclusion of house plants in the building would help provide an environment that mimics the way that nature cleans the earth's atmosphere.

It is in this light that this study sought to look at the potential of the use of plant materials in the landscaping of the surrounding areas in and around the Tema branch of Ghacem Ltd. in order to mitigate the effects of dust and indoor pollutants on their workers and people living and working around the factory.

1.3 OBJECTIVES

Specifically, the study looked at the

- Plants performing well and adapted to the industrial environment at Ghacem.
- Additional choice of plant species able to withstand pollution for outdoor use.
- Additional choice of plant species with purifying abilities for indoor use.

CHAPTER TWO

2.0 LITERATURE REVIEW

The Green Lane™ (2004) characterised air pollutants associated with cement manufacturing as follows:

Criteria Air Contaminants

- Particulate matter (PM);
- Nitrogen oxides (NO_x);
- Sulphur oxides (SO_x);
- Carbon monoxide (CO);
- Volatile Organic Compounds (VOCs)- e.g. Benzene, Toluene, Ethylene benzene, Xylene;
- Ammonia (NH_3);

Green House Gases

- Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxides (N_2O);

Other substances

- Acidic Compounds - e.g. Hydrogen chloride (HCl), Hydrogen fluoride (HF), Sulphuric acid (H_2SO_4);
- Heavy Metals- Arsenic (As), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), Nickel (Ni);
- Organic Compounds - e.g. Polychlorinated Dibenzo-p-dioxins (PCDD), Polychlorinated Dibenzofurans (PCDF), Polychlorinated Biphenyls (PCBs), Hexachlorobenzene (HCB), Polycyclic Aromatic Hydrocarbons (PAHs).

2.1 POLLUTANTS IN THE AIR

Pollutants are substances which, when present at high enough concentrations, produce harmful effects on people and/or the environment (Holper and Noonan, 2000). A number of pollutants affecting urban and/or regional air quality are listed in Table 1.

Table 1. Sources of major pollutants in the atmosphere and their health effects.

POLLUTANT	SOURCES	HEALTH EFFECTS
Carbon monoxide (CO)	Motor vehicles, burning of fossil fuels.	Blood absorbs Carbon monoxide more readily than oxygen, reducing the amount of oxygen being carried through the body. Carbon monoxide can produce tiredness and headaches. People with heart problems are particularly at risk.
Sulphur dioxide (SO_2)	Coal and oil burning power stations, mineral ore processing and chemical manufacture.	Attacks the throat and lungs. People with breathing problems can suffer severe illness.
Nitrogen dioxide (NO_2)	Fuel combustion.	Affects the throat and lungs
Volatile organic compounds (VOCs)	Fuel combustion, solvent use, Motor vehicles.	Some VOCs cause eye and skin irritation, headaches or nausea, while some are classed as carcinogens.
Ozone (O^3)	Formed from Nitrogen oxides and hydrocarbons in sunny conditions. These chemicals are released by motor vehicles and industries.	Ozone attacks the tissue of the throat and lungs and irritates the eyes.
Lead	Exhaust gases from motor vehicles that use leaded petrol, Smelters.	Cumulative poisons slowly build up in the body
Particles (aerosol)	Motor vehicles, burning of plant materials, bushfires.	May cause breathing difficulties and worsen respiratory diseases. Some particles contain cancer-producing materials.

Source: (Holper and Noonan, 2000). Urban and Regional Air Pollution, Information Sheet

2.1.1 Sulphur dioxide (SO_2)

Sulphur dioxide is produced when coal and oil are burnt or when minerals are "roasted" to remove the sulphur. In some countries, particularly in the northern hemisphere, coal and oil contain significant amounts of sulphur (Holper and Noonan, 2000). Unless special steps are taken to remove SO_2 it is released into the atmosphere (Holper and Noonan, 2000). Power stations and industrial plants, which are often sited close to cities, can produce large quantities of the gas.

SO_2 affects human health and can be harmful to plants; turns leaves yellow and drying, bleaching and even killing foliage. In the atmosphere, SO_2 can form acidic particles or react with cloud droplets, contributing to acid rain.

2.1.2 Particles

Particles in the air (also known as aerosol) come from a number of sources, including motor vehicles, industrial processes and wood burning. Secondary formation of particles (formation from gaseous emissions) can also contribute significantly to particle levels (Holper and Noonan, 2000). Some atmospheric particles are from natural sources. These include wind-blown dust, pollen, sea salt and material from volcanic eruptions (Holper and Noonan, 2000).

Fine particles (particles with a diameter of 10 micrometers or less) can be inhaled deeply into the lungs and have been associated with a wide range of adverse respiratory symptoms (Holper and Noonan, 2000). According to them, long-term and short-term exposure to such particles has been linked with increased deaths from heart and lung diseases.

2.1.3 Lead

Lead compounds, which are emitted by motor vehicles fuelled with leaded petrol, are cumulative poisons. They slowly build up in the body (Holper and Noonan, 2000).

2.1.4 Urban Haze

Urban haze is mainly due to fine particles, which cause scattering or absorption of light. Haze is typically brown and limits visibility (Holper and Noonan, 2000). Scientists have found that there are several types of particles present in haze in cities: organic carbon compounds, elemental carbon or soot, salt, sulphates, nitrates and dust (CSIRO, 2005).

2.1.5 Acid Rain

Pure rainwater is slightly acidic, primarily because of dissolved carbon dioxide. Air also contains naturally occurring organic acids and acidic particles. The pH of unpolluted rainwater ranges from about 6 to just below 5 (Holper and Noonan, 2000).

According to Holper and Noonan (2000), compounds containing oxides of sulphur and nitrogen are released into the air during combustion of fossil fuel and industrial processes. These compounds may then dissolve in cloud droplets, making rainwater more acidic. In addition, sulphur and nitrogen containing particles may mix through the atmosphere, eventually coming into direct contact with the ground and vegetation. In other words, the pollutants can reach the ground in a wet or dry form. Both forms can harm soil, lakes, plants, buildings and people. Emissions from power stations, motor vehicles, and industry also contribute to acid rain making rainwater slightly more acidic (Holper and Noonan, 2000).

2.1.6 Photochemical Smog

Sometimes, under certain meteorological conditions, the combined effects of a number of air pollutants are worse than the individual effects (Holper and Noonan, 2000). They reported photochemical smog sometimes being seen as a whitish haze present over cities.

According to Holper and Noonan (2000), photochemical smog is formed on still days when the sun shines on air containing volatile organic compounds (VOCs) and oxides of nitrogen. VOCs in the air arise mainly from automotive fuels and industrial solvents. Chemical reactions driven by sunlight and involving VOCs and oxides of nitrogen form ozone, a gas harmful to humans, animals and plants (Holper and Noonan, 2000).

In addition to ozone, photochemical smog contains a number of other harmful secondary pollutants such as Peroxyacetyl nitrate and aldehydes, which are severe irritants, particularly to the eyes. Ironically, ozone in the stratosphere is essential for life as we know it. This ozone layer prevents much of the sun's harmful ultraviolet light reaching us (Holper and Noonan, 2000).

A study conducted in a highly polluted industrial area in Shoubra Elkheima near Cairo on pot planted *Trifolium pratense* and *Malva parviflora* placed at increasing distances from the industrial pollution sources showed an increase in visible injury i.e. a reduction in chlorophyll content, an increased number of plants with visible damage in the area of injured leaves, a reduction in leaf number, a reduction in plant growth and weight near the industrial area compared with the controlled station (Ali, 1993).

2.2 POLLUTION EFFECTS ON VEGETATION

2.2.1 The manner in which atmospheric pollutants affect plants

The reaction of a plant, exposed to an atmospheric pollutant can be considered as the result of a succession of biochemical and physiological events, starting with the absorption of the pollutant and eventually ending in some damages (Garrec, 2008). He mentioned that generally, this process can be divided into four (4) steps:

1. Absorption of the pollutant: The main route through which atmospheric pollutants penetrate into plants is the stomata of the leaves.

2. Perturbations: these are the first phytotoxical effects of the pollutants, resulting from the change of structure and/or functions of the cells in the leaf interior, and the effects at the level of cellular metabolism, following them.

3. Homeostasis: after a perturbation, live systems try to restore their normal metabolism through reparation mechanisms (elimination of all malfunctions) or compensation mechanisms (the perturbation and its physiological consequences persist but mechanisms counterbalance their harmful effect). Reparation and compensation can be partial or complete: the damages vary from one plant to another. Resistant plants possess great capacity to recover cellular damages.

4. Damages, at the physiological and metabolic level: they result from the inability to repair or compensate for the malfunctions and the metabolic changes, resulting from the absorption of the pollutant. The sum of the pollutant's effect on

each cell results in change of metabolism of the tissues and organs. This is manifested first by hidden injuries (reduction of growth, loss of vitality, and, for the cultivated plants, reduction of yield and quality), and then, by visible injuries, generally at leaf level, (necrosis, chlorotic spots, premature ageing). It should be noted that this leaf necrosis could be typical of a certain pollutant: apical and marginal necrosis for fluoride, internerve necrosis for SO_2, and puncti-form necrosis for ozone.

Garrec (2008) again indicated that while the effects of a pollutant on a single plant is divided into hidden and visible injuries, in characterising the effects of a pollutant on vegetation communities (agricultural crops, forests, etc.), injuries and damages are used. The injuries result from a short exposure to high concentrations of the pollutant, with visible effects mainly at leaf level, and in most cases does not influence yield or reproduction. The damages correspond to the invisible effects of a pollutant, but with consequences for the plants' economic production, genetic resources and cultural values. Older leaves are the most likely to show symptoms, because they have been exposed to pollutants for longer periods. Fortunately most plants, even those sensitive to damage, are thought to be tolerant of air pollution injury during dormancy because deciduous trees and shrubs that drop their leaves do not suffer further injury (Garrec, 2008).

As a general rule, the appearance of leaf injuries is a reaction at some peak of pollution, while the loss of yield is the result of continuous exposure (Garrec, 2008).

2.2.2 Ozone (O_3)

Ozone is a gas formed by the chemical reaction driven by sunlight and involving Volatile organic compounds (VOCs) and oxides of nitrogen (NO_X). VOCs include hydrocarbons as well as alcohols, aldehydes and ethers. O_3 is not bio accumulated in plants and can only be detected by sensitive plants (Taylor *et al.*, 1990). It's major effects according to Kovács (1992) on terrestrial vegetation include visible foliar injury, reduction in growth and productivity, changes in crop quality and increased sensitivity to either abiotic or biotic stresses. In general, white, fawn, tan, grey and brown necrotic streaks on the upper surface of leaves are typical of O_3 injury (Kovács, 1992). Queen's Printer for Ontario (2008) also mentioned that O_3 symptoms (Plate 1) characteristically occur on the upper surface of affected leaves and appear as a flecking, bronzing or bleaching of the leaf tissues. Injury development on broad leaves is influenced by the stage of maturity, the youngest leaves are resistant: with expansion, they become successively susceptible at middle and basal portions and the leaves become resistant again at complete maturation (Queen's Printer for Ontario, 2008).

Plate 1. Ozone injury to soybean foliage.

Kovàcs (1992) presented typical O_3 injury symptoms on certain crop species. On conifers, chlorotic flecks later become pink lesions followed by orange-red tip necrosis on current pine needles in response to O_3. A variety of O_3 injury has been observed on deciduous trees and shrubs. Ash and Maple trees show dense purple and reddish stipple on upper leave surface. Many species including lime show leave bronzing while some species such as birch display leaf bleaching. Leaf curling and tip drying have been observed in lilac (Kovàcs, 1992).

2.2.2.1 Biochemical/Physiological Response of Plants to Ozone

- Photosynthesis/stomatal conductance/transpiration: According to Csintalan and Tuba (1992), stomatal response to O_3 varies between species and even cultivars. Some species show increase in stomatal conductance, some show a decrease and some are unaffected. However, at concentrations above 200 ppm O_3, most plants close their stomata. Under controlled conditions, loololly pine seedlings exposed to 12ppm O_3 for seven hours per day, five days per week for 12 weeks, displayed a 16% reduction in photosynthesis in comparison with plants exposed to charcoal filtered air (Spence *et al.*, 1990). The same plant failed to exhibit visible injury under the elevated O_3 conditions.

- Chlorophyll: chlorophyll levels are a direct measure to leaves damage but again not a specific measure of plant damage to pollutant type (Mulgrew and Williams, 2000). Tenge and Ormrod (1990) reported a decrease in level of chlorophyll with an increased O_3 exposure. Smith *et al.* (1990) and Fernandez-Bayon *et al.* (1993) also reported a reduction of chlorophyll content prior to the onset of visible injury.

- Metabolite content: metabolite content has been recommended as a potential response parameter in air pollution bio monitoring (Saxe, 1996). Fumigation of

Aleppo pine with O_3 resulted in delayed rate of ethene emissions, accumulation of total polyamines and increase pool sizes of reduced glutathione and ascorbate in current year needles (Wellburn *et al.*, 1990).

- Enzyme activity: all major pollutants affect enzymes and their activity (Saxe, 1996). Ranieri *et al.* (1994) demonstrated increased peroxidase-catalase detoxification in response to exposure to ambient air open-top field chambers.
- Ultrastructure: Turcsanyi (1992), reviewed plant cells and tissues as bioindicators of environmental pollution and found that ultrastructural responses to O_3 were not very specific. The effects of peroxy-acetyl-nitrate and O_3 are often indistinguishable. Barnes *et al.* (1990) also discovered that O_3 did not significantly alter the needle wax layer in Norway spruce.

2.2.3 Nitrogen oxides and Ammonia (NO_X and NH_3)

Nitrogen content in plants is regarded as a questionable bio indicator of NO_x and NH_3 because it is so easily translocated throughout the plant (Saxe, 1996). Young leaves and needles are more sensitive to NO_x than older ones (Helander, 1993). High relative humidity and N deficiency increase plant sensitivity to NO_x, whereas N excess and drought conditions decrease sensitivity. Relatively higher concentrations of NO_2 are needed to produce acute symptoms on plants in comparison to SO_2 (Mulgrew and Williams, 2000).

Different plant groups react differently to NO_x and NH_3 (Taylor *et al.*, 1990). Most reports of acute plant injury in response to NH_3 are in relation to accidental release or spillage. Many species of herbs, grasses or crops show a water soaked appearance on the leaves followed by necrosis in response to acute NO_x exposure. Necrotic streaking and interveinal necrosis has been recorded in many narrow-leaved and broad-leaved species (Saxe, 1996). Tip necrosis has been observed on other plant parts such as awns, bracts and sepals (Saxe, 1996). Chlorosis of young needles in coniferous trees is a common symptom in response to NO_x. Tip burn of older needles is often observed. Pine trees display bleaching followed by sharply defined red/brown bands between necrotic and healthy tissue in older needles (Taylor *et al.*, 1990). Immediate abscission of older needles occurs in spruce. Herringbone necrosis in the older leaves of beech, hazel and apple trees have been observed. Ivory necrosis, red/brown necrosis and black necrosis have been recorded in certain species (Mulgrew and Williams, 2000).

According to Taylor *et al.* (1990), yellow discolouration, water soaked appearance; glazing and bleaching have been observed on leaves in response to NH_3. Complete system expression on affected vegetation by NH_3 usually takes several days to develop and appears as irregular, bleached, bifacial, necrotic lesions (Plate 2) (Queen's Printer for Ontario, 2008).

Plate 2. Ammonia toxicity on Schefflera

Ivory necrosis, reddish necrosis and brown/black necrosis are typical NH_3-injury symptoms in certain species (Mulgrew and Williams, 2000). Red/yellow discolouration of young spruce needles has been observed. Grasses often show reddish, interveinal necrotic streaking or dark upper surface discolouration (Queen's Printer for Ontario, 2008). Many coniferous species display black discolouration and tip burn of older needles as NH_3-injury symptoms. Yellow discolouration of leaves has been observed in sycamore species (Taylor *et al.*, 1990).

Other symptoms recorded in many species include water soaked appearance on leaves, intercostal necrosis and finally desiccation and abscission of damaged leaves in deciduous trees and shrubs (Mulgrew and Williams, 2000). Flowers, fruit and woody tissues usually are not affected, and in the case of severe injury to fruit trees, recovery through the production of new leaves can occur.

2.2.4. Sulphur dioxide (SO_2)

Queen's Printer for Ontario (2008) mentioned entry of SO_2 into leaves mainly through the stomata (microscopic openings) and the resultant injury classified as either acute or chronic. Acute injury (Plate 3) is caused by absorption of high concentrations of SO_2 in a relatively short time. The symptoms appear as 2-sided (bifacial) lesions that usually occur between the veins and occasionally along the margins of the leaves. Kovács (1992) also indicated symptoms of acute damage of SO_2 >1 ppm as necrosis on the upper and lower leaf surfaces, at the apices, margins and between the veins. The colour of the necrotic area can vary from a light tan or near white to an orange-red or brown depending on the time of year, the plant species affected and weather conditions.

Plate 3 Acute Sulphur dioxide injury to raspberry. Note that the injury occurs between the veins and that the tissue nearest the vein remains healthy.

Many factors affect the sensitivity of plants/trees to SO_2 (Taylor *et al.*, 1990). Young fully expanded leaves/needles are more sensitive than older needles and generally seedlings are more sensitive than older plants and this was confirmed by Queen's Printer for Ontario (2008) which mentioned recently expanded leaves being usually most sensitive to acute SO_2 injury, the very youngest and oldest being somewhat more resistant. Different plant species and varieties and even individuals of the same species may vary considerably in their sensitivity to SO_2 (Queen's Printer for Ontario, 2008). These variations occur because of the differences in geographical location, climate, stage of growth and maturation. Drought, low temperature, nitrogen, sulphur and phosphorous deficiency all reduce SO_2 sensitivity whereas high relative humidity, wind, potassium and calcium deficiency increase sensitivity (Mulgrew and Williams, 2000).

