IMPACT OF AIR POLLUTION ON THE PERFORMANCE OF HYMENOPTERAN POLLINATORS

Dissertation Submitted

In partial fulfillment for the award of degree of

Master of Philosophy (M.Phil.)

in

ENVIRONMENTAL SCIENCE

By

SAKEENA JABEEN

Under the Supervision of

DR. G. A. BHAT

DEPARTMENT OF ENVIRONMENTAL SCIENCE

UNIVERSITY OF KASHMIR

Hazratbal, Srinagar, J&K, India

NAAC Accredited Grade "A"

2013

POST GRADUATE DEPARTMENT OF ENVIRONMENTAL SCIENCE
University of Kashmir,
Hazratbal, Srinagar 190006

CERTIFICATE

Certified that the work presented in this dissertation entitled ***"Impact of Air Pollution on the Performance of Hymenopteran Pollinators"*** is an original work of **Ms. Sakeena Jabeen** for the award of Master of Philosophy in Environmental Science from University of Kashmir. This study has been carried under my supervision and the same or a part of this dissertation has not been submitted for this or any other degree so far. Certified further that the candidate has fulfilled all the conditions necessary for the M. Phil. degree examination of University of Kashmir. The dissertation is worthy of consideration for the award of M. Phil. degree in Environmental Science.

PROF. A. N. KAMILI
Head
Department of Environmental Science,
University of Kashmir
Srinagar-190006

DR. G. A. BHAT
(Professor)
Supervisor
Department of Environmental Science
University of Kashmir
Srinagar-190006

DEDICATED

TO MY

PARENTS

&

HUSBAND

ACKNOWLEDGEMENT

To start with I bow in reverence to "Almighty Allah, The most Merciful, Beneficent, Omnipresent, Magnificent creator of creations, Cherisher and Sustainer of the Worlds" by whose grace I was able to complete my work. I testify that nothing deserves worship except Allah alone, with no partner and I testify that Muhammad (S.A.W) is his Messenger – may Allah send prayers upon him, his family and his companions.

*I would like to express my deep sense of gratitude and indebtedness to my esteemed supervisor, **Prof. G. A. Bhat** whose diligent supervision, intellectual guidance, deep concern and wisdom natured the growth and defined the direction of my study. His wide knowledge ad logical way of thinking has been of great value to me. He showed me diverse ways to approach a research problem and to be persistent to accomplish any goal. His ideas and concepts have had a remarkable influence on my entire career in both academics and in the field of my research.*

*With immense pleasure I express my deep sense of gratitude to **Prof. Azra N. Kamili,** Head, P. G. Department of Environmental Science and Director, Centre for Research and Development, University of Kashmir, for providing me excellent working facilities, encouragement and other invaluable help, without which, this task could not have been accomplished. I am grateful to **Prof. A. K. Pandit** and **Prof. A. R. Yousuf** Department of Environmental Science and CORD, University of Kashmir, Srinagar for their moral support, useful suggestions, friendly behavior and continuous encouragement all through the course of my study.*

Completion of this work was only possible due to cooperation and help of many people. I shall be failing in my duty if I do not record my indebtedness to my friends and colleagues, Aaliya Ismat Baba, Tabasum Yaseen, Sana Shafi, Sana Mehraj, Ruqaya Rashid, Asma Hassan, Anisa Khan and especially Mr. Peerzada Arshid Shabir from the Department of Botany who constantly helped and gave me the valuable suggestions I needed at many times.

My Sincere thanks go to my Parents, Mr. Mohammad Jamal Parray and Mrs. Mehbooba Akhter, my Brothers, Mr. Aijaz Wani and Mr. Mubashir Wani, my sisters, Nahida, Shaista, Nazima, Sabba and Azmat., my father in law Mr. Mohammad Yaqoob Gatoo and mother in law Mrs. Shamima Chapoo. My family deserves all the credit and accolades earned by this achievement of this distinction. You are and will always remain my true energy and strength.

I shall be failing in my duty if I don't record my gratitude and particular appreciation to my husband, Mr. Mohammad Waseem who has been a source of blessing, love, patience, affection and encouragement for me and played a great role in completion of this work.

Lastly I express my profound gratitude to teaching, technical and non-teaching staff members of Environmental Science for supporting in my research work.

SAKEENA JABEEN

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter – 1
INTRODUCTION

Pollination is a vital stage in the reproduction of flowering plants. It is the transport of pollen from male to the female part of a flower (McGregor, 1976; Crane & Walker, 1984). It is significant in horticulture and agriculture, because fruiting is reliant on fertilization, which is the end result of pollination. Abiotic pollination is mediated without the participation of other organisms while as in biotic pollination another organism or pollinator is required to carry or shift the pollen grains from the anther to the receptive part of the carpel or pistil. There are approximately 200,000 varieties of animal pollinators in the wild, most of which are insects .Entomophily, pollination by insects, often occurs on plants that have developed colored petals and a strong scent to draw insects such as, bees, wasps and occasionally ants (Hymenoptera), beetles (Coleoptera), moths and butterflies (Lepidoptera), and flies (Diptera). The Hymenoptera, which includes the bee, are a very diverse group and of extreme biological interest.

Pollination is one of the most essential mechanisms in the conservation and promotion of biodiversity and, in general, life on Earth. Many ecosystems, including human agro ecosystems, depend on pollinator diversity to preserve the whole biological diversity. Pollination benefits society by increasing food security and improving livelihoods (Khan and Khan, 2004). Pollinators are enormously diverse, with more than 16,000 pollinator bee species (Hymenoptera: Apidae) that have been described worldwide (Michener, 2000; Kevan, 2003). The ecological relationship of the pollinators was documented long before (Knutson et al., 1990) and that cross pollination is regarded as the only way of maintaining the ecological diversity. Both fruit yield and size are improved by efficient pollinators (Gautier-Hion and Maisels, 1994; Free, 1993).

It is estimated that bees accomplish more than eighty percent of the insect pollination. The yield of fruit, legumes and vegetable seeds time and again have been doubled or tripled by providing enough number of bees for pollination (McGregor, 1976). The wild bees including bumble bees, leaf-cutting bees, alkali bees and carpenter bees are particularly adapted for gathering pollens and nectars from flowers (Bohart, 1972). Pollinators besides honey bees are also enormously valuable although their value is hard to estimate. Globally, the yearly contribution of pollinators to the agricultural crop has been estimated at about US $54 billion (Buchmann and Nabhan 1996; Kenmore and Krell, 1998). But a Significant and constant decline in diversity of pollinators has been reported in recent years and this alarming decline in the health and populations of pollinators poses in turn a significant threat to the integrity of biodiversity, to global food webs and to human health and survival. According to FAO (1993), about 75% of the genetic diversity of agriculture crops is lost since the beginning of 20th century and 25% of the worlds species present in the mid 1980 will be lost by 2015. 0.2-0.3% of all species is lost every year. Disturbance of pollinator systems and declines of pollinators has been reported on every continent except Antarctica (Kearns *et al*., 1998). An estimated 62% of all blossoming plants may suffer reduced regeneration from seeds as a result of pollinator insufficiency (Burd, 1994). Farmers in Himalayan region have been complaining about decline in apple quantity and quality due to pollination related problems. The number of pollinators is declining which results in decreased seed and fruit set in the plants that they service (Buchnann and Nabhan, 1996). In USA, the decline in the number of commercial honeybee colonies varied from 5.9 million in 1940s to 4.3 million in 1985 to 2.7 million in 1995 (Maheshwari, 2003). In Costa Rica, wild bee species richness in degraded forest lands declined from 70-37 species in 14 years (Nebhan and Buchmann, 1997).