Symptoms of SO_2 on individual plants include light brown necrosis in daffodil, grey necrosis in geranium and tip necrosis on sepals has been observed in marigold and gladiolus. Necrosis on awns of grasses has been reported. Acute visible injury affecting various parts of coniferous trees has been observed in response to SO_2 (Mulgrew and Williams, 2000). Young needles show chlorosis and are poorly developed and stunted. Middle-aged needles often show yellow then red/brown discolouration succeeded by necrosis and abscission of older needles in fir trees. Symptoms of SO_2 on deciduous trees and shrubs include interveinal chlorosis, irregular interveinal necrosis and abscission in many species (Taylor *et al.*, 1990). Necrosis characterised by brown/orange colouring has been revealed in lime, beech and hazel trees while black necrosis has been observed in pear trees. Distortion, puckering and curling of leaves has been detected in birch and maple (Mulgrew and Williams, 2000).

2.2.4.1 Biochemical/Physiological Response of Plants to SO_2

- Photosynthesis/stomatal conductance/transpiration: Csintalan and Tuba (1992) and Saxe (1996) reviewed published experiments of the effects of SO_2 on photosynthesis, stomata functioning and transpiration. Depending on dose, exposure time and species and other abiotic and biotic factors, SO_2 can increase or decrease photosynthesis or open or close the stomata. Disruption of chloroplast metabolism has been implicated in the inhibition of photosynthesis due to SO_2 exposure under controlled conditions.
- Chlorophyll: Chlorophyll reduction directly relates to damage in plants; however it is often regarded, like chlorosis, as a non-specific indication of SO_2 stress. Chlorophyll content was lower in one-year-old needles of damaged spruce trees in comparison with healthy specimens when studied in three different sites in northern Germany (Godbold *et al.*, 1993). Total chlorophyll determination in potted plants

transferred to three different locations in Egypt showed correlation between pollution burdens at the sites (Ali, 1993).

- Metabolite content: Saxe (1996) provides several examples of metabolic changes to plants induced by air pollutants. These include changes in amino acid, polysaccharides and ATP/ADP ratios. A recent study by Julkunen-Titto and Lavola (1995) demonstrated changes in the production of phenolic secondary chemicals and soluble sugars by willow species in response to 0.11 ppm SO_2 fumigation for three weeks.

- Enzyme activity: Enzyme activity has been used as a biochemical stress bioindicator of air pollutants. In Germany, acid phosphatase and peroxidase activity in needles of healthy Norway spruce trees was generally lower than in damaged trees (Godbold *et al.*, 1993). However, the authors could not relate these effects to specific stress factors. Saxe's (1996) review summarised similar findings.

- Ultrastructure: Saxe (1996) documented varying responses of leaf cuticles to pollution stress in an published literature and concluded it was not a very specific bioindication tool. By applying electron microscopy, Manninen and Huttunen (1995) observed that the epicuticular wax structure of Scots pine needles was very badly degenerated in trees in close vicinity to an oil refinery in southern Finland. The destruction rate of the needle surface wax decreased with decreasing S content in needles. By affecting photosynthesis and translocation, gaseous pollutants may reduce carbon allocation to roots. This in turn may reduce root growth, turnover and capacity for water and nutrient uptake (Mulgrew and Williams, 2000).

2.3 AIR QUALITY INDOORS

Deterioration of indoor air quality started as a result of the energy crises in the 1970's when buildings were hermetic, limiting the exchange between the indoor and the outdoor air (Wolverton, 1996). This gave rise to gases trapped in from the cheaper and more effective textiles, synthetic materials, building products and other sources. A condition known as the Sick Building Syndrome (SBS) developed and it is the name given to those symptoms affecting the occupants of a building where complaints due to malaise are more frequent than might be reasonably expected or the adverse health complaints that appear to be associated with the indoor air contamination (Calleja, 2004; Kreiss, 1990). It has been intimated that 15% of indoor air pollution comes directly from the humans inhabiting the building and the remainder from non-human sources (AAO-HNS Foundation, 2000).

2.3.1 Indoor Pollution Sources and its Pollutants

Sources for indoor air pollution can either be biological or non-biological (AAO-HNS Foundation, 2000) and it can be from indoors or from outdoors (Calleja, 2004) and the indoor (internal sources) can fall under these categories:

1) Off-gassing building materials
2) Pollution from electro-mechanical equipment and appliances
3) Combustion
4) Cleaning and maintenance compounds (Gunderson and Farms, 2007).

Table 2 shows some examples of pollutants and the most common sources of emission that can be associated with a drop in quality of indoor air.

Table 2: The most common indoor pollutants and their sources.

SITE	SOURCES OF EMISSION	POLLUTANT/S
Indoors	Construction materials	
	Stone, Concrete	Radon
	Insulation	Formaldehyde, fibreglass
	Wood composites, Veneer	Formaldehyde, organic compounds
	Fire retardants	Asbestos
	Paint	Organic compounds, lead
Equipment and installation	Heating systems, kitchens Biological activity	CO, CO_2, SO_2, NO_X, Organic compounds, particulate matter
	Photocopiers	O_3
	Ventilation systems	Fibres, micro organisms
	Occupants	
	Metabolic activity	CO_2, water vapour, odours
	Biological activity	Micro organisms
	Human activity	
	Smoking	CO, other compounds, particulate matter
	Air fresheners	Fluorocarbons, odours
	Cleaning	Organic compounds odours
	Leisure, artistic activities	Organic compounds odours

Source: (Calleja, 2004) Control of indoor environments: general principles.

2.3.2 Improving Air Quality Indoors

There are different suggestions as to how best indoor air pollution can be solved. Gunderson and Farms (2007), listed the following as ways of improving air quality indoors:

1) Increasing ventilation; this is achieved actively by windows, doors, fans, vents and passively by infiltration of air through walls, roofs and floors.
2) Protection against the pollution source; this is done by isolating or segregating the offending source from exposure to interior air and is achieved with a vapour barrier (6 mil polyethylene plastic sheet) at the time of construction. Other less effective methods are the use of coating, sealers and caulks over the offending surfaces and cracks.
3) Removing the polluting source; the biggest offending material (e.g. carpets) can be removed and replaced with a clean material.
4) Building clean; they suggested the use of low-tech organic materials to build, e.g. are the use of solid wood for furniture and use of no or low VOC coatings on it.
5) Cleaning and conditioning the air; Electrostatic air filters and air-to-air exchanges are the conventional ways of cleaning the air but this does not remove the VOCs which are present in the urban "fresh" incoming air. They therefore suggested the use of plants as a promising alternative for the cleaning of air.

Calleja (2004) also mentioned the use of these factors including the above to eliminate or control indoor pollution:

- Selection of building sites; possible sites for a building should be considered taking into consideration the levels of environmental pollution in the area, analysis of nearby sources of pollution, levels of pollution in the soils and water and information on the climate and the predominate wind direction with its daily variation;

- Architectural design; buildings should be designed taking into consideration the proper planning of the indoor space and orientation of the openings to minimise the amount of contamination that will enter the building.

Wolverton (1996) also stated that attempts to reduce the incidence of "sick building syndrome" resulted in the above-mentioned measures but problems still persist. He made mention of the fact that this can be ironically solved by natural solution that are as old as the earth itself and this is through the living processes of plants. Houseplants can purify and revitalise the air indoors the way nature cleans the atmosphere.

2.3.3 Benefits of plants to the indoor and outdoor environment

Plants at work, Tropical Interior Inc. mentioned the following in their article "Green plants for greening buildings" as the benefits derived from adding green/living plants to our environments (Gilhooley and Anderson, 2004).

- Adding plants to your home or office adds real value to your property. The benefits of plants are quite diverse. Plants are always hard at work to make our environment happier, healthier, safer, and more productive. In Ghana for instance, one pays more for renting office premises that have been landscaped well with plants than one without plants (personal interaction). This is confirmed by BOMA/CEL Tenant Satisfaction A-List Award, 2001 which mentions that clients/employees perceive buildings with interior planting as more expensive- looking and more welcoming and more relaxed. Anderson and Cordell (1988) also mentioned that trees add about 1% to the sales price of a property.

- Plants can reduce stress: studies in a simulated office setting showed a 12% increase in productivity and a lower stressed participant in the environment with plants (Simmonds, 2008-2009). She also mentioned that research conducted by Dr Ulrich showed visual exposure to plant settings produced significant recovery from stress within five minutes and had a measurable effect on blood pressure.

- Plants control and lower distractions from office noise. The leaf and branches muffle noise from cars, air conditioners, generators and others. Additionally, plants can reduce busy office noise lessening the frequency of workplace distractions.

- Interior plants attract and retain selective employees. Studies from Oxford University indicate that plants have positive effects on employee perceptions and dispositions which may lead to increased employee retention. Data from surveys conducted by Unifi Network of Westport, Connecticut indicates that in order to attract and retain top employees, workplaces must include aspects of what inspires those employees during their time off. Research conducted indicated that most workers cited gardening as their favourite off-time hobby. It logically follows then that plants included in the work place will aid in their retention.

- Interior plants boost comfort levels and reduce operation and management costs. According to a study out of Washington State University, plants release moisture in interior applications creating a humidity level matching the recommended human comfort range of 30% to 60%. A comfortable office environment is more conducive to productivity. In addition when office air humidity falls below the recommended range, materials such as wood can become cracked. When office air humidity exceeds the recommended range, condensation on windows and exteriors walls can cause structural damage. By keeping office air humidity levels within the proper comfort range, interior plants can help to avoid costly repairs. Plants contribute to internal air by adding moisture to the air through transpiration and secondarily through evaporation from growing media and drainage dish (Anderson and Gilhooley, 2004).

- Cleaner Air Reduces employee Down Time; plant filled rooms contain 50% to 60% fewer airborne moulds and bacteria than rooms without plants. By cleaning workplace air, plants can significantly reduce sick leave expenses. Plants absorb office pollutants into their leaves and emit clean oxygen helping to reduce employee down time. This was confirmed by a study conducted by Professor Tove Fjeld of the Agricultural University in Oslo in an office who found that the following ailments reduced after the introduction of plants:

Table 3: Effect of the introduction of plants in the reduction of ailments

AILMENTS	% REDUCTION
Fatigue	20%
Headache	45%
Sore/dry throats	30%
Coughs	40%
Dry facial skin	25%

Source: — (Nelly, 2005)

- Plants according to Anderson and Gilhooley (2004) promote innovations and ideas. In a study conducted in an office with plants and one without plants, workers demonstrated more innovative thinking, generating more ideas and original solutions to problems in the office environment that included plants.

- Trees are important providers of shade; when trees are placed westwards where it provides maximum shading benefit, money on energy is saved by the cooling and shading effect provided by the tree (Land Use Consultants, 1993). Trees also cool and freshen the air around them by the evaporation of water from their leaves (Arboricultural Association, 1990).

- Trees intercept 760 gal of rainfall in their crown, thereby reducing runoff of polluted storm water and flooding (Arboricultural Association, 1990). Plants also have an advantage over artificial plants by being less expensive (Simmonds, 2008-2009). He mentioned that substantial amount of money was saved by a hotel by a switch from the use of artificial plants to natural plants. This was as a result of saved money on maintenance. Maintenance involves taking artificial plants outside, washing them, drying them and treating them with fire retardants and by the time cleaning is done twice they will require replacement whilst living plants can be tended in place and minor damage repaired by growing new leaves (Simmonds, 2008-2009).

- Plants are also known to clean the air by the removal of toxins. Trees also have the ability to trap pollutants; leaves of trees absorbs pollutants such as SO_2, NO_x and Pb. 10 lbs. of air pollutants including 4 lbs. of ozone and 3 lbs. of particulates (Arboricultural Association, 1990). Trees clean 330 lbs. of CO_2 (90 lbs. C) from the atmosphere through direct sequestration in the trees wood and reduce power plant emission due to cooling energy savings.

Table 4: The contribution of trees, shrubs and grass to the environment.

	TREES	SHRUBS	GRASS
Air pollution	••	•	•
Dust	••	••	••
Oxygen	•••	•	•
Heat	•••	•	•
Wind	•••		
Noise	••	•	

Source: (Arboricultural Association, 1990)

2.4 SOME CHARACTERISTICS OR PROPERTIES POSSESSED BY POLLUTION RESISTANT PLANTS

According to Zayed *et al.* (1991) a coniferous tree has a wood type which reduces the lateral transfer of contaminants between rings. Conifers were suggested as the most effective species choice for air pollution control due to their evergreen habit, high surface areas and arrangement of foliage: the young leaves of *Sorbus aria* are densely pubescent appearing white particularly on the abaxial surfaces- a property suspected of increasing the pollution –capturing ability (Beckett *et al.*, 1998).

Trees possessing rougher surfaced leaves are effective with the trapping and retention of particles (Sawidis *et al.*, 1995; Beckett *et al.*, 1998).

Some plant types are also chosen because of their rapid rate of dense growth which forms an impenetrable barrier (Beckett *et al.*, 1998). They also mentioned that plants with extremely bushy canopy structure i.e. dense and having complex canopy will be ideal for the interception of pollutant particles.

According to Simmonds (2008-2009), for indoors, plants that require lots of watering are the best for improving humidity levels and tends to have an active metabolism that is helpful in breaking down pollutants. Asaumi *et al.* (2007) also mentioned the use of plants with high transpiration rate for the purpose of keeping the humidity in the room higher as also ideal. Plants with a high leaf area per size of pot should be chosen as the bigger the surface area the more it can absorb pollutants and chemicals (Simmonds, 2008-2009).

Wolverton (1996) said most indoor plants remove at least one type of toxin, although most of them are not able to absorb high levels of all three (formaldehyde, benzene and trichloroethylene). He however, suggested the use of increased soil volume as this improves plant's rate of pollutant absorption.

2.5 HOW PLANTS CLEAN THE AIR

Individual plants from large trees to houseplants create their own mini – ecosystem around the leaves and roots which enables them to survive and grow (Wolverton *et al.*, 1989). They also mentioned that plants actively create and emit a cloud of complex, invisible substances around their leaves and roots that provide for their protection and well-being. Individual plants excrete a complex mixture of sugars, amino acids, hormones, organic acids and other substances that stimulates the growth of specific microbes it needs for survival, and inhibits microbes that would be harmful (Wolverton and Wolverton, 1996). These substances as mentioned by Wolverton and Wolverton (1996) appear to have beneficial functions such as controlling humidity levels and protecting the plant from invasion by insects and airborne microbes.

After more than fifteen years of extensive research by Dr B. C. Wolverton in the laboratories and "real world" environments, he mentioned in his book "eco-friendly house plants" the following as the processes by which houseplants function to improve air quality.

Houseplants, whose origins began underneath the canopy of tropical rainforests, have evolved over millions of years. These plants naturally thrive in dimly lit, warm and humid environments. Nature has equipped these plants with the ability to culture microbes on and around their roots that can degrade complex organic structures found in leaves and jungle debris (Wolverton, 1996). Plant leaves can absorb gaseous organic substances and digest or translocate them to their roots where they serve as food for the microbes (Wolverton, 1996). He mentioned that research has shown some organic substances applied to leaves are translocated not only to the roots, but even into the surrounding soil. This potential by plants to translocate organic chemicals from the atmosphere to the rhizosphere (root zone) demonstrates the potential by plant leaves to absorb VOCs from indoor air and translocate these chemicals unchanged to the root areas where they are broken down by microbes. Wolverton (1996) also explained that some organic chemicals absorbed by plants from the atmosphere are destroyed by the plant's own biological processes without involving the action of microbes in the soil. He also mentioned that the process has been confirmed by a German scientist who labelled formaldehyde with a radioactive carbon 14 tag and followed its absorption and metabolic destruction inside a spider plant (*Chlorophytum comosum*). The formaldehyde was metabolised and converted into tissue products such as organic acids, sugars and amino acids as demonstrated by the carbon 14 label (Giese *et al.*, 1994).

Wolverton (1996) also mentioned transpiration as another means by which plants move air-polluting substances to microbes around the roots which are then broken down. Whenever there is a significant difference in the temperature between leaf surfaces and air, convention currents are created that causes an air flow even when there is no other air flow (Wolverton, 1996). Also, as water rapidly moves from roots up through the plant, air is pulled down into the soil around the roots. This is one means by which plants can supply oxygen and gaseous nitrogen to their root microbes which is converted to nitrates for plants food. This ability to produce movement of air aids plants to remove toxins because the conditioned air inside buildings is naturally dry (Wolverton, 1996). He mentioned that higher transpiration rate aids the movement of toxin-laden air to the root zone where microbes in the soil can break down the gases into a source of food and energy. Then root microbe e.g. bacteria also use other chemical substances in the room air, such as toxic chemicals as a source of food and energy (Nelly, 2005). Microbes e.g. bacteria can rapidly adapt to chemical contaminants by producing new colonies that are resistant to the chemical (Wolverton, 1996).

Plants also release phytochemicals that suppress mould spores and bacteria found in the ambient air (Wolverton, 1996). Phytochemicals are produced in leaves or secreted by plant roots. He stated that research findings show rooms filled with plants contained 50% – 60% fewer airborne moulds and bacteria than rooms without plants. Note: bacteria in soils are not harmful to humans but that in ambient air is.

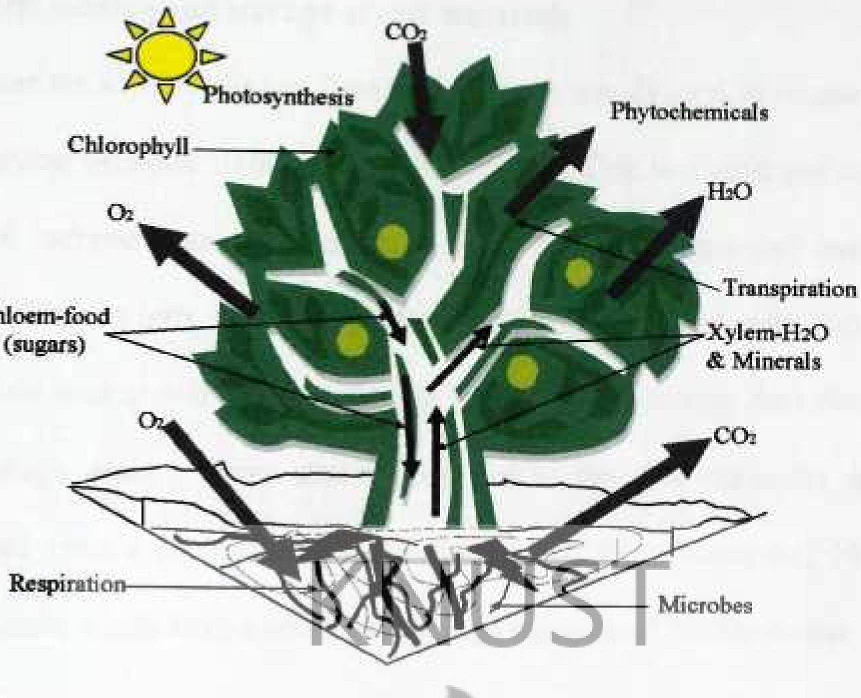

Fig.1 Biological functions of plants and their root microbes.

2.6 SPECIAL STUDIES ON CEMENT PRODUCTION

Ghacem operates a 1.2 million tonnes per year cement grinding plant located at the Heavy Industrial Area of the Tema Harbour (Ghacem Tema Works, 2001). Clinker, lime and gypsum are mixed as the raw materials in determined and specific proportions and ground to produce cement (Van Nostrand, 1992).

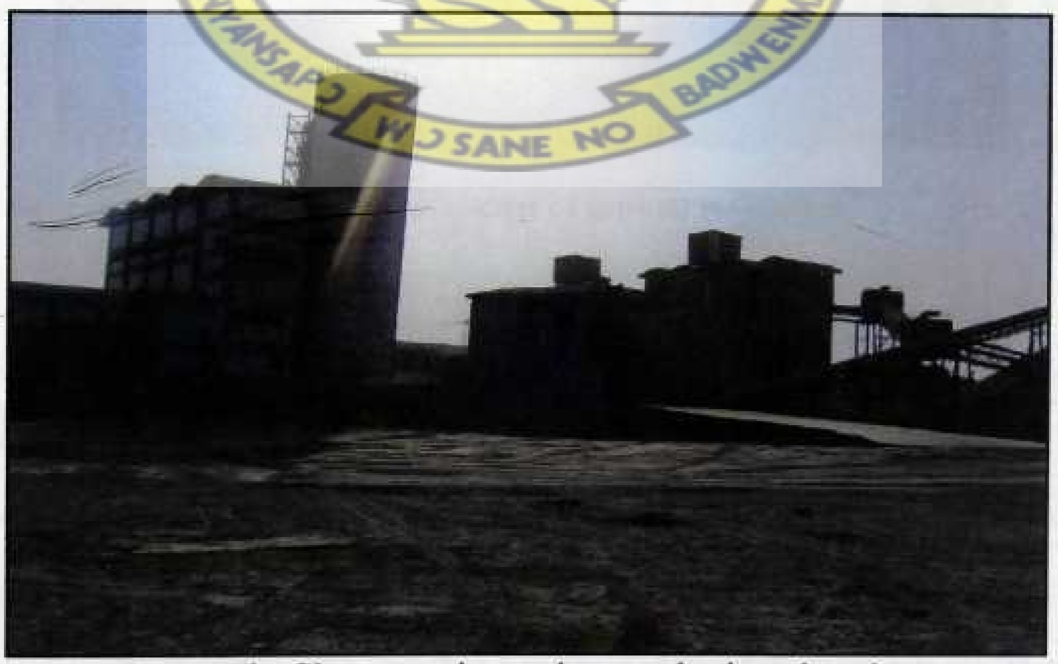

Plate 4 The Ghacem environs where production takes place.

2.6.1 Off-loading and storage of raw materials

Raw materials such as clinker, lime and gypsum are shipped in coarse form and in loads varying between 10,000 and 25,000 tonnes. This is discharged in a section of the Tema harbour from ships to trucks using the ship cranes and mobile hoppers. From the Ghacem jetty, trucks travel for approximately 500m to the factory yard and empty their load at two different tipping points or for gypsum lime directly into the open storage areas. From the tipping points the raw materials are gradually transferred onto a conveyor belt and transported (Van Nostrand, 1992) to three clinker sheds, which have a combined storage capacity of 75,000 tonnes.

Plate 5 Open-air storage of gypsum at Ghacem.

2.6.2 Processing

2.6.2.1 Grinding of raw materials

From their respective storage areas, clinker lime and gypsum are conveyed into mill bunkers, which feed four rotary ball mills (Van Nostrand, 1992). Metal balls grind the mixed raw material until a very fine powder is obtained. Cement particles that do not meet the required size are separated through a sieve located at the outlet of the mill and collected into bins for open recirculation into the feed mill. Cement is transported by air pressure to three silos, which have a combined storage capacity of 6,700 tonnes.

2.6.2.2 Packaging/Sale

From the silos, cement is transported by a bucket elevator to bunkers feeding three packing machines. Cement bags are then manually loaded onto Lorries.

2.6.3 Impact of dust

Although the dust from all these operations is generally non-toxic, non-corrosive, non-inflammable, non-explosive and not hazardous, they are known to cause health problems that are of both epidemiological and onchological concern and if not controlled constitutes a nuisance within the plant and the surroundings. Particulate pollutants (dust inclusive), is however said to be a hazard to human, plant or animal life because of their characteristic persistent presence in the air in low concentrations (Holper and Noonan, 2000).

Cement dust deposited on vegetation (Plate 9 and 10) can inhibit the normal respiration and photosynthesis mechanisms within the leaf and it may cause chlorosis and death of leaf tissue by the combination of a thick crust and alkaline toxicity produced in wet weather (Queen's Printer for Ontario, 2008). The dust coating also may affect the normal action of pesticides and other agricultural chemicals applied as sprays to foliage. In addition, accumulation of alkaline dusts in the soil can increase soil pH to levels adverse to crop growth (Queen's Printer for Ontario, 2008). Cement dust (up to 10 ppm) is noted as travelling up to 1 km in the direction of the wind

(Ghacem Tema Works, 2001). A marked reduction in the growth of poplar tree was observed by Lerman and Darley, 1.6 km from a cement plant after cement production was more than doubled (Iqbal and Shafig, 2001).

In comparison with gaseous air pollution, many of which are readily recognised as being the cause of injury to various types of vegetation, relatively little is known and limited studies have been carried out on the effects of cement dust pollution on the growth of plants (Iqbal and Shafig, 2001). However studies conducted by Iqbal and Shafig (2001) indicated that cement dust which is fine textured showed a high percentage of water holding capacity (65.72%), chemically the soils were alkaline in nature having a pH of 9.5 with 22% of Calcium carbonate and alkaline carbonate (2.45 meg/1). The chlorine and conductivity were 8.6 meq/1 and 506 µs/cm respectively.

Plate 6 Cement-dust coating on apple leaves and fruit

Cement dust which is a source of particulate matter deposits has different effects on different plants: it reduced the number of flower and yield in *Vigna mungo* (Prasad and Inamdar 1990), they also mentioned a reduction in the chlorophyll content, protein, starch, yield and phytomass in *Arachis hypogaea*; Abdullah and Iqbal (1991) observed cement dust clogging the stomata of *Iponia grandtiodes* Boiss; Darley *et al.*, (1966) noted plants were stunted and had few leaves in the heavily dusted portions of an alfalfa field downwind from a cement plant in California; Bradt and Rhoades (1972) also observed changes in structure and composition of the seedling, shrubs, sapling and tree strata when they compared dusted and non-dusted forest communities in the vicinity of cement processing plants; Iqbal and Shafig (2001) also attributed the reduction in the height, cover and number of leaves of *Carrissa carandas* to cement dust which contain toxic metals such as chromium and copper. These heavy metals play an important role in the disturbance of the various metabolic processes in plants. Iqbal and Shafig (2001) also mentioned a decrease in height of Flamboyant (*Poinciana regia*) due to a decrease in the phytomass, net primary production and chlorophyll content in response to the cement dust. In the study, Neem (*Azadirachta indica*) also showed no significant change in the cover and height with the exception of leaves which was reduced.

CHAPTER THREE

3.0 METHODOLOGY

3.1 STUDY AREA

The study was conducted at the Ghana Cement Limited in Tema in the Greater Accra region of Ghana to select most appropriate plant species that will perform dual function namely; manage air pollution while serving aesthetic purposes.

The study area lies in the coastal savannah, specifically the Accra plains which is almost flat and featureless and gradually descend to the gulf from a height of about 150m. The area receives about 750mm–1000mm of rainfall annually whiles the average minimum and maximum temperatures are 23°C and 29°C. Heavy rains fall from about April through late June. After a relatively short dry period in August, another rainy season begins in September and lasts through November, before the longer harmattan season sets in (Britannica, 2007). The soils are generally sandy and support mainly sparse shrubby vegetation. The direction of the wind from the factory is from southwest to northeast.

Tema, the industrial hub of Ghana houses the greater part of the heavy industry of the country including the first and largest cement producing industry Ghacem. There are no regular measurements of pollutants by automatic monitors in the greater part of the study area.

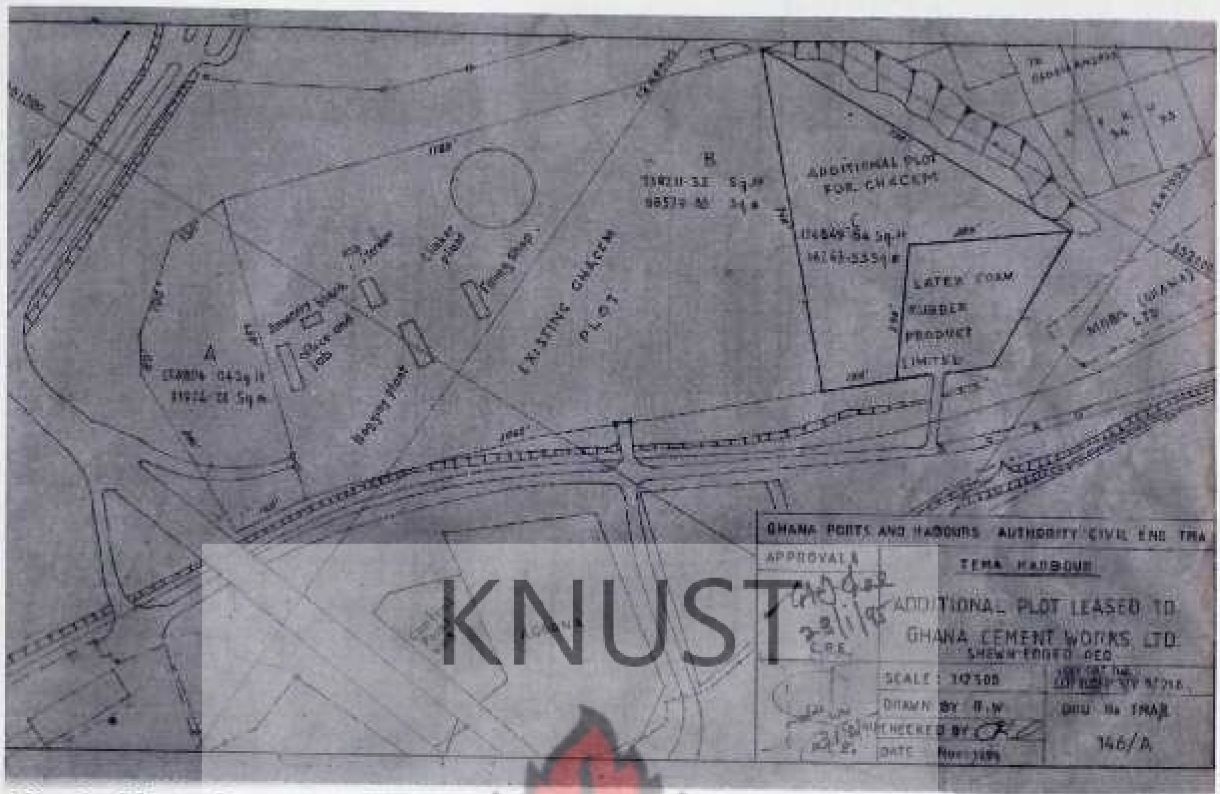

Fig. 2: Ghana Cement Ltd (Ghacem) and its environs

3.2 PLANT SAMPLING

Sixteen (16) ornamental plant species found growing around the Ghacem area were scored for defoliation and discolouration using a scale by Lorenz *et al.* (1997) and compared to the same species of plants growing in a residential area (Community Six) where no industrial activity takes place. Community Six is about 7km away and west of Ghacem opposite the average direction of prevailing winds (The direction of the wind from the factory is from southwest to northeast). The scoring class is presented in Table 5.

Table: 5 **Defoliation and Discolouration classes**

DEFOLIATION CLASS	LEAF LOSS	DEGREE OF DEFOLIATION
0	Up to 10%	None
1	>10-25%	Slight (warning stage)
2	>25-60%	Moderate
3	>60-<100%	Severe
4	100%	Dead
DISCOLOURATION CLASS	**FOLIAGE DISCOLOURED**	**DEGREE OF DISCOLOURATION**
0	Up to 10%	None
1	>10-25%	Slight (warning stage)
2	>25-60%	Moderate
3	>60-<100%	Severe
4	100%	Dead

Source: Lorenz *et al.* (1997); according to UN ECE and EU classification.

Samples of those found to have attained class of 1-4 were taken to the University for Development Studies Spanish Grant Laboratories for further examination. Samples of plants belonging to the same species were also taken from Community Six (6). This was to determine whether pollutants from the industry are the cause of defoliation and discolouration in the plants.

3.2.1 Measurement of Chlorophyll Content.

Five air-dried samples from each of the sites were ground to produce sub samples of 0.1 g. The total chlorophyll (*a* + *b*) content was determined according to Moran (1982) using 15 mL of Dimethyl sulfoxide (DMSO; Merck, analytical grade) as an extraction solvent (Ronen and Galun, 1984) and the extract run through an ultra violet spectrometer.

3.2.2 Species Selection

Defoliation and discolouration are the major assessment parameters of crown condition in transnational survey (Mulgrew and Williams, 2000). Foliar analysis has been used to assess the air pollution burden in national parks and landscape protection areas in Slovakia (Mankovska, 1997). Defoliation class was therefore used to select the most appropriate plants growing well in the area to manage pollution while at the same time providing an aesthetic view. Other plants from literature thought to be appropriate for the landscape (i.e. outdoors and indoors) in the industrial environment of Tema area were also recommended.

3.3 ASSESSING SOURCES OF INDOOR POLLUTION

The offices and premise were inspected for equipments and other materials that could be possible sources of indoor pollution (Calleja, 2004).

3.3.1 Assessing sources of dust emissions

On site studies were also done to observe the point sources and non-point sources of the cement dust emission from the factory through their processing which also serve as source for indoor pollution (Calleja, 2004).

CHAPTER FOUR

4.0 RESULTS

4.1 PLANTS PERFORMING WELL AND ADAPTED TO THE INDUSTRIAL ENVIRONMENT AT GHACEM.

Table 6: Defoliation and Discolouration Class of selected plants species growing at Ghacem

TREE	DEFOLIATION CLASS	LEAF LOSS
Albizia lebbeck	0	2%
Azadirachta indica	0	2%
Calotropis gigiantica	0	2%
Casuarina equisetifolia	0	4%
Cocos nucifera	0	3%
Duranta species	0	4%
Eucalyptus globulus	0	3%
Ipomoea carnea	1	>10-25%
Jatropha integerrima	0	2%
Lagerstroemia speciosa	0	3%
Leuceana leucocephala	0	2%
Milletia thonningii	3	90%
Pithecellobium dulce	0	2%
Polyalthia longifolia	1	>10-25%
Punica granatum	0	4%
Roystonea regia	0	3%
Terminalia catappa	0	2%

A defoliation and discolouration class of "0" was attained by fourteen (14) of the plants sampled with varying degrees of leaf loss with the highest being 4% and least of 1%. Two of the plants attained a class of "1". *Millingtonia hortensis* had a defoliation and discolouration class of "3" with a 90% leaf loss. A class of "4" was attained by *Elaeis guineensis* with a 100% leaf loss.

Table 7: Chlorophyll 'a' concentrations of selected plants species growing at Ghacem (mg/g).

PLANT NAMES	RESIDENTIAL SITE	INDUSTRIAL SITE
Albizia lebbeck	3.00	1.21
Azadirachta indica	3.30	2.80
Calotropis gigiantica	3.08	2.78
Casuarina equisetifolia	3.06	2.96
Cocos nucifera	2.98	1.63
Duranta species	1.80	0.92
Eucalyptus globulus	2.76	1.24
Ipomoea carnea	2.90	1.34
Jatropha integerrima	2.18	1.18
Lagerstroemia speciosa	2.68	1.42
Leuceana leucocephala	3.50	2.98
Pithecellobium dulce	3.08	1.98
Polyalthia longifolia	2.78	1.98
Punica granatum	2.02	1.18
Roystonea regia	2.03	1.40
Terminalia catappa	2.68	1.30

Chlorophyll content of Leuceana (*Leuceana leucocephala*) of 3.50 was the highest for the plants from the residential area, followed by (Neem) *Azadirachta indica* 3.30 and the lowest 1.80 for Yellow Duranta (*Duranta* species. However, the chlorophyll content of the same plants from the industrial area had lowered values i.e. 2.98 as the highest followed by 2.80 and a least of 0.92 respectively.