Major causes for pollinator decline are habitat loss, fragmentation and degradation, pesticides, invasive species, parasites and diseases, exploitation and climatic change (William and Osborne, 2009). According to them, degradation and fragmentation of the habitat are the most adverse changes for pollinator populations. Hedgerows, field margins, embankment, and various other waste places act as a nesting habitat for some native bees. Removal of these unrewarding habitats has been related with striking decline in Germany's native bee fauna since 1960s; Modern agriculture practices are large-scale, usually monoculture, and often involves removing immediate natural vegetation. Monocultures lessen floral diversity that limits the variety of pollinators that could visit. Agricultural practices that involve frequent tilling and irrigation also leads to decline in soil nesting bees. In India, the soil nesting bees *Andrena ilerda* and *A. laena* which are important pollinators of the oilseeds, *Brassica campestris* and *B. juncea,* showed six to thirteen-fold decline from 1980 to 1992.; Extensive use of pesticides is a major risk to pollinators worldwide. The pollinators feed on the contaminated flowers, which result in pollinator poisoning. Honeybees are prone to almost all pesticides used commercially to control pests and diseases; *Varroa jacobsoni* and *Acarapsis woodi,* the parasitic mites infect populations of commercial honeybees. *Varroa's* usual host was the Asian honeybee, *Apis cerana* from which it spread to *A. mellifera* when *A. mellifera* was introduced in Asia for beekeeping.; Rising use of external artificial lights interfere with the navigational ability of many moth species which hampers the pollination process.; Radiations that are transmitted by cell towers have an effect on the commercial apiary located near the towers.

Air pollution interferes with the capability of bees and other insects to follow the fragrance of flowers to their source, discouraging the vital process of pollination (Frederick *et al.,* 2008). Their studies may help solving part of the mystery regarding the current pollination calamity that is affecting a wide variety of crops. Scientists are eager to know the reasons for dying off of honeybees and bumblebees in United States and other countries. New studies point out that emission from power plants and automobiles may have a role in insect demise. Air pollution is definitely a stress on honey bees and other pollinators.

Decline of pollinators will lead to less flower visitation, sudden or gradual decrease in seed and fruit production. Beekeeping sector would be in danger and is rather being observed in several areas of the world. Monetary worth of a solitary wild bee that serves as a pollinator of blueberry was estimated at $20 (Cane, 1996). One hive of honeybees/ ha of apple orchards raised in return 700% of the cost of pollination services (Kevan, 1997). Worth of US crops yields of pollinators other than honeybees may be as high as $6.7 billion per annum (Nabhan and Buchmann, 1997).The financial impact of insect pollination on global basis amounted to 149 billion Euros or 21.3% of the total value of the crops that produce fruits or seeds for direct human use. The total value of crops used as food for humans is 1.65 billion Euros and 10 of the 20 most important crops globally depend to some extent on insect pollinators. Out of 99% of the total world crop values, 54% rely upon crops that depend on insect pollinators. Average value of crops that rely on insect pollinators is much higher than that of the crops not pollinated by insects such as cereals and sugarcane (Rs. 50, 160 and Rs. 9900/ metric ton, respectively). The pollinator deficit may raise the cost of production as the cost of providing pollinator services increases (Anonymous, 2008).

Owing to the rapid growth of cement factories and other industrial units in Kashmir valley, the plant pollinator interactions of various agricultural and horticultural crops in such industrial areas seem likely to be affected. However to the best of my knowledge, no research work has so far been conducted in Kashmir Valley in this regard. The present study was an attempt to investigate the impact of air pollution on the pollinators and pollination process in which two important crops, an agricultural crop, Mustard, *Brassica campestris* L. belonging to family Cruciferae and a horticultural crop Almond, *Prunus amygdalus* Batsch belonging to family Rosaceae were considered.

***Brassica campestris* L. (Cruciferae)**

This is the most important species of crop in Asia (Rubatzkky and Yamaguchi, 2000). The flowers of *B. campestris* are formed in the stem which elongates after the leaf stops growing. The stem bears many branches, small leaves, and bright yellow flower. Each flower has four petals and six stamens of which two stamens are shorter than the style but four others are longer. Approximately, 95% of species of Crucifers need cross-pollination, although some cauliflower varieties are self-pollinated. Anemophily is not a good mechanism of pollination in *Brassica* spp. but bees play an important role as pollen vectors.

***Prunus amygdalus* Batsch (Rosaceae)**

Originally indigenous to central and western Asia, in India it is cultivated in Kashmir at elevations of between 760m to 2400 m. It is a tree having oblong-lanceolate, minutely serrate leaves; the flowers are solitary, pink or nearly white and showy, sometimes red in colour, with five sepals and five petals. Stamens are plentiful. Flowers are borne singly, or in umbels of two to six or occasionally more on racemes, the fruit is a pubescent drupe; the seed is long, flattened, and oval, with a brownish seed coat. The bulk of commercial almond cultivars are self-incompatible, meaning that without cross-pollination a viable crop is highly improbable. As the commercial part of the fruit is the kernel, pollination and ovule fertilization are of significant importance to obtain most favorable yields, and in general require the joint planting of at least two inter-compatible and concurrently blooming cultivars, and the presence of pollinating insects for pollen transfer (Socias i Company *et al*., 2005). Setting of fruit and pollination has been described as the most prominent limiting factors for almond production (Hill *et al.*, 1985). All the flowers do not set and thus to obtain a maximum crop of almonds, essentially 100% of the flowers must be cross-pollinated (McGregor, 1976). The most efficient pollinators of almond blossom have been found to be honey bees by various authors (Degrandi-Hoffman *et al.*, 1992; and Somerville, 2007).

With the background of above contents an attempt was made to carry out a study which will fulfill the following objectives:

a) To assess the impact of air pollution on the frequencies of visit or pollination efficiency of a dominant pollinator of selected plant at the study site.
b) To assess density and diversity of pollinator insects in relation to seed set of selected plants at the study sites.
c) To observe the effects of pollinator insects on other parameters that reflects reproductive success of selected plants at different sites.

Chapter – 2

REVIEW OF LITERATURE

The field of interrelationship of air pollution with pollination process is relatively new in the discipline of ecology and only modest amount of literature is available on the subject. Literature related to the present study and related studies were reviewed and are presented under the following two sub- headings:

1. Review related to atmospheric pollution and its general impacts.
2. Pollination related review.

AIR POLLUTION AND ITS GENERAL IMPACTS

Themani *et al.* (1980) studied the gaseous and particulate pollutants in the environment of the thermal power plant at four locations. The predicted concentrations of So_2 due to emission from TPP and its likely impacts on the inhabitants and climate in the downward section were evaluated. The predicted concentration of So_2 at a distance of 1.8 km downward of the TPP, varied between 34 and 216 where wind directions ranged from 70 to 90. The highest calculated concentration was 23µgm^{-3}. The difference was due to the rapid fluctuations in the wind direction during the observation period over a range from 20° to 90°.

Hindy and Farag (1983) carried out a relative study in which particulate matter was collected in tandem by High volume air sampler and deposit gauge. The samples collected were analyzed for aerosol matter, flammable matter and ash fractions. In the last fraction, 14 metals were determined by using an atomic absorption spectroscope. The minerals present in different types of dusts were determined qualitatively by means of infrared spectroscopy.

Sachind and Pandey (1983) investigated the impact of a thermal power plant on the soil and vegetation in neighboring areas. The concentration of pollutants in the area progressively decreased along a belt in the existing wind direction and a gradient of structural and functional changes in soil and plants was observed. The effect of the power plant emissions on soil and eco-physiological uniqueness seemed to be function of pollution gradient existing in the area. Vegetation in the area varied considerably at different sites and on the basis of plant responses was classified as sensitive, intermediate and insensitive. Environmental factors influenced the degree of growth response to air pollution.

Kumar and Singh (1985) investigated the effects of sulphur dioxide and nitrogen dioxide singly as well as in combination on foliar damage and growth and yield of *Cicer arietinum* cv. C-235. There were considerable reduction in dry weight fractions of both root and shoot. The effects of SO_2 + NO_2 on plant growth and dry weight reduction were synergistic and amplified with plant age. The yield was decreased by 17.6% and 2.9% and 26.8% in SO_2, NO_2 and SO_2+NO_2 treatments respectively. Blossoming and fruiting also advanced as a result of exposure to the pollutants.