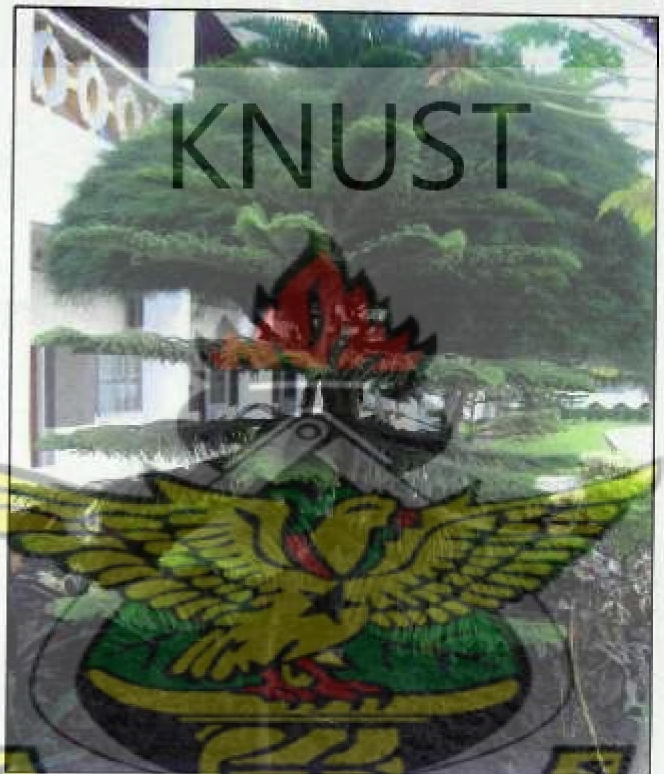

Plate 7 Visible cement dust on *Araucaria heterophylla*

Plate 8 Dust covered *Casuarina equisetifolia*

4.2 INDOOR AIR POLLUTION SOURCES

4.2.1 Indoors:

- The hermetic offices of Ghacem (Plate 11).
- Off gassing building materials; concrete, paints, wood composites, carpets, adhesives.
- Pollution from electromechanical equipment and appliances; photocopiers, fax machines, telephones, printers, refrigerators, e.t.c. (Plate 12).
- Cleaning and maintenance compounds; any cleaning and repair product.
- Occupants' activities; metabolic activities of occupants, biological activities of microorganisms and tobacco smoking.

Plate 9 Hermetic offices of Ghacem

Plate 10 A typical office at Ghacem

4.2.2 Outdoors:

The following were noted as sources of dust which is visible around the production area from the cement production process which also pollutes the indoors.

- Unloading of clinker from harbour.
- Filling of the hoppers.
- Movement of the haulage trucks, clinker falling from the haulage trucks.
- Tipping of the clinker.
- Offloading of lime.
- Manufacturing process; conveying system.
- Packaging; spillage from damaged bags and defective bags.

Plate 11 Dust causes a haze in and around the production area

CHAPTER FIVE

5.0 DISCUSSION

5.1 PLANTS PERFORMING WELL AND ADAPTED TO THE INDUSTRIAL ENVIRONMENT AT GHACEM.

5.1.1 Defoliation and discolouration classes.

The defoliation class of '0' for *Albizia lebbeck* (Albizia) (Table 6) indicates no visible effect on the foliage. The following characteristics make it a good choice of plant to aid in the reduction of pollutants: it is fast growing, it is deciduous; leaf structure/arrangement is compound and therefore has a wide surface area to capture dust particles (Sawidis *et al.*, 1995). It sheds its leaves in the dry season which is a dormant state and therefore the tree does not suffer further injury by pollution (Garrec, 2008). The production of new leaves creates new surface areas for pollution interception and young leaves are more resistant to pollutants (Queen's Printer for Ontario, 2008).

A defoliation and discolouration class of '0' indicating no visible effect on the plants by pollutants was attained by *Calotropis gigiantica* (Crown flower). Its leaf surface is waxy and rough and therefore can afford to trap some dust particles (Sawidis *et al.*, 1995).

Casuarina equisetifolia (Whistling pine) with a defoliation and discolouration class of '0' is able to withstand pollution around industrial environments. It is fast growing and deciduous making it a good choice for pollution reduction (Sawidis *et al.*, 1995). Its conifer-like leaves called phyllodes have rough surfaces enabling them to trap dust pollutants (Sawidis *et al.*, 1995). Their stomata are sunk in ridges in a thick waxy cuticle and would therefore reduce clogging by dust and also, are salt resistant (NFTA, 1990).

A defoliation and discolouration class '0' for *Cocos nucifera* (Coconut) indicates no effect on its foliage. This plant has been mentioned as having a high tolerance rate of salts (Duke, 1983) hence it can withstand pollutants in salt forms.

Duranta species (Yellow Duranta) with defoliation and discolouration class of '0' indicates ability to withstand pollution. It is fast growing, dense and evergreen foliage which is all attributes of a plant which can withstand pollution according to (Sawidis *et al.*, 1995 and Beckett *et al.*, 1998).

A defoliation and discolouration class of '0'by *Eucalyptus globulus* (Eucalyptus) indicates no visible pollution effect on the plant. The leathery textured leaves that hang obliquely or vertically give it a complex canopy which will easily intercept pollutants (Sawidis *et al.*, 1995). Leaves are pubescent. Young leaves stay up to 4-5 years before matured ones take over and it is an advantage because young leaves are more resistant to pollutants (Queen's Printer for Ontario, 2008).

A class of '1' for defoliation and discolouration by *Ipomoea carnea* (Morning glory) shows a slight damage from pollutants. Its character that aids as a pollution resistant plant is its naturalization near sea level (Stone, 1970) indicating an ability to withstand salts.

Jatropha integerrima (Jatropha) had defoliation and discolouration class of '0' meaning there is no visible effect on the plant. It is an evergreen plant and therefore can be recommended for use as a pollution resistant plant (Sawidis *et al.*, 1995).

Lagerstroemia speciosa (Queen's flower) had defoliation and discolouration class of '0' indicating no visible effect of pollutants on the plant. It is a good choice for the area because it is a fast growing deciduous plant which is very hardy and vigorous (Sawidis *et al.*, 1995 and Beckett *et al.*, 1998).

Leuceana leucocephala (Leuceana) with defoliation and discolouration class of '0'from Table 6 indicate a resistance to effects of pollution. It is a deciduous plant with dense foliage which can form an impenetrable barrier and therefore can withstand pollution (Sawidis *et al.*, 1995). It is a nitrogen fixing plant and therefore has microbes at the root zone which enhances the breakdown of pollutants that are translocated to the roots (Wolverton, 1996).

Pithecellobium dulce (Manila tamarind) with defoliation and discolouration class of '0' means no visible effect on the plant. It has spines and a lot of foliage which will serve as surfaces for pollutant trappings and therefore is a good pollution resistant plant (Beckett *et al.*, 1998).

Defoliation and discolouration class of '1' attained by *Polyalthia longifolia* (Weeping willow) indicate slight visible effect on the plant. It is a good plant for pollution abatement because it is evergreen with willowy pendulous branches and unique leave arrangements which give more surface area for interception of pollution particles (Beckett *et al.*, 1998).

The defoliation and discolouration class of '0' by *Punica granatum* (Punica) indicate no visible effect on the plant. The characteristics it has for pollution tolerance includes its ability to form a dense hedge and salt resistance.

Defoliation and discolouration class of '0' for *Roystonea regia* (Royal palm) indicates no visible effect on the plant. It can be fast growing if water and fertilizer are provided (Floridata, 1996-2007) and the leaves will serve as surfaces for pollution absorption (Beckett *et al.*, 1998). It is also salt tolerant and can therefore intercept pollutants that are in the dry form.

Terminalia catappa (India almond) with a defoliation and discolouration class of '0' is an indication of no visible effect of pollution. Its large size of leaves gives a larger surface area for the absorption of pollutants (Wolverton, 1996). Leaves drop and are quickly replaced by new growth hence new surfaces for the absorption of pollutants and according to Queen's Printer for Ontario (2008) younger leaves are more resistant. It is also a deciduous plant, a quality identified for choosing pollution resistant plants (Beckett *et al.*, 1998).

Plants apart from *Elaeis guineensis* (Oil palm) and *Milletia thonningii* (Milletia) were resistant because their life systems were able to restore their normal metabolic activities through the reparation mechanisms (elimination of all malfunctions) or compensation mechanisms (the perturbation and its physiological consequences persist but mechanisms counterbalance their harmful effect) (Garrec, 2008). *Elaeis guineensis* (Oil palm) and *Milletia thonningii* (Milletia) died and severely affected respectively as a result of their inability to repair or compensate for the malfunctions and the metabolic changes, resulting from the absorption of pollutants (Garrec, 2008).

5.1.2 Chlorophyll concentration.

The higher chlorophyll content recorded for all the plants from the residential area (ranging from 2.18-3.50) as against those from the Ghacem site (ranging from 0.92-2.98). Different plant species and varieties and even individuals of the same species may vary considerably in their sensitivity to pollutants (Queen's Printer for Ontario, 2008) and this may have accounted for the differences. They mentioned variations in chlorophyll concentration to be as a result of the differences in the plants stage of growth and maturation. Cement dust deposit on vegetation can inhibit the normal respiration and photosynthetic mechanisms within the leaf and it may cause chlorosis and death of leaf tissue by the combination of a thick crust and alkaline toxicity produced in wet weather (Queen's Printer for Ontario, 2008), this can also account for the differences.

Chlorophyll concentration from residential areas being higher than the industrial area agrees with Prasad and Inamdar (1990), who mentioned a reduction in the chlorophyll content, protein, starch, yield and phytomass in *Arachis hypogaea* and also; Bradt and Rhoades (1972) observation on the changes in structure and composition of the seedling, shrubs, sapling and tree strata when they compared dusted and non-dusted forest communities near cement processing plants. Chlorophyll reduction directly relates to damage in plants by affecting photosynthesis and translocation, gaseous pollutants may reduce carbon allocation to roots. This in turn may reduce root growth, turnover and capacity for water and nutrient uptake (Mulgrew and Williams, 2000) of the various plants.

The differences in the residential and industrial site in Table 7 may be an indication that although most of the plants at the Ghacem site were resistant to pollutants emanating from the industry, there is still some effect on the plants which may be due to clogging of the stomata by cement dust (Plate 4 and 5) (Abdullah and Iqbal (1991) which contains toxic metals such as chromium and copper that play an important role in the disturbance of the various metabolic processes in plants (Iqbal and Shafig, 2001). In addition, accumulation of alkaline dusts in the soil can increase soil pH to levels adverse to crop growth (Queen's Printer for Ontario). They also mentioned a decrease in height of *Poinciana regia* to be due to the decrease in the phytomass, net primary production and chlorophyll content in response to the cement dust. A study conducted in a highly polluted industrial area in Shoubra Elkheima near Cairo on pot planted *Trifolium pratense* and *Malva parviflora* placed at increasing distances from the industrial pollution sources also showed an increase in visible injury i.e. a reduction in chlorophyll content, an increased number of plants with visible damage in the area of injured leaves, a reduction in leaf number, a reduction in plant growth and weight near the industrial area compared with the controlled station (Ali, 1993). Chlorophyll content was also lower in one-year-old needles of damaged spruce trees in comparison with healthy specimens when studied in three different sites in northern Germany (Godbold *et al.*, 1993). Pollutants such as sulphur and the combined effects of the various air pollutants may also have their effect on these plants (Holper and Noonan, 2000).

5.2 INDOOR AIR POLLUTION SOURCES:

5.2.1 Indoor sources;

The Ghacem office buildings are hermetic (Plate 11) and therefore limits the exchange of air between the indoor and the outdoors giving rise to trapped gases indoors (Wolverton, 1996). This reduces the quality of the indoor air. Indoor air pollutant sources include off-gassing building materials, pollution from electro-mechanical equipment and appliances, combustion and cleaning and maintenance compounds (Gunderson and Farms, 2007). All these sources were observed as present in the Ghacem offices (Plate 12) and the cleaning agents also contributed to a drop in air quality indoors.

5.2.2 Outdoor Sources: Sources of Dust and Observation.

The major sources of dust releases from the Ghacem process have been noticed during the various monitoring periods. Within the Ghacem processing plant, potential dust emissions are released essentially from point sources and to some extent from non-point sources. The direction of the wind from the factory is from southwest to northeast carrying the dust particles along on its path.

Unloading operations of clinker from ships at the harbour produce substantial amount of dust and create nuisances to the dry docks located just 100m away. High amounts of dust are generated during filling of the hoppers and subsequently the haul trucks. Clinker is transported by trucks, for approximately 500m to one of the two tipping points located in the factory. This operation also generated some dust as the road is untarred and clinker falling from the trucks is crushed hence generating dust.

Clinker is off-loaded from the trucks into a ground hopper enclosed in a building called the tipping point. From the bottom of the hopper, clinker is deposited onto a conveyor belt and transported to the top of one of the three filters. The volume of the air within the tipping zone at each of the conveyor transfer point and from holes or openings in the clinker sheds also produced a lot of dust at virtually all stages of the process.

During off-loading of gypsum/lime, because the dust control system is inefficient, a lot of dust is produced, but in much lesser quantities due to the nature of these raw materials. Throughout the entire conveying process, high levels of dust are emitted into the environment, especially at conveyer intersections.

Dust is also lost to the environment (Plate 13) during the manufacturing process, feeding the mills and screening units. During packaging and dispatch, considerable amount of dust is also lost to the environment. Cement is transported hermetically from the silos into packing machine feeders. The packing machines, though equipped with dust filters, are considered to be an important intermittent point source of dust within and outside the packing plant building (Plate 13). This is due to the breakage of defective bags. Spillage from damaged or defective bags soils the floor of the loading bays during the loading of bags; and this can be dispersed into the atmosphere by winds, lorry tyres and exhausts. During bulk loading, cement dust is dispersed into the atmosphere via displaced air.

A review of the environmental auditing done for the industry in 2001of the process and associated impact is summarised in the following flow chart. The Baseline information is presented through identified environmental impacts of Ghacem operations, which have been assessed through several studies of the environment undertaken by internal and external environmental consultants.

The main negative impact is also dust releases into the atmosphere, which result from mechanical handling and grinding of raw materials and packaging of the cement (Plate13). Other impacts are releases of non-process liquid effluents into an open drain, production of domestic and non-hazardous industrial wastes and generation of physical nuisances such as noise and heat (Ghacem Tema Works, 2001).

Table 8: Summary of Potential Impacts (Releases) to the Environment

process of support operations	activity or process unit	into atmospheric environment	onto aquatic environment	onto land environment	other nuisance
Raw material (clinker, gypsum and lime)	*Ship crane grab	Dust	-	-	-
	*Crane release	Dust	Spillage		-
	*Hoppers	Dust	-	Spillage	-
	*Hauling	Dust	-	Spillage	-
	*Tipping	Dust	-	Spillage	-
	*Transfer points	Dust	-	Spillage	-
	*Storage in shed	Dust (minimal)	-	Spillage	-
	*Open storage	Dust	-		-
	*Pay loader	Dust	-	Spillage	-
Processing, grinding and product storage	*Conveyors	Dust	-	Spillage	-
	*Transfer point	Dust	-	Spillage	-
	*Mill hoppers	Dust	-	Spillage	-
	filling	-	-	Spillage,	Noise, Hea
	*Milling	Dust	-	Waste oil	
	*Screening	-	-	Spillage	Noise
	*Compressor	Dust	-	Waste oil	
	*Flux pump	Dust	-	Spillage	Noise
	*Silos				
Packing and sale	*Bulk cement	Dust	-	Spillage	-
	*Bucket elevator	-	-	-	-
	*Feeder	Dust	-	-	-
	*Packing machine	Dust	-	Spillage	Noise
	*Loading of trucks	Dust	-	Spillage	-
Ready mix concrete plant	*Mixing	-	-	Spillage	-
	*Loading unto	Dust	-	Spillage	-
	trucks	-	Effluent	-	-
	*Washing of trucks				

Source: (Ghacem Tema Works, 2001)

5.3 RECOMMENDED PLANT SPECIES

5.3.1 DESCRIPTION OF PLANT SPECIES PERFORMING WELL IN THE GHACEM ENVIRONS.

- **ALBIZIA LEBBECK (ALBIZIA)**

Family: Fabaceae

Growth structure: it is a large deciduous tree. It grows up to 30m tall with a diameter of up to 1m, but more often 15-20m tall and a diameter of 0.50m and is a shallow rooted plant (Prinsens, 1988).

Leaves: are pinnately compound and have glands at the base of the petiole. It sheds its leaves in the dry season (Prinsens, 1988).

Flowers: flowers are clustered in globose heads, are white, bipinnate, 30cm long and fragrant especially in the early evenings.

Fruits: Are pods, 19-28cm long and 3-5.5cm wide and are straw coloured and remain on the trees for long periods, rattling in the winds when they brush together (Prinsens, 1988).

Additional information: May be a noxious weed or invasive. It can be planted in exposed areas as a quick growing shelter and also used as a roadside tree (Prinsens, 1988).

Plate 12 *Albizia lebbeck* (Albizia)

♦ **AZADIRACHTA INDICA (NEEM)**

Family: Meliaceae.

Origin: is native to Bangladesh, India, Myanmar and Pakistan.

Other names: *Azad Dirakht* , DogonYaro, Margosa, Neeb, Nimtree, Nimba.

Growth structure: Neem is a fast-growing tree that can reach a height of 15-20 m, rarely to 35-40 m. The branches are wide spread. The fairly dense crown is roundish or oval and may reach the diameter of 15-20 m in old, freestanding specimens. The trunk is relatively short, straight and may reach a diameter of 1.2 m. The bark is hard, fissured or scaly, and whitish-grey to reddish-brown. The sapwood is greyish-white and the heartwood reddish when first exposed to the air becoming reddish-brown after exposure. The root system consists of a strong taproot and well-developed lateral roots (Wikipedia, 2008).

Leaves: The alternate, pinnate leaves are 20-40 cm long, with 20-31 medium to dark green leaflets about 3-8 cm long. The terminal leaflet is often missing. The petioles are short. Very young leaves are reddish to purplish in colour. The shape of mature leaflets is more or less asymmetric and their margins are dentate with the exception of the base of their basiscopal half, which is normally very strongly reduced and cuneate (Wikipedia, 2008).

Flowers: The flowers (white and fragrant) are arranged axillary, normally more-or-less drooping panicles which are up to 25 cm long. The inflorescences, which branch up to the third degree, bear 150-250 flowers. An individual flower is 5-6 mm long and 8-11 mm wide. Protandrous, bisexual flowers and male flowers exist on the same individual (polygamous) (Wikipedia, 2008).

Fruits: The fruit is a glabrous olive-like drupe which varies in shape from elongate oval to nearly roundish, and when ripe are 1.4-2.8 x 1.0-1.5 cm. The fruit skin (exocarp) is thin and the bittersweet pulp (mesocarp) is yellowish-white and very fibrous. The mesocarp is 0.3-0.5 cm thick. The white, hard inner shell (endocarp) of the fruit encloses one, rarely two or three, elongated seeds (kernels) having a brown seed coat (Wikipedia, 2008).

Additional information: The neem is a tree noted for its drought resistance. Neem is a life-giving tree in South India, especially for the dry coastal southern districts (Wikipedia, 2008).

Plate 13 Neem tree growing around Ghacem

- **CALOTROPIS GIGIANTICA (CROWN FLOWER)**

Family: Apogynaceae

Origin: it is found growing at coasts and in relatively dry locations. It originated in Pakistan and Southern Asia.

Other names: Crown flower; Giant milkweed; Ivory plant; Madar.

Most important features: all parts of the plant have a milky sap. They are set opposite. They are stiff, leathery, and a waxy bluish grey. The flowers are cream white to violet. They grow in a group that forms a sort of pyramid (Austin, 2004).

Growth structure: the bush has firm branches and grows from 1-5m high. Occasionally it grows as a small tree (Austin, 2004).

Leaves: the leaves have short petioles and a heart-shaped bottom. They are elliptical, 8-20cm long and 4-12cm wide with pointed ends (Austin, 2004).

Flowers: the inflorescences appear like false umbels. They are 2.5-4.5cm long. The waxy petals widen. The pyramid developed the corona is 1.5cm high and often slightly darker than the petals. The stigma is greenish yellow (Austin, 2004).

Fruits: these are bluish green, 7-8cm long, and 2.5-4cm thick. The fruits are bent at the bottom and have many seeds. Each seed has a hairy tuft (Austin, 2004).

Plate 14 *Calotropis gigiantica* (Crown flower).

- **CASUARINA EQUISETIFOLIA (WHISTLING PINE)**

Family: Casuarinaceae

Origin: It is native to the southern hemisphere particularly Australia and the Indonesian region.

Other names: Iron wood, Coast she-oak, Horsetail, Australian pine, beefwood,

Most important feature: all casuarinas are nitrogen fixing and can be distinguished from conifers by the fact that their "needles" are segmented each one being a branchlet called phyllode, consisting of a number of fused leaves (Torrey and Berg, 1988).

Growth structure: they are fast growing hardwoods and have conifer-like appearance which is increased by hanging green branchlets and cone-like fruits. The stomata are sunk in ridges in a thick waxy cuticle: both are adaptations for water conservation (NFTA, 1990; Wood 1987). The stem of Casuarinaceae is composed of two parts: indeterminant persistent branches which, after secondary thickening form the permanent above ground plant body; and determinant deciduous branchlets about 1.5-2.5mm in diameter (NFTA, 1990). They grow up to 10-40m (Wood 1987; NFTA, 1990).

Leaves: they are reduced to white or brown scales (Torry and Berg, 1988) and appear as whorls of tiny teeth around regularly spaced nodes.

Flowers: they are reduced unisexual flowers with catkin-like inflorescences which are wind pollinated (Wood 1987; NFTA, 1990). They are dioecious and monoecious. They produce large quantities of seeds.

Additional information: the leaf structure is a valuable adaptation to survival in arid climate (Wood, 1987). Whistling pine is widely used to stabilize coastal sand dunes because of its resistance to salt spray (NFTA, 1990).

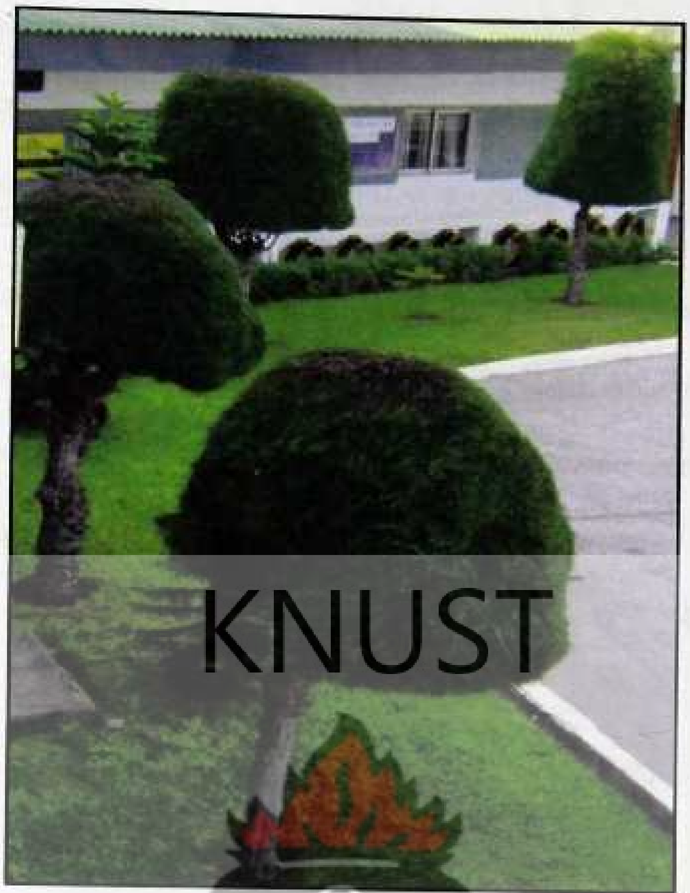

Plate 15 *Casuarina equisetifolia* doing well in the Ghacem environs.

- **COCOS NUCIFERA (COCONUT)**

Family: Arecaceae

Growth structure: it grows up to 27 m or more, bearing crown of large pinnate leaves; trunk stout, 30-45 cm in diameter, straight or slightly curved, rising from a swollen base surrounded by mass of roots; rarely branched, marked with rings of leaf scars (Duke,1983).

Leaves: leaves 2-6 m long, pinnatisect, leaflets 0.6-1 m long, narrow, tapering (Duke, 1983).

Flowers: inflorescence in axil of each leaf as spathe enclosing a spadix 1.3-2 m long, stout, straw or orange coloured, simply branched; female flowers numerous, small, sweet-scented, borne towards top of panicle (Duke,1983).

Fruits: fruits are ovoid, 3-angled, 15-30 cm long, containing single seed; exocarp is a thick fibrous, husk, enclosing a hard, bony endocarp or shell. Adhering inside wall of endocarp is testa with thick aluminous endosperm, the coconut meat; embryo below one of the three pores at end of fruit, cavity of endosperm filled in unripe fruit with watery fluid, the coconut water, and only partially filled when ripe (Duke,1983).

Plate 16 *Cocos nucifera* (Coconut)

- **DURANTA ERECTA (YELLOW DURANTA)**

Family: Verbenaceae

Other names: Golden Dew Drop, Sky Flower, Pigeon Berry 'Gold Mound'

Growth structure: it is an irregular rapid growing spreading plant that can be grown as a shrub or tree ranging between 45cm to 6m in height (Daves garden, 2000).

Leaves: the yellowish evergreen foliage is smooth-textured, shiny/glossy-textured veined and dense (Daves garden, 2000).

Flowers: Violet/Lavender.

Plate 17 *Duranta species* (Yellow Duranta)

- **EUCALYPTUS GLOBULUS (EUCALYPTUS)**

Family: Myrtaceae

Other names: Blue gum tree, Stringy bark tree.

Growth structure: Eucalyptus trees are quick growers and many species reach a great height as much as 144m (Botanical, 1995).

Leaves: The first leaves are broad, without stalks, of a shining whitish-green and are opposite and horizontal, but after four or five years these are succeeded by others of a more sword-shaped form, 15-30cm long, bluish-green in hue, which are alternate and vertical, i.e. with the edges turned towards the sky. The leaves are leathery in texture and are studded with glands containing a fragrant volatile oil (Botanical, 1995).

Flowers: The flowers in bud are covered with a cup-like membrane (whence the name of the genus, derived from the Greek *eucalyptos*, well covered), which is thrown off as a lid when the flower expands (Botanical, 1995).

Fruits: The fruit is surrounded by a woody, cup shaped receptacle and contains numerous minute seeds (Botanical, 1995).

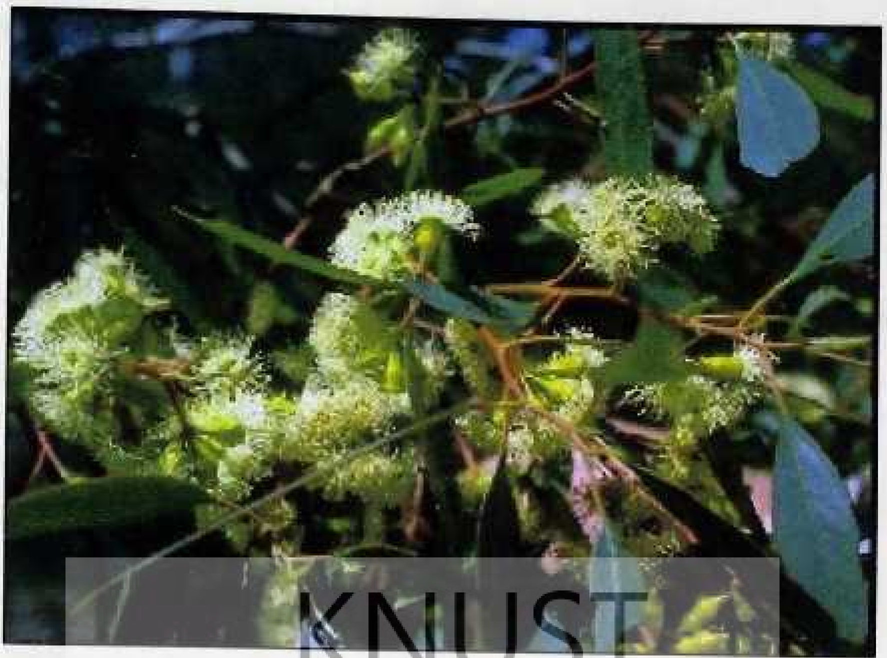

Plate 18 *Eucalyptus globulus* (Eucalyptus)

- **IPOMOEA CARNEA (MORNING GLORY)**

Family: Convolvulaceae.

Origin: Tropical America.

Most important feature: it is immediately recognizable from other morning glories by its shrubby, not vine-like, habit (Stone, 1970).

Growth structure: Shrub 1-5 m high, cultivated and occasionally naturalized near sea level; stems are hollow; petiole 2.5-15 cm long (Stone, 1970).

Leaves: leaf blades ovate to lanceolate, 10-25 cm long, truncate to shallowly cordate at base, long acuminate; sepals suborbicular, 5-6 mm long (Stone, 1970).

Flowers: corolla 5-9 cm long, finely tomentose without, rich pink, deeper pink to purple at base, the limb spreading to 11 cm in diameter; filaments unequal, dilated and pilose at base (Stone, 1970).

Fruits: fruit ovoid to subglobose, 1.5-2 cm long, the seeds covered with long, woolly, brown trichomes (Smith, 1991).

Plate 19 *Ipomoea carnea* (Morning Glory)

- **JATROPHA INTEGERRIMA (JATROPHA)**

Family: Euphorbiaceae.

Origin: West Indies and Cuba.

Other names: Fiddle-leaved, Physic-nut, Peregrina, Spicy, Jatropha.

Most important feature: Jatropha contains a milky sap that can irritate sensitive skin. All parts of the plant are reported to be poisonous if ingested.

Growth structure: Jatropha is an evergreen shrub or small tree with leaves, and plant has a rounded or narrow domed form and gets up to 4.6 m tall with a spread of 3.1 m or so, although in cultivation it is usually smaller. Jatropha often grows shrublike with several slender trunks, but it can be pruned to a single trunk.

Leaves: The glossy leaves are extremely variable; they may be entire and elliptic or oval or they may be fiddle shaped, or they may have three sharp pointed lobes. They are bronze when young and brownish on the undersides.

Flowers: these are clusters of

'star shaped bright scarlet or vermilion flowers about 2.5 cm across and borne in ''

multi-flowered terminal clusters almost all year round.

Additional information: Jatropha is a very diverse genus which includes cactus like succulents, herbaceous perennials, and woody trees. They are all united in the same genus because their very similar flower structures suggest a relatively recent common ancestor.

Plate 20 *Jatropha integerrima* (Jatropha)

- **LAGERSTROEMIA INDICA (QUEEN'S FLOWER)**

Family: Lythraceae.

Origins: Asia.

Other Names: crape myrtle, crepe myrtle.

The deciduous crape myrtle is among the longest blooming trees in existence with flowering periods lasting from 60-120 days. Crapes come in heights as short as 46 cm and as tall as 12 m.

Leaves: Leaves are alternate and smooth, but leaf size depends on variety.

Flowers: Flowers are borne in summer in big showy clusters and come in white and many shades of pink, purple, lavender and red.

Fruits: The fruits that follow are brown or black. When mature they dry and split releasing disk shaped seeds.

Additional information: Depending on variety, crapes grow as large shrubs or as trees that may be either upright or spreading. Large varieties are very fast growing and can put on several feet in a single growing season. Many types have interesting bark that exfoliates in thin flakes exposing lovely cinnamon or gray inner bark. Crapes tend to produce many suckers that should be removed as they appear if you want to maintain them as trees with distinct trunks. They are enthusiastic reseeders so you may find yourself pulling up baby crapes throughout the summer

Plate 21 *Lagerstroemia indica* (Queen's flower)

- **LEUCEANA LEUCOCEPHALA (LEUCEANA)**

Family: Fabaceae.

Origin: Native throughout the West Indies from Bahamas and Cuba to Trinidad and Tobago, and from southern Mexico to northern South America.

Other names: Leadtree, Loa haole, Ekoa, Hediondilla, Zarcilla, Tanta, Jumbie bean.

Growth structure: it is an arborescent deciduous small tree or shrub, to 20 m tall, it is fast-growing; trunk is about10–25 cm in diameter, forming dense stands; where crowded, slender trunks are formed with short bushy tuft at crown, spreading if singly grown (Motooka *et al*, 2003).

Leaves: leaves are evergreen, alternate, 10–25 cm long, malodorous when crushed, bipinnate with 3–10 pairs of pinnae, each with 10–20 pairs of sessile narrowly oblong to lanceolate, gray-green leaflets 1–2 cm long, less than 0.3 cm wide (Motooka *et al*, 2003).

Flowers: flowers are numerous, axillary on long stalks, white, in dense global heads 1–2 cm across (Motooka *et al*, 2003).

Fruits: fruits are pods with raised border, flat, thin, becoming dark brown and hard, 10–15 cm long, 1.6–2.5 cm wide, dehiscent at both sutures; seeds are copiously produced, 15–30 per pod, oval, flattish, shining brown, taproot long, strong, well-developed (Motooka *et al*, 2003).

Additional information: Tree can grow as an annual when harvested for forage. It flowers and fruits nearly throughout the year. *Leucanthus* means white flowered; *leucocephallus*, white headed, both names referring to its inflorescence.

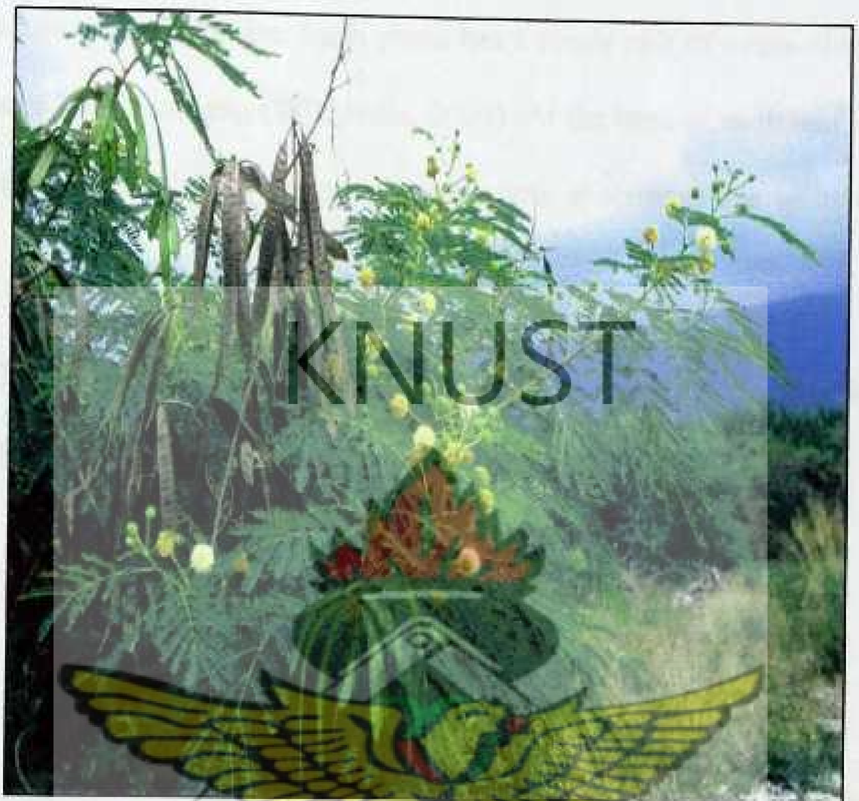

Plate **22** *Leuceana leucocephala* (Leuceana)

- **PITHECELLOBIUM DULCE (MANILA TAMARIND)**

Family: Fabaceae

Origin: Native to Mexico through Central America to Colombia and Venezuela (Duke, 1983).

Other names: Guamachili, Monkeypod.

Growth structure: A large, nearly evergreen tree that grows up to 20 m or more in height. Manila tamarind has a broad crown (up to 30 m across) and a short bole (up to 1 m thick). Its trunk is spiny (Wikipedia, 2008).