Vora *et al.* (1986), in a comparative study of dust fall on the leaves in high and low pollution areas and its effect on carbohydrates, revealed that manufacturing dust pollution caused undesirable effect on plants. The total sugar and reducing sugar contents were found to be less in dust loaded leaves of high pollution areas in contrast to clean leaves of low pollution areas.

Gupta (1987) studied the effect of coal –smoke pollutants on the growth, yield and leaf epidermal features of *Abelmoschus esculentus*

Moench. The reduction in plant height and stem diameter jeopardized the production of leaves and flower buds and encouraged leaf and flower fall, resulting in decrease in the number of fruits per plant. The length of fruits was affected and the boundary and fresh weight suffered appreciably, causing a decrease in plant yield. The net productivity of stems, roots and leaves faced losses of 22.5%, 24.0% and 37.5% respectively that resulted in 28.3% loss in the total net productivity of polluted plants.

The effects of SO_2 (0.5 ppm for 1.5 h), Ekalux –Ec 25 (0.015%) and SO_2 (0.5ppm for 1.5h) + Ekalux (500ml of 0.076% aqueous solution) on chlorophyll and carotenoid pigments of *Oryza sativa* was investigated by Agarwal *et al.* (1987). Plants treated with SO_2 either singly or along with Ekalux, showed evident foliar damage symptoms with decreasing levels of chlorophyll and carotenoid pigments. The percentage of leaf area injury and reduction in chlorophyll and carotenoid contents were maximum in SO_2 treated plants followed by SO_2 + Ekalux and then Ekalux treated ones.

Dueck *et al.* (1987) made a study on growth and reproduction of Silene cucubalus WIB, intermittently exposed to low concentrations of air pollutants, Zinc and Copper and concluded that the number of seeds and individual seed weights were significantly influenced by heavy metal pollutants present in air.

Synder *et al.* (1988) evaluated the effects of ambient ozone on Muskmelon and concluded with the suggestion of use of open-top chambers. Superstar Muskmelons grown in charcoal-filtered (CF) chambers compared to grown in non filtered chambers showed differences in the harshness of visible foliar O_3 damage. Furthermore, plants grown in NF conditions had significantly less (21.3%) profitable fruit and fewer (20.9%) profitable fruit number than those from CF chambers.

Nyman *et al.* (1990) investigated the effects of ozone and sulfur dioxide on two epiphytic orchids. Plants of *Encyclia tampensis (Epidendrum tampense*) and *Epidendrum rigidum* (Orchidazeae) exposed to 0.3, 0.6 and 1.2 ppm SO_2 or 0.15, 0.3 and 0.45 ppm O_3 for 6 hr as well as sequentially to 0.3 ppm O_3 (2 hr), 0.3 ppm O_3 plus 0.06 ppm SO_2 (2 hr) did not exhibit visible damage. Exposures to these pollutants were also without effect on stomatal conductance and Crassulacean acid metabolism (CAM, i.e. carbon fixation at night). The leaf resistance of the two orchids to these gases can be due to structural factors as well as to the usually lower sensitivity of CAM plants to pollutants.

Prasad and Inamdar (1991) reported decline in growth and yield of *Vigna aconififolia*, *Vigna rediata* and *Vigna ungulata* by cement dust from cement kiln.

Effect of cement dust pollution on growth and production of cotton was examined by Satao *et al.* (1993). In a field experiment during Kharif season of 1990-92, cotton cv. AHH-468 and AKH-4 were dusted with 4, 7 or 10g cement dust/m^2 per day from seedling to physiological maturity phase daily or not dusted. Cotton yield declined with increasing levels of cement dust. In AHH-468, cement dusting declined cotton yields by 13.32-56.5% compared with 14.07-39.92% in AKH-4.

Salgare and Palathingal (1993) evaluated the effects of industrial pollution on the physiology of pollen of *Peltophorum ferrugineum* Benth. Potentiality of pollen germination was observed only in open flowers both from polluted and unpolluted regions. Industrial pollution leads upto 70.14% and 50.5% inhibition in the rate of pollen germination and pollen-tube growth respectively.

Piotrowski (1993) obtained data from air pollution monitoring caused by industrial discharge. The results revealed that the area was little threatened by gaseous pollutants and largely being affected only by particulate pollutants from the cement plant.

Mortensen (1993) investigated the effect of ozone (O_3) concentration on the growth of *Lycopersicon esculentum* at various photosynthetic photon flux densities (PPFD), relative air humidities (RH) and carbon dioxide (CO_2) concentrations. Elevating the O_3 concentration from < 10 to 85 nl 1^{-1} for 6 h per day reduced the shoot dry weight 35% at 70% RH and 62% at 90% RH. Elevating the PPFD from 100 to 350 µmol $m^{-2}s^{-1}$ significantly reduced the effect of O_3 in one of two experiments. The most prominent interaction between RH, PPFD and O_3 was found on plant height. High O_3 levels usually decreased plant height at low PPFD and had no or a stimulating effect at high PPFD.

Uma *et al.* (1994) while assessing the impact of cement kiln dust pollution on growth, yield and metabolic changes of *Brassica junicea* concluded that although there were no visible injuries and variations in morphological features, the growth of dusted plants was relatively retarded, besides the decline in metabolites like starch, protein, amino acids, lipids, sugars which suggest that cement kiln dust pollution had influenced the growth of *Brassica junicea.*

According to Saralabai (1995) the use of electrostatic precipitator (ESP) for reducing the dust inflow to the soil and leaves of *Cajanus cajan, Vigna mungo, Vigna radiata, Glycine max, Vigna unguiculata* improved the biomass, chlorophyll pigment, leaf enzyme activity and crop production of all the species.

A vegetation examination was conducted by Iqbal and Habib (1995) at distances of 150-600m from a cement plant. The survey revealed that *Prosopis juliflora, Aerva javanica* and *Senna holosericea* were the dominant species at various distances from the factory. The lowest number of species and individuals were noticed near to the factory.

The effect of various gaseous and particulate pollutants emitting from brick kilns on the surrounding vegetation was studied by Sarkar and Kundu (1996). The relative densities of various herbs showed that there was distinct decline in densities of herbs in the surrounding area of brick kiln as compared to control although some plants like *Blumia lacera*, *Calotropis* sp. and *Gnaphalium* sp. remained unaffected/less affected. The percent frequency of the plant community showed that excepting *Blumia lacera* and *Calotropis procera*, the occurrence of plant species diminished towards the brick kilns.

Effect of sulphur dioxide on Bell Pepper was studied by Srath *et al.* (1996). The tolerance of Capsicum (*Capsicum fruitescens* L. cv. Californian Wonder) to sulphur dioxide exposure was conducted and concluded that fumigation of SO_2 at 1.0 ppm for three hours adversely affected the number of leaves, leaf area, number of buds, flower and fruits and the dry matter and the chlorophyll contents of the leaves.

A study carried out by Saralabai and Vivekanandan (1997) in some leguminous species that were treated with cement dust observed no effect on vegetative growth, seed yield and harvest index of *Cajanus cajanus*, *Vigna mango, V. radiate and V. unguiculata*. However, the overall number of fruit and seed weight of *Capsicum annum* and *Okras* was reduced by 30%.

Rao and Narayanan (1998) conducted a pot experiment in which cv. IR 64 was dusted with 0 or 50 g cement kiln dust/m^2 at pre-flowering + flowering, or pre-flowering + flowering + post-flowering growth phases. Plant growth and yield were decreased by cement dust, predominantly when applied at all 3 growth stages.

Black *et al.* (2000) investigated the impact of ozone on the reproductive development of plants and concluded that exposure to ozone, even at current ambient levels in many industrialized countries, reduces grain and fruit yields and adversely affects yield quality. The impact of exposure is highly reliant on ozone concentration and the duration and timing of exposure.

Singh and Agarwal (2003) conducted the field-based experimentation to evaluate the effect of simulated acid rain (SAR) of different pH i.e. 5.6 (control), 5.0, 4.5, 4.0 and 3.0 on two cultivars of wheat (*Triticum aestivum*, Malviya 213(M213) and Sonalika). Shoot and root lengths significantly reduced at pH 3.0 in both varieties. Leaf area declined at pH 4.0 and 3.0 in M213 at both ages and at 75 days in Sonalika. Total biomass of 75 days plants declined significantly at pH range 4.5–3.0 in M213 and at pH 4.0 and 3.0 in Sonalika. Net assimilation rate (NAR) declined significantly at pH 3.0 in both varieties. Compared to control, yield of M213 revealed significant reductions at pH 4.0 and 3.0, whereas Sonalika responded negatively at pH 3.0.

The species composition, mound population densities, relative abundance and colony sizes of red wood ants along an air pollution gradient of a copper smelter in Southwest Finland was studied by Eeva *et al.* (2004). Five species belonging to *Formica* genus were found and two of them showed changes in their relative abundance that could not be explained by natural habitat differences. Nest mound volumes were 34% smaller in the polluted areas signifying that smaller colonies can be maintained there. Their data revealed that red wood ants can tolerate fairly high amounts of heavy metals and maintain reproducing colonies even in heavily polluted areas, but on the basis of smaller colony sizes, pollution stress may also cause trade-offs in reproduction

According to Cape (2007) and Vuorinen *et al*. (2004), air pollutants are degrading scent plumes and therefore are disrupting scent-mediated interactions, e.g., an essential process of pollination.

Lovett *et al.* (2009) studied effects of air pollution on ecosystems and biological diversity in the eastern United States. Four air pollutants (sulphur, nitrogen, ozone, and mercury) and eight ecosystem types ranging from estuaries to alpine tundra were considered. Effects of air pollution were recognized, with varying levels of certainty, in all the ecosystem types examined. None of these ecosystem types were free of the impacts of air pollution, and most are affected by multiple pollutants.

POLLINATION RELATED REVIEW

Benoit et al. (1983) along the Blue Ridge Parkway in Virginia, collected branch lets and pollen from indigenous eastern white pine (Pinusstrobus L.) trees that were sensitive, intermediate, and tolerant to oxidants of air and concluded that fumigation of branch lets with ppm ozone (O 0.103h/day until anthesis did not affect) for 4 or 8 pollen production or germinability but the percent germination was significantly (P0.01) reduced in pollen exposed under wet conditions ≤ to 0.15 O3 h.

Cox (1984) carried out a study on In vitro and In vivo Sensitivity of Oenothera parviflora L. pollen to simulated acid rain. Response of pollen in vitro showed significant inhibitory effects of pH, and demonstrated that pH values ≤3.6 were inhibitory to both germination and tube growth, when compared with the treatment of pH 5.6. Stigma receptivity assessed by germination and initial tube growth on the stigmatic surface also decreased significantly ($P< 0.01$) in response to acid rain simulation prior to hand pollinations.

Wolters *et al.* (1987) investigated the effects of air pollutants on pollen and concluded that in both in vivo and in vitro, pollen germination and pollen tube growth are affected by air pollutants. The stimulation and inhibition of these pollen characteristics depend on the pollen species as well as on the type of pollutant and its concentration, the exposure time, the relative humidity during exposure. Mitosis, gaseous exchange, size and chemistry of pollen can also be influenced by air pollutants. Pollen germination and tube elongation vary in their response to air pollution stress, and both are more vulnerable in in vitro compared to the in vivo situation.

Cox (1988) carried out a study on the sensitivity of pollen from various coniferous and broad-leaved trees to combinations of acidity and trace metals and found that most pollen assayed revealed noteworthy inhibition of germination and germ tube growth in response to pHs currently observed in rain samples in eastern Canada. Pollen in vitro showed higher sensitivity to pH in combination with copper while as copper by itself either did not affect pollen function or was stimulatory in other species. Zinc has little or no effect, whereas lead at the concentrations significantly inhibited both germination of Pinus strobus L. pollen at pH 5.6-3.6 and tube growth of both P. strobus and Pinus resinosa Ait. The increase in pollen mortality in reaction to air pollution at the time of pollination raises certain implications for reproduction and breeding.

According to Barrett and Kohn (1991), declining abundance of pollinator species can speed up its demise, because a decline in numbers is often accompanied by a decline in genetic variability via genetic drift, which increases the likelihood that populations and species will become extinct. Fragmentation and habitat destruction could also lead to genetic erosion by reducing gene flow between demes.

The financial gains due to honey bee (*Apis mellifera* L.) were evaluated by Southwick *et al.* (1992) whose method of examination focuses on the gains to consumers through lower prices for crops that were benefited by honey bees. Financial demand functions for the major agricultural crops that are pollinated by bees were estimated. The amounts by which the yields of pollinated crops are increased were estimated from an array of sources. In the ultimate step, the surplus realized by consumers of these crops that would be lost if honey bees were depleted was determined and it was concluded that the annual gains were estimated to range between $1.6 and $5.7 billion.

Bosac *et al.* (1993) investigated the impact of O_3 and SO_2 on reproductive development of Oilseed rape (Brassica napus L.). I., pollen germination and pollen tube growth and concluded that pollen germination was significantly reduced and pollen tube growth impaired in both cultivars (in vitro and in vivo) as pollen was exposed in unbuffered incubation medium to 200 nl l-1 SO_2. The pH of the unbuffered medium cut down from 6.5 to 5.5 during fumigation, reflecting a role for acidification in the observed SO_2 induced effects. Pollen tube growth was also impaired at pHs of 5.6 and below.

Rathcke and Jules (1993) reported that plant-pollinator interaction may be affected by fragmentation and concluded that pollinator abundance and diversity declines with fragmentation.

Sampson *et al.* (1999) investigated the impacts of enhanced ultraviolet-B radiation ranging between 2.74 and 15.93 kJ·m-2·d-1 on flower, pollen, and nectar production of a new crop plant, Limnanthes alba (Limnathaceae), and a wildflower, Phacelia campanularia (Hydrophyllaceae), and concluded that intensified UV-B can alter some flowering traits that impinge upon plant competition for pollinator services, as well as plant and pollinator reproductive success.

It was reported by Cunningham (2000) that in central New South Wales, Australia, flowers of *Acacia brachybotrya* and *Eremophila glabra* plants growing in linear vegetation leftovers received a lesser amount of pollen than conspecifics in close by reserves. Fruit production of both species was increased by pollen supplementation reflecting the pollen limitation of fruit set and thus it can be concluded from the study that habitat fragmentation can lead to decline in pollination and subsequent fruit set in wild plant population.

Kearns (2001) suggested that flies are important pollinators but their role in pollination is less well known than those of bees. They are constant visitors of flowers, predominantly those that have easy access, and in spite of their relative hairlessness, are expected to be important pollinators of some flowering species in some ecosystems. Flies are entangled in ecosystems in different and more complicated ways than bees. Floral products feed all life stages of bees while flies do not use flower products throughout their life and mostly use as adults; their immature progeny typically eat unrelated foodstuffs.

Kerr (2001) effectively correlates the geographic distribution of Canadian butterfly diversity (292 species) with current biotic and climatic parameters, particularly habitat heterogeneity and potential evapo transpiration, which is a measure of climatic energy by using GIS. More butterfly species are present in warmer and more heterogeneous habitats. The spatial distribution of climate energy is of particular concern as it will shift with global warming. This method holds promise for other well-sampled faunas of floral visitors, particularly if it proves to be a valid link between remotely sensed surface features and pollinator biodiversity on the ground.