Leaves: its leaves are bipinnate. Each pinna has a single pair of ovate-oblong leaflets that are about 2 to 4 cm long (Wikipedia, 2008). At the base of each leaf is normally found a pair of short, sharp spines, though some specimens are spineless (Duke, 1983).

Flowers: The flowers are greenish-white, fragrant, and sessile and reach about 12 cm long though looks shorter due to coiling (Wikipedia, 2008).

Fruits: The flowers produce a pod with an edible pulp. The seeds are black.

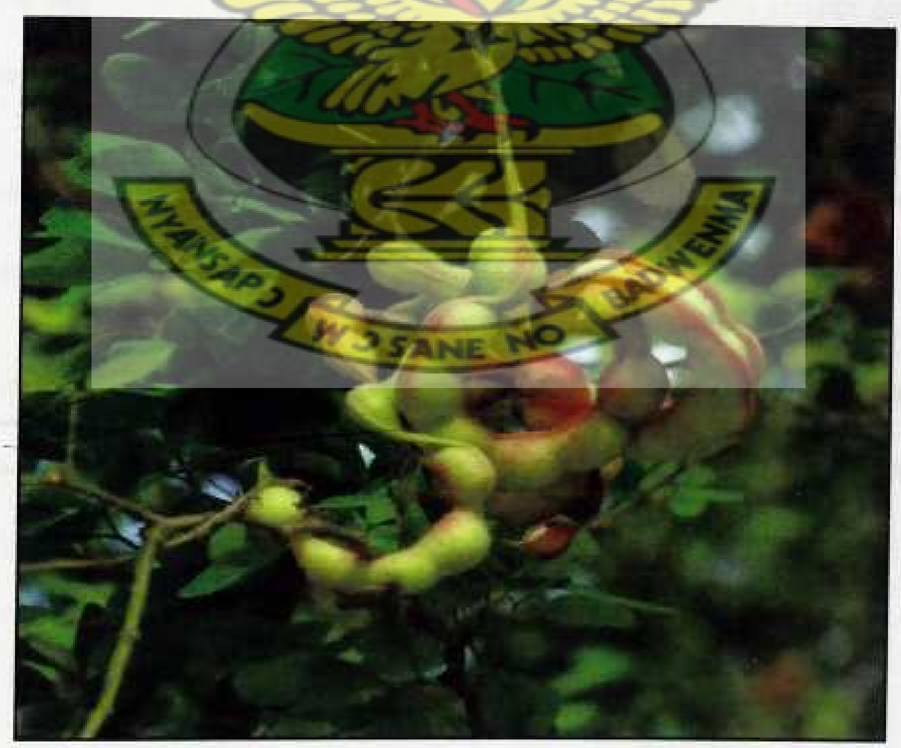

Plate 23 *Pithecellobium dulce* (Manila tamarind)

- **POLYALTHIA LONGIFOLIA (WEEPING WILLOW)**

Family: Annonaceae.

Origin: Native to India and Sri Lanka.

Other names: Asopal, Green Champa, Indian mast tree, False Ashoka.

Growth structure: it is a lofty evergreen tree. It exhibits symmetrical pyramidal growth with willowy weeping pendulous branches and the tree is known to grow over 9.1 m in height (Wikipedia, 2008).

Leaves: Fresh leaves are a coppery brown colour and are soft and delicate to touch; as the leaves grow older the colour becomes a light green and finally a dark green long narrow lanceolate leaves with undulate margins (Wikipedia, 2008).

Flowers: it has delicate star-like pale green flowers. The flowers are not conspicuous due to their colour (Wikipedia, 2008).

Fruits: are borne in clusters of 10-20 and are initially green but turns purple or black when ripe (Wikipedia, 2008).

Additional information: it is commonly planted due to its effectiveness in alleviating noise pollution. The tree can be trimmed into various shapes and maintained in required sizes (Wikipedia, 2008).

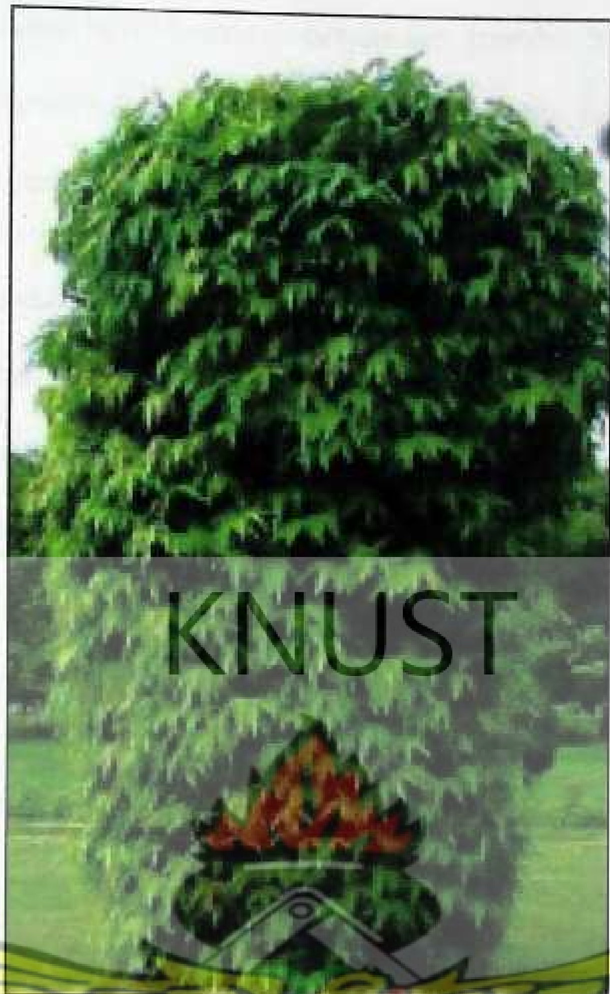

Plate 24 *Polyalthia longifolia* (Weeping willow)

PUNICA GRANATUM **(POMEGRANATE)**

Family: Punicaceae

Growth structure: The pomegranate is a shrub, usually with multiple stems, that commonly grows 1.8-4.6 m tall. The slender branches start out upright then droop gracefully. Unpruned shrubs have a decidedly weeping or fountain shaped habit.

Leaves: The deciduous leaves are shiny and about 7.6 cm long.

Flowers: Pomegranates have beautiful orange-red trumpet shaped flowers with ruffled petals. The flowers are about 5 cm long, often double, and are produced over a long period in the year.

Fruits: The pomegranate fruit is globose, 5 - 7.6 cm in diameter, and shiny reddish or yellowish green when mature. It has a persistent calyx opposite the stem end that looks like a little crown. The fruit is technically a berry. It is filled with crunchy seeds each of which is encased in a juicy, somewhat acidic pulp that is itself enclosed in a membranous skin. The seeds, juice and pulp are eaten, but the yellowish membrane is too astringent (Christman, 2000).

Occurrence: it is native to Asia, from the Middle East to the Himalayas.

Other names: Punica.

Additional information: There are several cultivars selected just for the showy flowers and they are fairly salt tolerant (Christman, 2000).

Plate 25 *Punica granatum* (Pomegranate).

- **ROYSTONEA REGIA (ROYAL PALM)**

Family: Arecacea/Palmae

Origin: Cuba and Florida.

Growth structure: the canopy sits atop the crown shaft - a smooth, glossy extension of the trunk composed of the overlapping bases of the leaves. The trunks are a smooth light gray that looks as if it had been cast concrete.

Leaves: Eight-inch long leaflets are arranged in rows along the 25.4cm length of bright green pinnate leaves, composed of 15 - 20 leaves.

Flowers: it produces a large 8 cm to 10cm inflorescence on which both male and female flowers are borne (Floridata, 1996-2007d).

Plate 26 *Roystonea regia* in Ghacem (Royal palm).

- **TERMINALIA CATAPPA (INDIA-ALMOND)**

Family: Combretaceae.

Other name: Tropical Almond.

Most important feature: Due to the large size of leaves, they may be considered a nuisance to some people as they drop when they grow old. The leaves are quickly replaced by new growth so the tree is bare for only a short period of time (Gilman and Watson, 1993).

Growth structure: it grows to a height of 9-16.5m tall, deciduous tree which forms a symmetrical, upright silhouette in youth with horizontal branches reaching 9.5 m in width (Gilman and Watson, 1993).The branches are arranged in obvious tiers, giving the tree a pagoda-like shape. As the tree grows older, the crown spreads and flattens on the top to form a wide-spreading vase shape (Gilman and Watson, 1993).

Leaves: The large 30 cm long and 16 cm wide, glossy green leathery leaves change to beautiful shades of red, yellow and purple before dropping (Gilman and Watson, 1993). The inconspicuous, greenish-white, springtime blossoms appear in 16 cm long terminal clusters and are followed by the edible fruits (Gilman and Watson, 1993).

Fruits: These drupes are 6.25 cm long and mature from green to yellow or red. The outside husk is a corky fibre with an inner thin green flesh (Gilman and Watson, 1993). The inside holds the edible, almond-like kernel. The fruit is high in tannic acid (Gilman and Watson, 1993).

Additional information: It also causes significant litter on the ground.

Plate 27 *Terminalia catappa*

5.3.2 DESCRIPTION OF ADDITIONAL PLANTS FOR OUTDOOR USE.

These plants have been recommended by Sharma and Roy (1999) and approved by the International Society of Environmental Botanist as ornamentals that aid in the reduction of urban pollution and are pollution tolerant and would be adopted as additional plants for outdoor use in the Ghacem environs.

- Plantings by the road, central verge and traffic islands; *Albizia lebbeck, Acacia auriculiformis, Acalypha wilkesiana, Bougainvillea species, Caesalpinia pulcherrima, Catharanthus rosea, Duranta species, Euphorbia milii, Hibiscus rosa-sinensis, Ixora coccinea, Jatropha integerrima, Lantana camara, Murraya paniculata, Nerium oleander*, etc.

- Plants used in Greenbelts. Greenbelts is defined as the mass of plantation of pollution tolerant trees and shrubs in an area for the purpose of minimizing air pollution by filtering, intercepting and absorbing pollutants in an effective manner for the improvement of the environment (Sharma and Roy, 1999). These plants include: *Acacia auriculiformis, Albizia lebbeck, Azadirachta indica, Bougainvillea species, Bauhinia purpurea, Cassia siamea, Ficus benjamina* (would be discussed under indoor plants), *Lagerstroemia speciosa, Millingtonia hortensis, Murraya paniculata, Nerium oleander, Polyalthia longifolia,* etc.

Plant species already described above will be skipped and the grass *Cynodon dactylon* has been added to be planted in open space in between trees and shrubs.

- **ACACIA AURICULIFORMIS (DARWIN BLACK WATTLE)**

Family: Fabaceae.

Origin: Native to the savannas of New Guinea, Islands of the Torres Strait and Northern Australia.

Other names: Earleaf acacia.

Most important feature: Spikes 5-8cm long, paired at both ends of the leaf.

Growth structure: Resilient, vigorously growing, crooked or gnarled deciduous or evergreen tree attaining 30m height (Duke, 1983).

Leaves: leaves alternate, simple flattened phyllodes, lanceolate or oblong, arcuate, long attenuate at both ends, 10-16cm long, thick, coriaceous, globorous with several long parallel veins from the base (Duke, 1983).

Flowers: Duke (1983) mentioned that the flowers are sessile, 3mm long, the calyx glabrous and 5-toothed. Stamens are numerous, filiform and 3mm long. Its ovary is pubescent, the style filiform.

Pods: Pods 6-8cm long, 1-1.5cm broad, flattened but coiled. Seeds are several, flattened-ellipsoid with a reddish or orangish aril (Duke, 1983).

Additional information: it tolerates alkalinity, desiccation, drought, fire, high pH, poor soil, sand dunes and savannah and intolerant to shade and weeds in the early stages (Duke, 1983).

Plate 28 *Acacia auriculiformis* (Darwin black wattle).

- **ACALYPHA WILKESIANA (ACALYPHA)**

Family: Euphorbiaceae

Other names: Copper-leaf, Jacob's coat.

Growth structure: it is a fast growing plant which is upright, round, dense with a spread of 15-20 cm and coarse. It grows to a plant height of 20-30 cm (Gilman, 1999).

Leaves: leaves are variegated and it may be green and white or green and yellow, or various combinations of dark red, bronze, reddish brown and brown. The leaves of some forms are flat but in some others they are strongly undulate and the variegation may be in a form of a simple coloured margin or it may appear as an irregular patterning which is different on every leaf.

Flowers: it is an unusual, red, fuzzy, and cat-like and hangs pendulously from the leaf axils and is 20-30 cm long.

Plate 29 *Acalypha wilkesiana* (Acalypha)

- **BAUHINIA PURPUREA (PURPLE ORCHID-TREE)**

Family: Leguminosae

Growth structure: A fast-growing Orchid Tree which ultimately reaches 35 feet in height and width, the slender trunks topped with arching branches clothed in large, two-lobed, deciduous leaves (Gilman and Watson, 1993). The branches droop when tree grows older, it has a moderately dense canopy and coarse in structure (Gilman and Watson, 1993).

Leaves: the 2-4 inch leaves are deciduous, simple, alternate and lobed or cleft and drop in the dry season (Gilman and Watson, 1993).

Flowers: Orchid Tree is festooned with many showy and delightfully fragrant, five-inch-wide blossoms, the narrow purple, pink, and lavender petals arranged to closely resemble an orchid. These flowers appear on the trees from September through November and are a beautiful sight to see, creating a vivid splash of colour in the landscape.

Fruits: The flowers are followed by 12-inch-long, slender, brown, flat seedpods which usually persist on the tree throughout the dry season then fall to create a mess to clean up.

Additional information: The spectacular flower display makes orchid tree a favourite for specimen plantings. Tree wants to grow with several trunks but can be trained to grow with a single plant. It is also susceptible to breakage (Gilman and Watson, 1993). It has a high drought tolerance and moderate salt resistance (Gilman and Watson, 1993).

Plate 30 *Bauhinia purpurea* (Purple orchid tree)

- **BOUGAINVILLEA SPECIES (BOUGAINVILLEA)**

Family: Nyctaginaceae.

Most important feature: Their woody, thorn-armoured canes soar to great heights and then tend to flop over sprawling across whatever is adjacent.

Growth structure: The bougainvilleas are mostly evergreen or semi-evergreen dropping their leaves briefly. This sprawling woody vine is a colourful show boaster wherever it is grown (Scheper, 1999).

Leaves: The heart shaped leaves are rich green and 7.6-12.7 cm long and hairy beneath (Scheper, 1999).

Flowers: Bougainvillea flowers are small yellow white waxy tubes that are not very impressive. However they are surrounded by three 1-2 in (2.5-5.1 cm) long papery bracts and it is these that are responsible for the colourful displays for which this genus is famous (Scheper, 1999). Flowers are available in a dazzling spectrum of colours ranging from purple to magenta to scarlet to brick red to crimson and also look for white, pink, orange and salmon (Scheper, 1999).

Additional information: Bougainvillea is famous for its brilliantly coloured floral displays and quick growth rate. It is also inexpensive, commonly available and easy to care for.

Plate 31 *Bougainvillea species* (Bougainvillea)

- **CATHARANTHUS ROSEA (PERIWINKLE)**

Family: Apocynaceae.

Origin: it is native to Madagascar.

Other names: Madagascar periwinkle, rose periwinkle.

Growth structure: it is a small, upright, semi woody evergreen perennial 0.6-0.9 m tall and spread out just as wide (Christman, 2000).

Leaves: they are green and glossy, oval leaves are1.5 - 3mm long, has a white centre vain, and is borne in opposite pairs on a slender fairly rigid stem.

Flowers: one or more flowers are produced at stem tips. Each flower has a1.5mm tube flattened out into lance-shaped petals at the mouth, which is up to 2.25mm wide. The five petaled flowers are typically rose pink, but among the many cultivars are those with pink, red, purple and white flowers (Christman, 2000).

Additional information: it is drought tolerant once established.

Plate 32 *Catharanthus rosea* (Periwinkle)

- **CYNODON DACTYLON (BERMUDA GRASS)**

Family: Poaceae.

Origin: Africa and India.

Other names: Dog's tooth grass, "Kweekgras" (S. Africa), couch grass (Australia and Africa), devil's grass (India) and gramillia (Argentina) (Duble, 2008).

Growth structure: it is a highly variable, sod forming perennial that spreads by stolons, rhizomes and seed (Duble, 2008). Stolons of Bermuda grass readily root at the nodes. Lateral buds develop at the nodes to produce erect or ascending stems that reach 5 to 40 cm (rarely over 90 cm) in height (Duble, 2008).

Leaves: leaves are borne on stems with long internodes alternating with one or more very short internodes (Duble, 2008). This characteristic gives the impression that the species has multiple-leaved nodes. Leaf sheaths are compressed to round, loose, split, smooth, sparsely hairy, up to 15 cm long, and with a tuft of hairs 2 to 5 mm long (Duble, 2008). Auricles are absent. Collar is continuous, narrow, glabrous and hairy on margins. Leaf blades are 2 to 16 cm long, 1.5 to 5 mm wide, smooth to sparsely pubescent, folded or loosely rolled in the bud and sharply-pointed (Duble, 2008).

Inflorescence: The inflorescence consists of 3 to 7 spikes in a single whorl in a fingerlike arrangement and 3 to 10 cm long (Duble, 2008). In robust forms there may be up to 10 spikes, sometimes in two whorls. Spikelets are 2 to 3 mm long, in 2 rows tightly pressed to one side of the rachis (Duble, 2008).

Seeds: seed is 1.5 mm long, oval, straw to red-coloured (Duble, 2008).

Roots: Bermuda grass has a fibrous, perennial root system with vigorous, deep rhizomes. Roots are produced at the nodes after new leaves or tillers are produced during the growing season. Mature roots are yellow to brown while new roots are white. Mature roots deteriorate throughout the growing season and new roots are produced continuously (Duble, 2008).