Cane (2001) reviews the worldwide literature of habitat fragmentation and Concluded that linking habitat fragmentation with pollinator demise are premature. In particular, he advocated that future studies need to consider the habitat needs for nesting by bees when evaluating the effects of fragmentation.

Packer and Owen (2001) compared genetic variation between species of two important higher taxa of invertebrate pollinators, bees and Lepidopterans. Bees are distinguished for their limited natural genetic variability due to factors such as their haplodiploid genetic system, aggregated nesting, central-place foraging habits, viscous population structure, and, may be, sociality. They suggested that bee populations may consequently be more genetically resilient of facing declining population size than are butterflies and moths.

According to Thomson (2001), if pollinators are in decline, the results of their absence will lead to reductions in fruit or seed production in natural or agricultural ecosystems.

Kevan and Phillips (2001) inspected pollination deficits in agro ecosystems from an economic market perspective and concluded that shortfalls in agricultural production stemming from pollination deficits may spawn both short-term winners and losers in the producer and trade economies and in all cases the consumer will have to pay higher prices for a depleted wealth of food products in the retail market place.

Harris *et al.* (2007) studied the consequences of habitat fragmentation for plant–pollinator mutualisms and concluded that there are substantial evidences for disruption of plant-pollinator mutualisms in fragmented landscapes. The causes can be countless, varying from deficiency in nesting sites for key insect pollinators, to a decline in pollinator visits when plant population sizes are condensed by fragmentation. Most important and well-documented consequence of disruption in pollination systems is reduced seed production in plant populations in fragments as a result of pollen-limitation. Reduced seed production, in turn, has a negative effect on net production.

Oryx (2007) investigated the decline of the bumble bees and cuckoo bees (Hymenoptera: Apidae: Bombini) of Western and Central Europe and concluded that amongst the factors unfavourably affecting the Bombini, anthropogenic factors (predominantly those linked with large-scale farming techniques) appear to be of greater magnitude than natural factors. To arrest population declines and species extinctions it will be essential to preserve aspects of traditional farming practices and for all Bombini to be afforded legal protection in all countries of the region.

Devaux *et al.* (2008) studied environmental and landscape effects on cross-pollination rates, observed at long distance among French oilseed rape, *Brassica napus* commercial fields. The observed CPR varied from 0% to 0.092%, CPR differed among years, being nil for the last 3 successive years, partly because of different environmental conditions and detection issues.

Gallai *et al.* (2008) observed that vegetables and fruits were the principal crop categories in worth of insect pollination with about €50 billion each, followed by edible oil crops, stimulants, nuts and spices. The production value of a ton of the crop categories that do not depend on insect pollination averaged €151 whereas those that is pollinator-dependent averaged €761. The vulnerability ratio was calculated for each crop type at the local and world scales as the ratio between the economic value of pollination and the current total crop value. This ratio varied significantly among crop categories and there was a positive correlation between the rate of vulnerability to pollinator's decline of a crop category and its value per production unit.

Frederick *et al.* (2008) studied Air pollution modifies floral scent trials and concluded that the recognized increases in air pollution concentrations, from pre-industrial to present times has lead to reductions in volatile compound concentrations that insects detect as they pollinate flowers.

Aizen *et al*. (2009) reported that the probable direct reduction in total agricultural production in the absence of animal pollination ranged from 3 to 8%. The percentage increase in cultivated area required to compensate for these deficits was several times higher, mainly in the developing world, which comprises two-thirds of the land devoted to crop cultivation worldwide. Crops with lower yield growth tended to have undergone greater extension in cultivated area. Agriculture has turned out to be more pollinator-dependent over time, and this movement is more distinct in the developing than developed world.

Winfree *et al*. (2009) used meta-analysis to produce the literature on how bees, the most essential group of pollinators, are influenced by human disturbances such as habitat loss, grazing, logging, pollution and agriculture. They obtained 130 end products from 54 published studies recording bee abundance and species richness as a function of anthropogenic disturbance and concluded that bee abundance and species richness were significantly, harmfully affected by disturbance.

Fuentes *et al*. (2009) studied the effects of air pollution on biogenic volatiles and ecological interactions and concluded that the Chemical signals play important roles in ecological interactions but are susceptible to perturbation by air pollution. In polluted air masses, signals may travel shorter distances before being damaged by chemical reactions with pollutants, thus losing their specificity. They found that pollination, attraction of natural enemies of plant pests, aggregation pheromones, and mate attraction are expected to be affected.

Dupree *et al*. (2009) studied impact of currently used or potentially useful insecticides for canola agro ecosystems on Bombus impatiens (Hymenoptera: Apidae), Megachile rotundata (Hymenoptera: Megachilidae), and Osmia lignaria (Hymenoptera: Megachilidae) and concluded Clothianidin and to a lesser extent imidacloprid were highly toxic to all three species, deltamethrin and spinosad were intermediate in toxicity, and novaluron was nontoxic. Bumble bees were generally more tolerant to the direct contact applications >O. lignaria > leaf cutting bees.

Chapter – 3

STUDY AREA
AND
STUDY SITES

The mountainous state of Jammu and Kashmir, comprising the subtropical Jammu, alpine-temperate Kashmir and arid Ladakh regions, is located in the Western fraction of the Himalaya. The state of Jammu and Kashmir lies within the geographical coordinates of 32^0 17' to 37^0 05′ N latitude and 72^0 31′ to 80^0 20′ E longitude. The effective geographical area of the state is 101387 km^2 that accounts for about 42% of the Indian Himalaya.

Kashmir valley, a world prominent health resort once known for the clean and fresh atmosphere, is also under the severe risk of atmospheric pollution. Major sources of air pollution in Kashmir valley are cement factories, brick kilns, stone crushers and vehicle exhaust. In Kashmir valley there is an enormous potential to manufacture adequate cement and presently several factories are in operation in the areas like Khrew, Wuyan (district Pulwama) and Khunmoh (district Srinagar). In 1982 a cement plant under the banner of Jammu and Kashmir Cements Ltd., with daily production of 600 tons, was set up at Khrew. The cement plant releases a vast quantity of cement dust into the atmosphere apparently affecting the flora and fauna of the region. Cement dust from the cement plants forms a thick deposition layer over the adjoining agricultural fields. The undesirable effects of cement pollution are well confirmed in Khrew - Khunmoh area which has been experiencing such effects for the last three decades. The region is a live laboratory of environmental degradation. A visit to the area is sufficient for one, of course without any pre-conceived notions and prejudices, to have a firsthand comprehension of the unfortunate and uninterrupted exposure to the cement pollution. As one drives from Pampore on national Highway to Lethpore one can see on the left side the area from Khunmoh to Ladhu engulfed in a thick cover of pollutants allowing no visibility at all. If one takes the north-eastern turn at Pampora or Lethpora and moves towards the Khrew valley the damage becomes more and more apparent. The green flora has turned pale, the roof tops are covered with a deposit at places more than a centimeter thick with pollutants and the fields that used to be lush green reveal a 'burnt' look. There has been a considerable decrease in yield of mustard, saffron and variety of horticultural crops. Moreover, loss of the refined product into the atmosphere during its manufacture is a huge economic loss. Additionally, physical properties of soil and growth pattern of soil biota are also altered in negative ways which eventually damage the ecology of the whole area (Shukla *et al.*, 1990; Armolaitis *et al.,* 1996 and Saravanan and Appavu, 1997). Besides, there are apprehensions about the interference of the air pollution caused by such industries on the plant pollinator interactions. Hence research works with the background knowledge of environmental sciences are required to be carried out in such important areas of the region. The present study was carried out in the industrial areas of Khrew; Wuyun and Darbagh (Harwan) was taken as control for assessment and evaluation of the same in respect of some crop and wildlife floristic species.

In order to investigate/assess the impact of air pollution on the pollinators and pollination of considered agriculturally important crops, three sites were selected.

2.1. STUDY SITES

Site-I / Factory site (FS): This was near to cement factory at an altitude of 1773m with the geographical coordinates of N 34º 02′ 07.2″ latitude and E 75º 01′ 01.5″ longitude. This area was the recipient of heaviest dust and vehicular pollution. The area was under saffron and Mustard cultivation with scattered horticultural trees of Almond (*Prunus amygdalus*), Walnut (*Juglans regia*) and Apricot (*Prunus armeniaca*). The soil was covered with a brittle crust of about 2mm thick cement dust.

Site-II / Wuyan field (WF): This was located at 10 km away from the cement factory at an altitude of 1625m with the geographical coordinates of N 34º 02′ 4.70″ latitude and E 074º 57′ 30.1″ longitude. Although this site was quite far away from the main factory but was also in receipt of cement dust released from the other smaller industrial units. Vehicular emission also added to the pollution level. The level of air pollution there was lesser and not apparent. There also existed horticultural trees and agricultural crops as mentioned for Site I.

Site –III / Control site / Darbagh,Harwan (DH): This was situated in Darbagh very close to Harwan and represented the control site. This site was fairly distant from the cement factory at an altitude of 1635m with the geographical co-ordinates of N 34º 09′ 58.01″ latitude and E 074º 53′ 39.1″ longitude .The site was under mustard and rice cultivation with scattered horticultural trees, like, almond, apple and was not in receipt of any cement dust from the factory. Vehicular movements in the control site were also considerably very less.

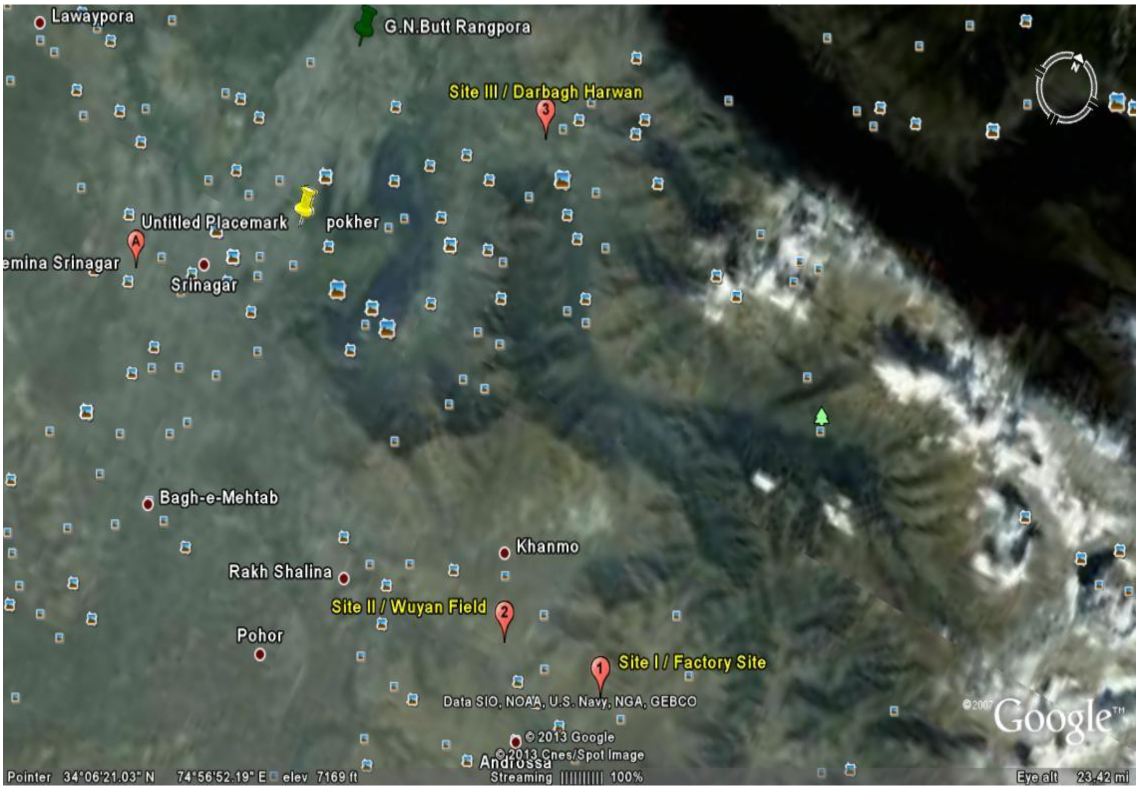
Mustard Field at Factory Site

Almond Scattered in Mustard Field at Factory Site

Almond and Mustard Crop at Wuyan Field

Almond Tress at Darbagh Harwan in their Blossoming Season

Mustard at Darbagh Harwan



Satellite Imagery Showing Different Study Sites

Chapter – 4

MATERIAL AND METHODS

The following protocol/methodology was observed to carry out various aspects of air analysis and pollination process during the present study.

A) Air analysis

Air sampling for four parameters i.e. RSPM, NRSPM, SO_2 and NO_2 was done on the monthly basis from March 2011 to December 2011 at 3 different study sites using High Volume Air sampler. The sampler measures the concentration of SPM, RSPM and gaseous pollutants (SO_2 and NO_2) in the ambient air. The sampler was equipped with impringers to collect the gaseous pollutants (SO_2 and NO_2). The sampling instruments were placed about 3 m above ground level and air sampling was carried out for 1 hour (as also provided in the instructions of manual of the equipment) at each of the three sites for all the parameters. Samples were transported to the laboratory and refrigerated until analysis in order to minimize volatilization and was analyzed within 24 hrs.

Particulate matter

Oven dried and pre-weighed glass microfiber filter paper (Whatman, size Gf/A 20.3 × 25.4 cm) was mounted on the hood of the High Volume Air Sampler. Sampler was run for fixed time duration and the glass microfiber filter paper was reweighed. The increase in the weight gave the concentration of RSPM in the atmosphere. NRSPM in the same manner was estimated by calculating the increase in weight of the pre-weighed sampling bottles fixed at the bottom of air sampler where in the coarser particles are collected. NRSPM and RSPM values were calculated by using the following formula.

Air Volume Sampled (m^3) = $L_{1} + L_{2 \times T/2}$

Where,

L_1 = Initial water level (adjusted at zero)

L_2 = Final water level

T = Time for which sampler is operated (min)

Thus,

RSPM ($\mu g/m^3$) = $Fw_2 - Fw_1 \times 10^{-6}$ / Air volume sampled

and

NRSPM ($\mu gm/m^3$) = $B_2 - B_1 \times 10^{-6}$ / Air volume sampled

Where,

FW_1 = Initial weight of filter paper

FW_2 = Final weight of filter paper

B_1 = Initial weight of sampling bottle

B_2 = Final weight of sampling bottle

SPM ($\mu g/m^3$) = NRSPM + RSPM

Sulphur dioxide (SO_2)

Modified West and Gaeke method (1956) was adopted for measuring Sulphur dioxide. Sulphur dioxide from air is absorbed in a solution of potassium tetrachloro mercurate (TCM) prepared by dissolving 5.43g mercuric chloride, 0.033g EDTA and 3g potassium chloride or 2.34g sodium chloride in one liter distilled water. 10ml of this solution was taken in impingers and the samples were collected at the rate of 1 l/ml (using a rotometer) for an hour. Using this method SO_2 can be measured in the range of 20-1050$\mu g/m^3$.On exposure to atmospheric air a dichlorosulphitomercurate complex is formed which on reaction with pararosaniline and formaldehyde formed an intensively colored solution (pararosaniline methyl sulphonic acid). The absorbance of this solution was measured at 560nm using a spectrophotomer and the concentration of SO_2 was determined using a calibrated curve. Simultaneously a blank was run using the same procedure as for exposed samples.

Calculations:

SO_2 (µg/m^3) = µg SO_2 / ml × 10^3 / V

Where,

V = Volume of air sample in liters and µgSO_2/ ml = concentrations of SO_2 in sample deducted from the graph.