Additional information: Bermuda grasses, in general, are drought tolerant; that is, they survive dry soil conditions longer than most turf grasses.

Plate 33 *Cynodon dactylon* (Bermuda grass).

- **EUPHORBIA MILII (CHRIST'S THORN)**

Family: Euphorbiaceae.

Other names: Crown of thorns, Christ plant, Christ-thorns.

Most important feature: The well-named crown of thorns is armed with 13 mm vicious black thorns all over the stems and branches. *Euphorbia milii* oozes milky sap from bruised or broken stems and leaves (Christman, 2007).

Growth structure: Crown of thorns is a bushy, very spiny, semi-succulent shrub that gets to about 1 m in height, with a spread around 60 cm (Christman, 2007).

Leaves: It has tough, leathery bright green leaves on slender fleshy stems, but the leaves often drop off on all but the youngest stems. The plant is sometimes completely leafless (Christman, 2007).

Flowers: In subtropical climates, crown of thorns bears tiny yellow-green flowers surrounded by two showy bright red bracts in spring and summer. In tropical climates, it blooms in cycles following rain throughout the year (Christman, 2007).

Fruits: All euphorbs have a three-lobed fruit that splits apart when ripe, but crown of thorns rarely fruits in cultivation (Christman, 2007).

Additional Information: This species also has been hybridized with other euphorbs, resulting in cultivars with larger and flashier bracts. Several named cultivars and varieties are noteworthy for their different coloured bracts (pink, yellow, white and orange) and/or different growth habits (Christman, 2007).

Plate 34 *Euphorbia milii* (Christ's thorn)

♦ **HIBISCUS ROSA-SINENSIS (HIBISCUS)**

Family: Malvaceae.

Origin: Native to southern Asia.

Other Names: Chinese hibiscus, Rose-of-China, Hawaiian hibiscus.

Leaves: The toothed leaves are arranged alternately and vary a lot, but tend to be large, dark green, and shiny (Floridata, 1996-2007b).

Growth structure: This large shrub or small tree grows to 4.6m high. This plant has a coarse texture and may be upright or broad and spreading. It is often many-stemmed (Floridata, 1996-2007b).

Flowers: Flowers are glorious and huge at their best up to 6" in diameter and occur in many colours. Most are flared and have a bell shape and may be single or double, smooth or scalloped. They have a long central tube with stamens and pistils at the tip (Floridata, 1996-2007b).

Additional information: regular pruning is necessary in most cases to shape and control size, and to remove unwanted stems (Floridata, 1996-2007b).

Plate 35 *Hibiscus rosa sinensis* (Hibiscus).

- **IXORA COCCINEA (IXORA)**

Family: Rubiaceae

Origin: it is native to tropical Southeast Asia

Growth structure: Ixora is a dense, multi-branched evergreen shrub, commonly 1.2 – 2m in height, but capable of reaching up to 3.6 m high. Ixora has a rounded form, with a spread that may exceed its height (Christman, 2006).

Leaves: The glossy, leathery, oblong leaves are about 10 cm long, with entire margins, and are carried in opposite pairs or whorled on the stems (Christman, 2006).

Flowers: Small tubular, scarlet flowers in dense rounded clusters 5-13 cm across are produced almost all year long. There are numerous named cultivars differing in flower colour (yellow, pink, orange) and plant size (Christman, 2006).

Additional information: Several popular cultivars are dwarfs, usually staying under 1 m in height. It is moderately salt tolerant (Christman, 2006).

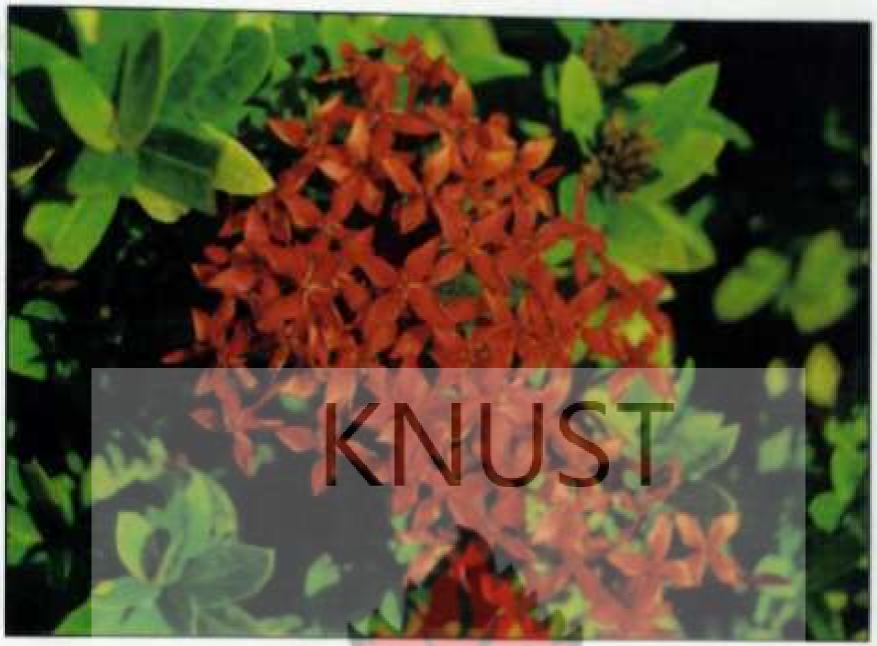

Plate 36 *Ixora coccinea* (Ixora)

- **LANTANA CAMARA (LANTANA)**

Family: Verbenaceae.

Origin: it is native to tropical regions.

Growth structure: is a rugged evergreen shrub which will grow to 1.8 m high and may spread to 2.4 m in width with some vine like varieties able to climb up supports to greater heights. Stems and leaves are covered with rough hairs and emit an unpleasant aroma when crushed (Scheper, 1996).

Leaves: The leaves are 5-12.7 cm long by 2.5-5 cm wide with rounded tooth edges and a textured surface (Scheper, 1996).

Flowers: The small flowers are held in clusters (called umbels) that are typically 2.5-5.1 cm across. In the tropics lantana is a non-stop bloomer (Scheper, 1996).

Additional information: it tolerates salt spray and drought resistant (Scheper, 1996).

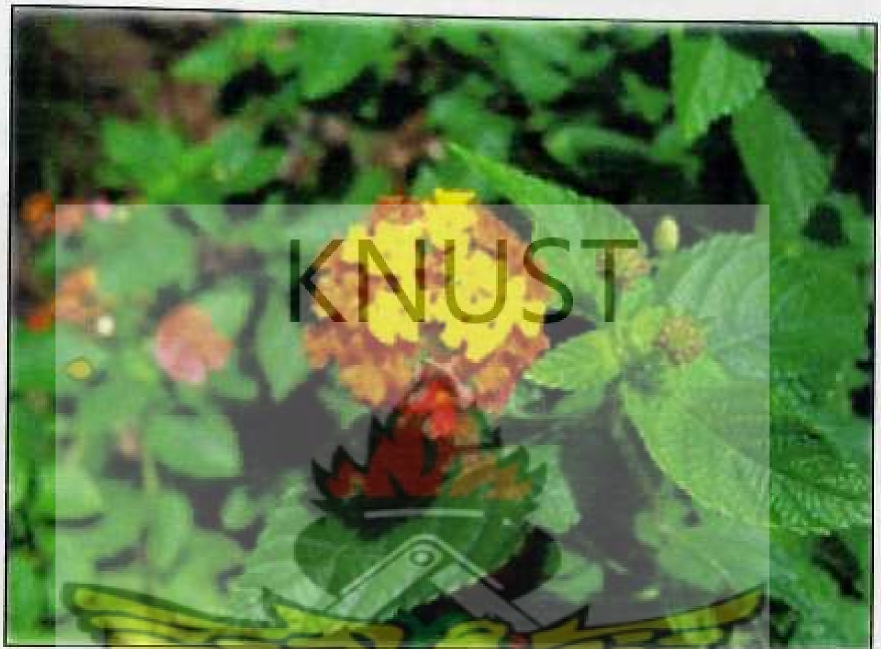

Plate 37 *Lantana camara* (Lantana)

- **MILLINGTONIA HORTENSIS (CORK TREE)**

Family: Bignoniaceae.

Origin: Burma

Other names: Akas Nim, Nim Chameli, Betati Nim, Mini Chameli.

Most important feature: It flowers at night and shed flowers early in the morning (Eco India, 2008).

Growth structure: It is an ornamental, a fine, tall deciduous and fast growing tree, has a cracked, corky bark, straight trunk and a few branches (Eco India, 2008).

Leaves: it has attractive pinnate foliage divided into large, shiny, pointed, oval leaflets (Eco India, 2008).

Flowers: Flowers is corymbose, long tubular, white and fragrant and age to pale yellow, sometimes delicately tinted with rose (Eco India, 2008).

Fruits: The fruit is a capsule (Eco India, 2008).

Plate 38 *Millingtonia hortensis* (Cork tree)

- **MURRAYA PANICULATA (MURRAYA)**

Family: Rutaceae.

Origin: South and Southeast Asia.

Other names: Orange Jasmine, Chinese box, Mock orange, Mock lime, Satinwood.

Most important feature: The fragrance of the plant in flower could be smelled 3m from it and the berries stay throughout the year (Gilman, 1999).

Growth structure: it is a tropical and evergreen shrub or a small tree, usually 2-3m in height but reaching 7.5m and 13cm in stem diameter (Gilman, 1999).

Leaves: Its leaves are glabrous and glossy, occurring in 3-7 oddly pinnate leaflets which are elliptic to cuneate-obovate to rhombic (Gilman, 1999).

Flowers: Flowers are terminal, corymbose, few-flowered, dense and fragrant. Petals are 12-18mm long, recurved and white (or fading cream) (Gilman, 1999).

Fruits: The fruit of *Murraya paniculata* is fleshy, oblong-ovoid, coloured red to orange (Welsh, 1998), and grows up to 2.5cm length (Gilman, 1999).

Plate 39 *Murraya paniculata* (Murraya)

- **SENNA SIAMEA (CASSOD TREE)**

Family: Fabaceae.

Other names: Kassod tree, Pheasantwood, Siamese senna, Thialand cassia.

Most important feature /Growth structure: trees grow up to 30m, spreading, pubescent on the leaf undersides and inflorescence, soon glabescent .

Growth structure: it is a medium-size, evergreen tree growing up to 18 m tall, with a straight trunk of up to 30 cm in diameter; bole short, crown usually dense and rounded at first, later becoming irregular and spreading with drooping branches (ICRAF, 2008). Bark grey or light brown, smooth but becoming slightly fissured with age. The root system consists of a few thick roots, growing to considerable depth, and a dense mat of rootlets in the top 10-20 cm of soil, which may reach a distance of 7 m from the stem in 1 year and eventually a distance up to 15 m (ICRAF, 2008).

Leaves: Leaves alternate, pinnately compound, 23-33 cm long, with slender, green-reddish, tinged axis; leaflets 6-12 pairs on short stalks of 3 mm, oblong, 3-7 cm long, 12-20 mm wide, rounded at both ends, with tiny bristle tip (ICRAF, 2008).

Flower: Flower clusters are upright at ends of twigs, large branched, 20-30 cm long, 13 cm broad, with many bright yellow flowers 3 cm across, pentamerous; sepals imbricate, obtuse at the apex; petals sub equal to heteromorphic, yellow; stamens 10, accrescent toward the abaxial side of the flower; filaments straight and not more than twice as long as the anthers; ovary superior, linear and curved (ICRAF, 2008).

Fruits: Pods numerous, long, narrow, 5-25 cm long, 12-20 mm broad, flat, dark brown, strap shaped, stipitate, terete to compressed, dehiscent, with septae between the numerous seeds; seeds are bean shaped, shiny, dark brown, 8 mm long, with distinct areole (ICRAF, 2008).

Plate 40 *Senna siamea* (Cassod tree)

5.3.3 ADDITIONAL PLANTS SPECIES FOR INDOOR USE

Plants recommended by different authors as able to aid in improving air quality indoors includes: *Chamaedorea seifiritzii, Chlorophytum comosum* "vittatum", *Chrysalidocarpus lutescens, Dieffenbachia "Exotica Compacta", Dracaena deremensis, Dracaena fragrans, Epipremmum pinnatum, Ficus benjamina, Ficus robusta, Nephrolepis exaltata, Philodendron domesticum, Phoenix roebelenii, Rhapis excelsa, Sanseviera trifasciata, Spathiphyllum species*; and they also form the first sixteen plants suggested by Dr Wolverton based on their ability to absorb formaldehyde a commonly found toxin in indoor air (Wolverton, 1996) and form part of the ten suggested recommended by National Aeronautics and Space Administration (NASA Zone 10 Inc., 2002). The indoor plants have been graded overall ranging from one to ten based on removal rate of chemical vapours, ease of growth and maintenance, resistance to insect infestation and transpiration (Wolverton, 1996).

- **CHAMAEDOREA SEIFRIZII (BAMBOO PALM)**

Family: Arecacea/Palmae.

Origin: is native to Mexico and Central America.

Common name: reed palm.

Growth structure: is a relatively small graceful palm that grows to about 2.1m. Each stem is long and slender with "nodes" very similar in appearance to Bamboo (Floridata, 1996-2007a).

Leaves: The tall stems have about 10-15 fronds each with about 12 dark green pinnate leaflets (Floridata, 1996-2007a).

Flowers: The flowers arise from the leaf sheaths or covering and are dull yellow in colour (Floridata, 1996-2007a).

Fruits: The fruits are usually small pea-sized berries that are orange/red in colour.

Overall rating of bamboo palm: 8.4

Table 9: Removal rate of Formaldehyde by **Bamboo palm**.

Chemical	**µg per hour**
Formaldehyde	[redacted]

Plate 41 *Chamaedorea seifrizii* (Bamboo palm)

♦ **CHLOROPHYTUM COMOSUM (SPIDER PLANT)**

Family: Liliaceae

Origin: South Africa.

Other names: Airplane Plant, St. Bernard's Lily, Spider Ivy and Ribbon Plant.

Most important feature: it sends up slender, arching shoots that forms the plantlets.

Growth structure/Leaves: it has long recurved medium to dark green satiny leaves with a broad central white stripe which are 15-30cm long (Wolverton, 1996).

Flowers: the shoots yield small white flowers at virtually any time of the year (Wolverton, 1996).

Additional information: Vittatum means white stripped leaves and is the most commonly grown spider plant (Wolverton, 1996).

Overall rating of Spider plant: 5.4

Table 10: Removal rate of Formaldehyde by **Spider plant**.

Chemical	**µg per hour**
Formaldehyde	[redacted]

Source: (Wolverton, 1996).

Plate 42 *Chlorophytum comosum* (Spider plant).

♦ **CHRYSALIDOCARPUS LUTESCENS (ARECA PALM)**

Family: Arecacea/Palmae

Origin: is native to Madagascar.

Common Names: areca palm, golden cane palm, Madagascar palm, Areca lutescens.

Growth structure: it can grow up to 6 m tall, although it is usually smaller.

Leaves: Six to eight leaves on long petioles (leaf stems) arise from the main trunk and gracefully arch outward and downward. Each leaf has about 80-100 leaflets which are arranged on the leaf stem in a shallow V. The common name derives from the beautiful golden yellow colour of the petioles.

Flowers: The yellow flowers are borne in branches about 1 m long that emerge from the tops of the stems.

Fruits: The fruits are about 2.5 cm in diameter and are yellow to purple (Bielski, 2000).

Overall rating of plant: 8.5

Table 11: Removal rate of chemicals by **Areca palm**.

Chemical	**µg per hour**
Formaldehyde	■■■■■■■
Xylene and toluene	■■■■■■■■■■■■■■■■■■■

Source: (Wolverton, 1996).

Plate 43 *Chrysalidocarpus lutescens* (Areca palm).

- **DIEFFENBACHIA "EXOTICA COMPACTA"**

Family: Araceae.

Origin: Dieffenbachias are natives from Costa Rica to Columbia.

Growth structure: They are sturdy, thick-stemmed plants which grow to a maximum height of 0.6m. The leaves spread outwards from unbranched stems and arch downwards, making it one of the showy foliage plants (Wolverton, 1996).

Leaves: are colourful, oblong, wide, pointed, glabrous leaves which are generally green and cream coloured.

Additional information: it derives its common name from the calcium oxalate in it's sap and the 'compacta' is it's dwarf variety. Variegated lose their colour if there is not enough light (Wolverton, 1996). The main drawback is the fast growth and tendency to grow towards a light source. Its large leave surface makes it an effective plant for removing indoor air contaminants (Wolverton, 1996).

Overall rating of Dumb cane: 6.2

Table 12: Removal rate of chemicals by **Dumb cane**.

Chemical	**µg per hour**
Formaldehyde	■■■■■■■
Xylene and toluene	■■■■■■■■■■

Source: (Wolverton, 1996).

Plate 44 *Dieffenbachia exotica* (Dump cane).

♦ DRACAENA DEREMENSIS "JANET CRAIG"

Family: Agavaceae.

Origin: Canary Islands, Africa (Ethiopia, Guinea and Nigeria) (Wolverton, 1996), Asia and Madagascar.

Growth structure: it is a shrub with an upright, unbranched multiple stems with rosettes of arching, broad evergreen leaves that grows to a height of 10m and spread to 1m (Gillman, 1999).

Leaves: the dark green leaves which are spirally arranged have a parallel venation and measure 4-6cm (Gillman, 1999).

Additional information: it is one of the best plants for removing trichloroethylene (Wolverton, 1996).

Overall rating of dracaena "Janet Craig" is 7.8.

Table 13: Removal rate of chemicals by **Dracaena "Janet Craig"**.

Air Pollutant	**µg per hour**
Formaldehyde	■■■■■■■■■■
Xylene and toluene	■■■■■■■■
Ammonia	■■■

Source (Wolverton, 1996).

Plate 45 *Dracaena deremensis* 'Janet Craig'.

- **DRACAENA FRAGRANS "MASSANGEANA" (CORN PLANT).**

Family: Agavaceae.