Nitrogen dioxide (NO_2)

Standard method given by Jacob and Hochheiser (1958) was followed for measurement of Nitrogen dioxide. The normal range of measurement of this method is 9 - 750µg/m^3. Nitrogen dioxide was collected by bubbling air through a 30 ml solution of sodium hydroxide and sodium arsenate (used as absorbing solution) in the glass impringers. 10 ml of this sample solution was again treated with 1ml hydrogen peroxide, 10ml sulphanilamide and 1.4ml N-(1-naphtyl)-ethylenediamine di hydrochloride (NEDA) and the volume of the solution was raised to 50ml. In the same way a blank was prepared using 10ml of unexposed absorbing reagent instead of sample solution. After 10 minutes of color development interval, absorbance was measured at 540 nm against the blank. Concentration of NO_2 in µg was determined from the calibration curve.

Calculations:

$V= F_i+F_f \times t_i \times 10^{-6} / 2$

Where,

V= volume of air sample (m^3)

F_i = air flow rate before sampling (cm^3/min)

F_f= air flow rate after sampling (cm^3/min)

10^{-6} = convergence of cm^3 to m^3

NO_2 µg/m^3= µg/ml NO_2× 10^3 / V

Where V is volume of air sampled in liters and NO_2µg/ml = NO_2 concentration in analyzed samples as deduced from the graph.

B) Pollination study

Basic equipments used for the Collection and Preservation of Insects

The items of equipments that were included in the general collector's bag were fine, lightweight forceps, vials containing alcohol or other preservatives, killing bottles of various sizes, small boxes or containers for storing specimens after removal from killing bottles, absorbent tissue for use in killing bottles, notebook and writing equipment for writing down notes, counting the pollinators and labeling data, a hand lens, a sweep net for collection of representative samples and a camera for taking photographs of the site and pollinators visiting particular plant and also the ones which were not identified on the site.

Sweep net designed especially for collecting bees, butterflies and other flying insects consists of the bag and handle which are relatively light weighted. Sweep net is similar to other aerial nets but is stronger and has more durable bag to withstand when being dragged through dense vegetation.

Collection of specimens in flight calls for the basic stroke-swing the net rapidly to capture the specimen, then followed through to force the insect into the very bottom of the bag. Wrist was twisted so the bottom of the bag hangs over the rim which helped in entrapping the specimen.

The catch was transferred from the bag to a killing jar carefully in one of several ways Single specimens were transferred most easily by lightly holding them in a fold of the net with one hand while inserting the open killing jar into the net with the other. When numerous specimens were in the net after prolonged sweeping, it was desirable to put the entire tip of the bag into a large killing jar for few minutes to stun the insects. They may then be removed and the desired specimen or the entire mass may be dumped into plastic jars for later sorting and identification. The specimens of insects collected through standard practices were then identified with the help of literature and already existing identification reports.

Field method of observation

Visits to the 3 comparable study sites were performed in the flowering seasons of the selected plants. A total of 12 visits were carried out for the selected (mustard and almond) plants in the whole study period. Field works or visits took place mostly in the months of March and April of the year 2011. Insect counts were carried out during approximately 45 minutes Systematic Walking Surveys (Kumar *et al.,* 2009); during the warmer time or intervals of the day, when the weather conditions were suitable, temperature was above 15ºC and wind speed was favorable. The species and number of individual species of the hymenopteran insects were determined by sight at each study site. When a species of pollinator was not identified at site, the individual was caught with an insect or sweep net for its taxonomic determination in the laboratory.

Pollination efficiency

Flower visitor observations were carried out for both species at all 3 selected sites over the course of the field season 2011. Investigations on each study site were made between 09:00 am and 11:00 am and between 12:00 am and 02:00 pm, the period with highest insect activity and when temperature and wind speed was favorable.

To allow for comparisons, all observations were conducted during the peak flowering time of each species. Observations were carried out in blocks of 30 min of continuous undisturbed monitoring on at least four occasions and voucher specimens were identified. Observations were done randomly and in every observation unit, for every bee, we then recorded;

1. The number of flowers visited.
2. The time spent on each flower it visited.
3. The total time spent per plant.

These parameters provide us the pollination efficiency of the dominant pollinator, presuming that all foragers carried pollen.

Representative insect visitors were also collected; however, collections were not made during observation time to prevent altering natural visitation rates.

Seed set

For estimating the seed set and reproductive success, plants were selected at random in different study sites and scored for number of floral heads per plant, and number of seeds produced per flower following Lubbers and Christensen, (1986).

$$\%\text{age seed set} = \frac{Total\ number\ \ of\ seeds\ per\ pod}{total\ number\ \ of\ ovules\ born\ by\ pod} \text{ x } 100$$

Seed viability test

Seed viability was determined using Tetrazolium-test. Three sets of thirty mustard seeds from three different sites and three sets of ten almond seeds collected from different study sites were placed on a moist filter paper for 24hrs and then longitudinally sectioned to expose embryos. The sections were then incubated in dark in 1% aqueous solution of 2,3,5 triphenyl tetrazolium chloride for 24hrs. Seeds showing strong stained embryos were considered viable.

Recording counts of hymenopteran on mustard and almond crop

Using sweep net in the mustard crop field

Transferring the captured pollen collectors from sweep net to the killing jar

Chapter – 5

RESULTS

Air analysis

Air monitoring of different air pollutants namely, suspended particulate matter (SPM), respirable suspended particulate matter (RSPM), non-respirable suspended particulate matter (NRSPM), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) was carried out at 3 different study sites during the study period and their results are presented in Tables 1, Table 2, Table 3, Table 4 and Table 5 and figures 1 to 5.

Respirable suspended particulate matter (RSPM)

The concentration of RSPM at different study sites is shown in Table 1. Results indicated that at factory site (FS), the maximum of 882.95µg/m^3 concentration of RSPM was found in the month of December while as minimum of 560 µg/m^3 values were recorded in March (Fig. i). In Wuyan field (WF), highest values of 600µg/m^3 were recorded in the month of December and lowest values of 475.11µg/m^3 in September and at Darbagh, Harwan (DH), highest values of 169.72µg/m^3 were recorded in the month of October and lowest values of 119.12µg/m^3 in May. The mean values of RSPM ranged from a minimum of 128.554µg/m^3 at Darbagh, Harwan (DH) to a maximum of 660.802µg/m^3 at factory site (FS).

Non Respirable suspended particulate matter (NRSPM)

The concentration of NRSPM at different study sites is presented in Table 2. Results indicated that at factory site (FS) the maximum of 900.33µg/m^3 concentration of NRSPM was found in the month of July while a minimum of 330.52µg/m^3 values were recorded in May (Fig. ii). In Wuyan field, highest values of 753µg/m^3 were recorded in the month of June and lowest values of 300µg/m^3 in April and also in May and at Darbagh, Harwan highest values of 199µg/m^3 were recorded in the month of July and lowest values of 144µg/m^3 in August. The mean values of RSPM ranged between a minimum of 163.03µg/m^3 at Darbagh, Harwan to a maximum of 566.45µg/m^3 at factory site (FS).

Suspended particulate matter (SPM)

Suspended particulate matter was found to be highest, 1713.24 µg/m^3 and lowest, 995.17 µg/m^3 at factory site (FS) in the month of December and April respectively (Fig. iii). Factory site (FS) recorded highest values of SPM as compared to two other sites (Table 3). The mean values of SPM ranged between a minimum of 291.587µg/m^3 at Darbagh, Harwan and a maximum of 1227.252µg/m^3 at factory site (FS).