Origin: it can survive dimly lit areas; it originated from Ethiopia, Guinea and Nigeria (Wolverton, 1996).

Most Important feature: *Dracaena fragrans* `Massangeana' is the most popular cultivar, has leaves with a broad yellow central stripe and with multiple heads made up of concentrated leaves on a cane (Poole *et al.*, 2007; Wolverton, 1996).

Growth structure: it is a foliage plant which develops a solid woody stem as it matures. They grow up to a size of 3m tall (Wolverton, 1996).

Leaves: leaves are lance shaped and from 7.6 to 61 cm long. The leaves are shiny and medium-green in colour (Poole *et al.*, 2007).

Flowers: it occasionally sends up a small spray of fragrant flowers (Wolverton, 1996).

Additional Information: Corn plant gets its common name from its upright growth and graceful leaves which resemble corn foliage (Poole *et al.*, 2007). It is exceptionally effective in the removal indoor air toxins such as formaldehyde (Wolverton, 1996).

Overall rating of Corn palm: 7.5

Table 14: Removal rate of chemicals by **Corn palm**.

Air Pollutant	**µg per hour**
Formaldehyde	■■■■■■■■■■
Xylene and toluene	■■■■■■■■
Ammonia	■■■

Source: (Wolverton, 1996).

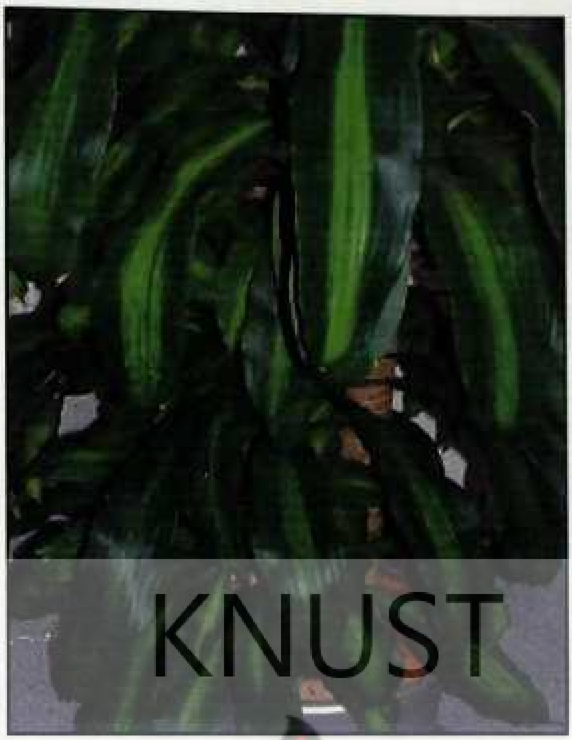

Plate 46 *Dracaena fragrans* 'Massangeana' (Corn palm).

- **EPIPREMNUM PINNATUM 'AUREUM'**

(GOLDEN POTHOS)

Family: Araceae

Origin: Devil's Ivy grows anywhere in the tropics. One finds it on house walls and tree trunks. Originally, it was from Solomon Islands.

Other names: Marble Queen, Devils Ivy.

Most important feature: it is a root climber with long petiolates. The leaves are ovate to heart shaped. They have yellow strips and spots. On older plants, the leaves can be very large and have holes and cuts on the sides.

Growth structure: this is a climbing plant that grows up to 15m high. The fleshy shoots have aerial roots.

Leaves: the leaves are altering with firm petioles that cling to the shoot with membranous flanks. On young plants, the leaves are undivided and up to 15cm long; on large plants, they are up to 80cm long and 60cm wide.

Flowers: hundreds of tiny flowers grow on cob is surrounded by a pale green to yellowish whorl of bracts.

Fruits: the fruits are small, yellowish berries densely crammed together on the cob.

Additional information: Golden Pothos is a modest ornamental plant that survives even in the darkest corners of our offices and apartments where it never grows beyond its youthful shape. It however grows into a very large plant in the tropics.

Overall rating of Golden pothos: 7.5

Table 15: Removal rate of chemicals by **Golden pothos**.

Chemical	**µg per hour**
Formaldehyde	■■■■■

Source: (Wolverton, 1996).

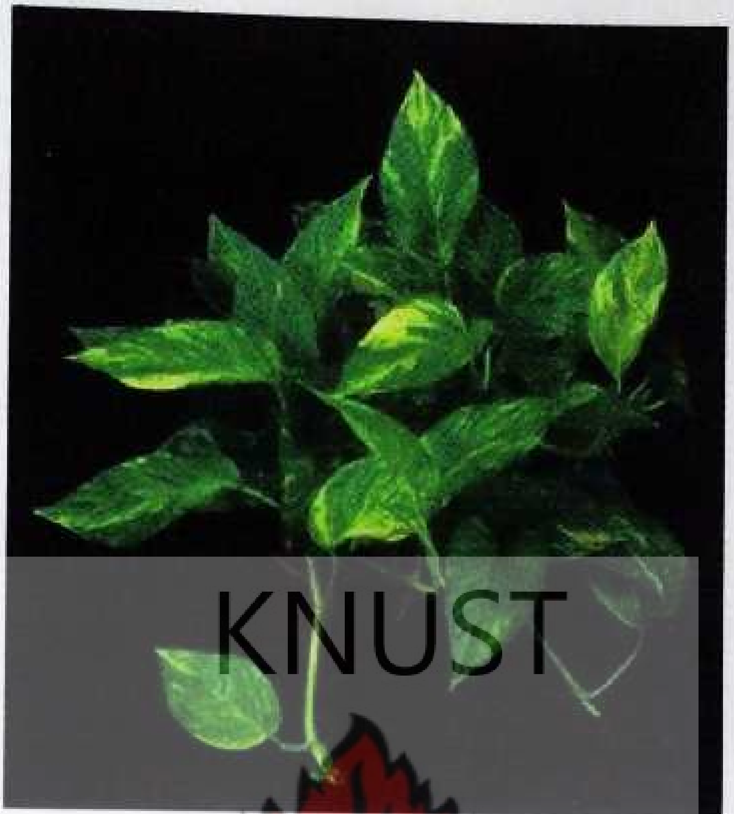

Plate 47 *Epipremnum pinnatum* 'Aureum' (Golden Pothos).

- **FICUS BENJAMINA (WEEPING FIG)**

Family: Moraceae.

Most important feature: the presence of aerial roots or the general Gestalt of the plant will give them away. All figs possess a white to yellowish sap (latex), some in copious quantities; the twig has paired stipules or a circular stipule scar if the stipules have fallen off; and the lateral veins at the base of the leaf are steep, that is they form a tighter angle with the midrib than the other lateral veins, a feature referred to as a "tri-veined" (Wikipedia, 2008).

Growth structure: it is a small tree that grows up to 1.8m and its weeping, treelike appearance becoming more and more pronounced. The many short twig-like branches and leafstalks have a stringy bark which peels off.

Leaves: leaves are 5cm-11cm long, slightly undulate, and apple green when young and darker with age.

Overall rating of Golden pothos: 7.5

Table 16: Removal rate of chemicals by **Weeping fig**.

Chemical	**µg per hour**
Formaldehyde	■■
Xylene and toluene	■■■■■■■■
Ammonia	■■■■

Source: (Wolverton, 1996).

Plate 48 Ficus *benjamina* (Weeping fig).

♦ **FICUS ROBUSTA (RUBBER PLANT)**

Family: Moraceae.

Origin: India and Malaya.

Most important feature: All figs possess a white to yellowish sap (latex), some in copious quantities; the twig has paired stipules or a circular stipule scar if the stipules have fallen off; and the lateral veins at the base of the leaf are steep, that is they form a tighter angle with the midrib than the other lateral veins, a feature referred to as a "tri-veined".

Growth structure: it reaches a height of 2.5m (Wolverton, 1996).

Leaves: it is thick, leather like, dark green leaves and contains a rubber like latex (Wolverton, 1996).

Flowers: The fig fruit is an enclosed inflorescence, sometimes referred to as a syconium, an urn-like structure lined on the inside with the fig's tiny flowers. Finally, there are three vegetative traits that together are unique to figs (Wikipedia Foundation, Inc., 2008).

Additional information; it is exceptionally effective at removing formaldehyde. Its common name is derived from its thick, leather like, dark green leaves that contain a rubber like latex (Wolverton, 1996).

Overall rating of Rubber plant: 8.0

Table 17: Removal of Formaldehyde by **Rubber plant**.

Chemical	**µg per hour**
Formaldehyde	■■■■■■■■■■■■

Source: (Wolverton, 1996).

Plate 49 *Ficus robusta* (Rubber plant)

- **NEPHROLEPIS EXALTATA (BOSTON FERN)**

Family: Nephrolepidaceae.

Origin: native in South America, Mexico and Central America, the West Indies, Polynesia and Africa.

Growth structure: Wild Boston fern has erect fronds up to 7 long and 6" wide in tufted clusters arising from underground stems called rhizomes (Floridata, 1996-2007c).

Leaves: The individual pinnae (leaflets) are as much as 3" long and shallowly toothed, but not further divided. The round sori (clusters of spore-bearing organs) are in two rows near the margins on the underside of the pinnae. Boston fern has broader fronds that arch gracefully downward (Floridata, 1996-2007c).

Additional information: it thrives only under conditions of high humidity and is the most tolerant of indoor conditions and has the ability of wind to disperse tiny spores (Floridata, 1996-2007c).

Other names: sword fern, wild Boston fern.

Overall rating of Boston fern: 7.5

Table 18: Removal rate of chemicals by **Boston fern**.

Chemical	**µg per hour**
Formaldehyde	■■■■■■■■■■■■■■■■■■■■

Source: (Wolverton, 1996).

Plate 50 *Nephrolepis exaltata* (Boston fern)

♦ **PHILODENDRON DOMESTICUM**

(ELEPHANT EAR PHILODENDRON)

Family: Araceae

Origin: Brazil

Other name: Spade leaf philodendron.

Most important feature: These plants have long aerial roots.

Growth structure: they have long aerial roots that are used for climbing.

Leaves: they are elongated, triangular, to 17cm long and 10cm across at its widest point. Petioles are equal to leaf length (Wolverton, 1996).

Flowers: The inflorescences (flowers) have spathes that come in different shades of purple, pink, red, or greenish-white. The central columns that bear the tiny flowers (spadices) can either be yellow, cream or white (Hillclimb Media, 1997-2009).

Overall rating of elephant ear philodendron: 6.2

Table 19: Removal rate of Formaldehyde by **Elephant ear philodendron**.

Chemical	**µg per hour**
Formaldehyde	■■■■■

Source: (Wolverton, 1996).

Plate 51 *Philodendron domesticum* (Elephant ear philodendron).

- **PHOENIX ROEBELENII (DWARF DATE PALM)**

Family: Palmae

Growth structure: it reaches a height of 1.5-2m. It produces a stately main trunk with green fronds that droop elegantly (Wolverton, 1996).

Leaves: the green fronds reach about 0.9m and grow almost horizontally.

Origin: Tropical and sub tropical Africa and Asia.

Additional information: it is one of the best palms for indoor air pollutants and is especially effective for the removal of xylene (Wolverton, 1996).

Overall rating of Dwarf date palm: 7.8

Table 20: Removal rate of Formaldehyde by **Dwarf date palm**.

Chemical	µg per hour
Formaldehyde	■■■■■■■■■■■■■■■■

Source: (Wolverton, 1996).

Plate 52 *Phoenix roebelenii* (Dwarf date palm)

- **RHAPIS EXCELSA (LADY PALM)**

Family: Palmae

Origin: Southern China.

Additional information: it spreads with underground stems.

Growth structure: it is a slow growing evergreen plant which forms dense clumps of bamboo-like stalks. Plant height is from 1.3m to 3.6m and a spread of 0.9 m to 3.6m (Gilman, 1999).

Leaves: are very dark green, broad 8-12 inches and fan-shaped.

Flowers: are yellow and has a pleasant fragrance.

Fruits: it is oval in shape and white. Length is 1-3 inches. It is inconspicuous and not showy (Gilman, 1999).

Overall rating of Lady Palm: 7.5

Table 21: Removal rate of chemicals by **Lady Palm**.

Chemical	**µg per hour**
Formaldehyde	■■■■■■■■■
Ammonia	■■■■■■■■■■■■■■■■■■■■■■■

Source: (Wolverton, 1996).

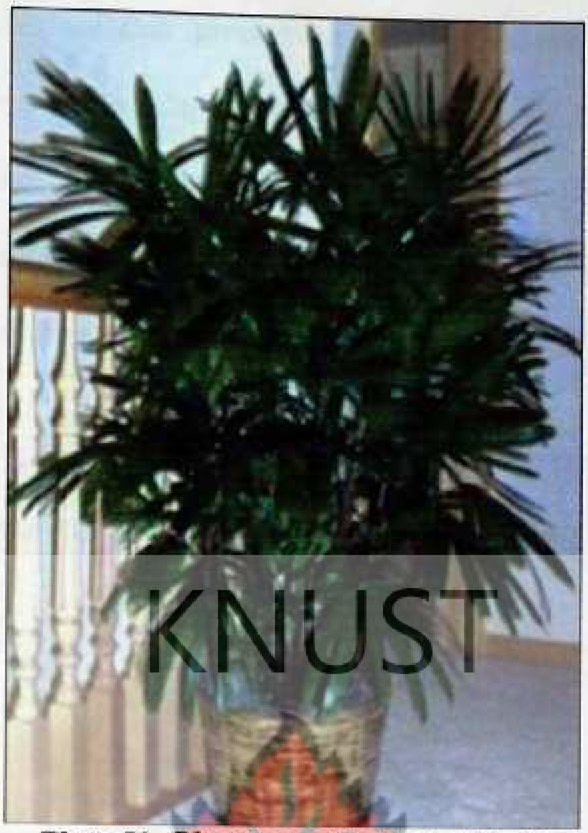

Plate 53 *Rhapis excelsa* (Lady Palm)

- **SANSEVIERIA TRIFASCIATA, (SNAKE PLANTS)**

Family: Agavacea.

Origin: Indigenous to Africa, Arabia, and India (Hanley *et al.*, 2007).

Other names: Mother-in-law's tongue, Sansevieria.

Most Important feature: it produces oxygen and removes carbon dioxide at night (Wolverton, 1996).

Growth structure: it features stiff, spear-like leaves that stand rigidly with 6 leaves per rosette.

Leaves: Mature leaves are dark green with light grey-green cross banding, and usually range between 0.6 to 1.2m in length and approximately 5cm wide. Leaves which develop under bright light out of doors or in bright greenhouses have prominent light cross-bands, while those which develop under low light intensities, have nearly solid dark green leaves (Wolverton, 1996; Hanley *et al.*, 2007).

Flowers: they occasionally bloom, sending forth small, greenish-white fragrant flowers which release a honey-like substance (Wolverton, 1996).

Additional Information: The genus *Sansevieria* contains approximately 70 species (Wolverton, 1996).

Overall rating of Sansevieria: 6.3

Table 22: Removal rate of Formaldehyde by Sansevieria.

Chemical	**µg per hour**
Formaldehyde	[redacted]

Source: (Wolverton, 1996).

Plate 54 *Sansevieria trifasciata* (Snake plant)

- **SPATHIPHYLLUM FLORIBUNDUM (PEACE LILY)**

Family: Araceae.

Origin: the peace lily is found in gardens. It originated in Panama, Venezuela and Colombia.

Other names: Snow flower, Spathe flower, white flag.

Most important feature: the leaves have a leaf sheath running down the petiole as a limb. They also have a leaf joint shortly below the blade. The inflorescence is white or partly greenish. It spreads out of a bract at the bottom of a yellowish cob.

Growth structures: peace lily is a herb with a crawling shoot. It grows 20-45cm high.

Leaves: almost all the leaves start from the ground. They are tapering and ovate up to very narrow. The leaves grow on the petioles that are 10-20cm long. The leaves are 12-25cm long and 3-7cm wide with a firm midrib and slightly wavy lateral veins.

Flowers: the flowers are tiny and densely packed on the cob that is 2-8cm long and 5-8mm thick. The cob grows on a petiole that is 20-35cm long. The bract is 6-10cm long, 2-3cm wide and tapering. The midrib and pointed end are often greenish.

Fruits: the fruits are small, ovate and yellowish to orange. They are densely packed on the cob.

Additional information: in the tropics they are planted in semi shady areas in the garden. It is poisonous because of its high content of oxalic acid.

Overall rating of Peace lily: 7.5

Table 23: Removal rate of chemicals by **Peace lily**.

Chemicals	**µg per hour**
Acetone	■■■■■■■■■■■■■■■■■■■
Methyl alcohol	■■■■■■■■■■■■■
Ethyl acetate	■■■■■■■■■
Benzene	■■■■■■■
Ammonia	■■■■■
Trichloroethylene	■■■■
Formaldehyde	■■■
Xylene	■

Source: (Wolverton, 1996).

Plate 55 *Spathiphyllum floribundum* (Peace Lily)

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

- Fourteen of the plants sampled were found to be growing well around Ghacem and out of these seven (7) were amongst plants recommended by Sharma and Roy (1999) as pollution resistant.

- Twenty eight (28) plants that aid in the reduction of outdoor pollution in an industrial environment was recommended.

- Fifteen (15) additional indoor plants with purifying abilities were recommended to improve indoor air quality.

- Equipments used in the offices, hermetic nature of offices and processing of cement were identified as sources of indoor pollution.

- Dust was the major outdoor pollutant at Ghacem which served also as a source of reduced air quality indoors.

6.2 RECOMMENDATIONS

- Ghacem should do some landscape along their roads that border it at the east, west and in front–with recommended plant materials that are pollution resistant.

- Central verges and traffic islands should also be filled with these ornamental plants and shelterbelts created.

- Mixed plants with purifying abilities should be put in the offices and verandas to safeguard workers from pollution and other benefits of indoor plants achieved.

- More research should be done on recommended plant species to help gather more baseline information on pollution resistant plant materials in Ghana.

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