Sulphur dioxide (SO_2)

The values of SO_2 estimated for different sites are shown in Table 4. At factory site (FS) the lowest of 106.12µg/m^3 existed in the month of April while as the highest of 140.34 µg/m^3 values were observed in the month of December. In Wuyan field (WF) and Darbagh, Harwan (DH) the highest of 118.64 µg/m^3 and 33.44 µg/m^3 values of SO_2 were recorded in the months of December and October while the lowest of 98.22 µg/m^3 and 21.44 µg/m^3 were estimated in the months of July and March respectively (Fig. iv).The mean values of 121.82 µg/m^3, 105.32 µg/m^3, and 28.13 µg/m^3 of SO_2 was recorded at factory site (FS), Wuyan field (WF) and Darbagh, Harwan (DH) respectively.

Nitrogen dioxide (NO_2)

The values of NO_2 at different sites are shown in Table 5. At factory site (FS) the lowest concentration of 100.56 µg/m^3 of NO_2 was found in the month of March while the highest of 145.44µg/m^3 was observed in the month of December. In Wuyan field (WF) and Darbagh, Harwan (DH), the highest of 125.24 µg/m^3 and 26 µg/m^3 values of NO_2 were recorded in the months of December and March and the lowest of 95.46 µg/m^3 and 13 µg/m^3 in the months of July and May respectively (Fig. v).The mean values of 120.49

μg/m^3, 104.06 μg/m^3, and 19.46 μg/m^3 of NO_2 was recorded at factory site (FS), Wuyan field (WF) and Darbagh, Harwan (DH) respectively.

Table 1. Monthly estimates of RSPM levels (μg/m^3) for the year 2011μg/m

S.No.	**Month**	**RSPM (μg/m^3)**		
		Site I / (FS)	Site II / (WF)	Site III /(DH)
1	March	560	476.24	128.23
2	April	564.5	480.22	120.11
3	May	625.1	488.01	119.12
4	June	622.05	488.81	119.23
5	July	668.67	500	120.24
6	August	780.18	550.12	125.23
7	September	560.24	475.11	129.22
8	October	589.33	490.02	169.72
9	November	755	570	121.23
10	December	882.95	600	133.11
	Mean	660.802	511.353	128.554

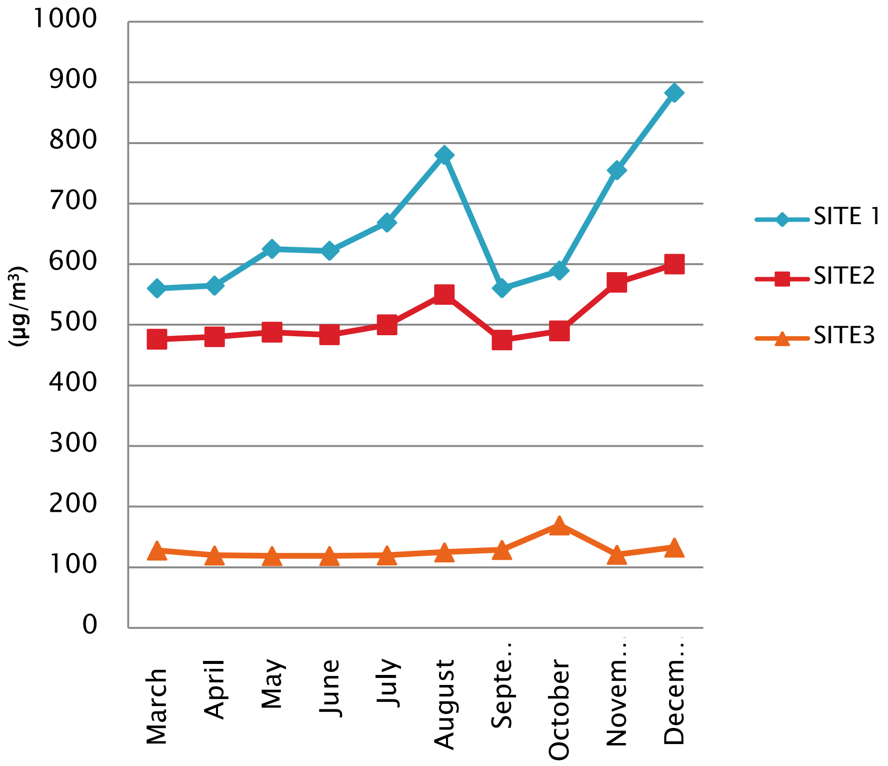


Fig. 1. Monthly variation in RSPM levels (µg/m^3)

for ten months of the year 2011

Table 2. Monthly NRSPM levels (μg/m^3) for ten months of the year 2011g

S.No.	Month	NRSPM (μg/m^3)		
		Site I / (FS)	Site II / (WF)	Site III/ (DH)
1	March	480.19	300.19	150.13
2	April	430.67	300	155.1
3	May	330.52	300	149.11
4	June	488.19	753	166.96
5	July	900.33	399	199
6	August	587.56	530	144
7	September	484.19	400	149
8	October	642	500	150
9	November	590.56	511.22	190
10	December	730.29	677.11	177
	Mean	566.45	467.05	163.03

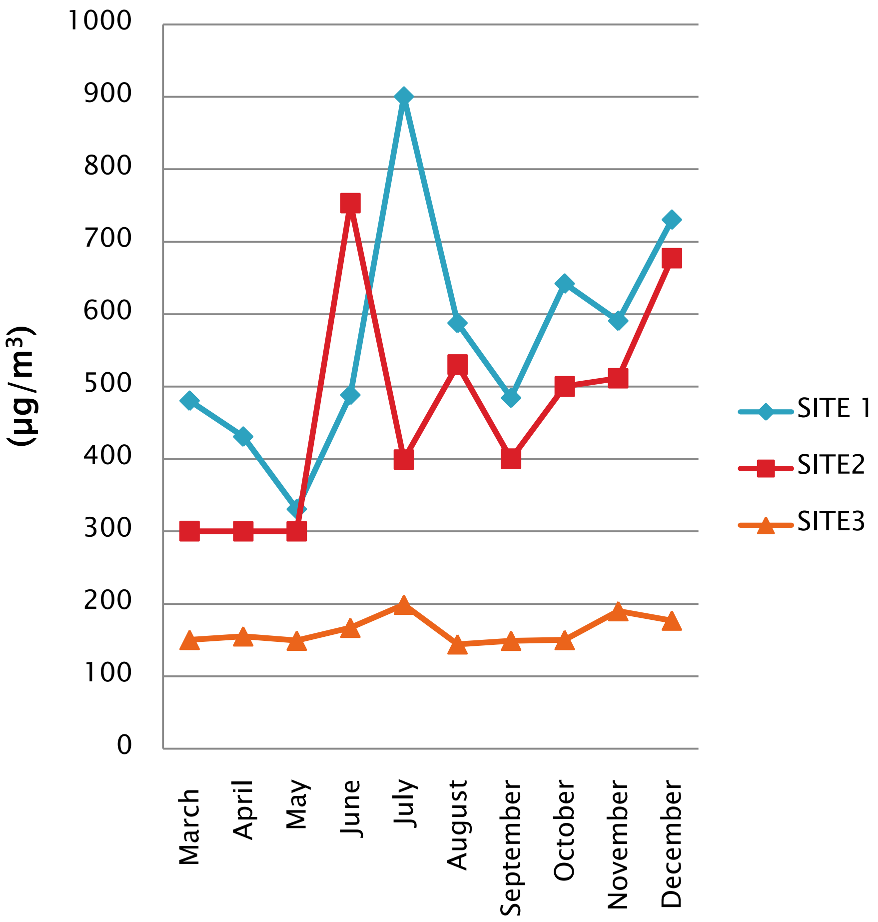


Fig. 2. Monthly variation in NRSPM levels (µg/m^3) from March upto December of the year 2011

Table 3. Monthly SPM levels (µg/m^3) for ten months of the year 2011

S.No.	Month	SPM (µg/m^3) = RSPM+NRSPM		
		Site I/ (FS)	Site II/(WF)	Site III/(DH)
1	March	1040.19	776.43	278.36
2	April	995.17	780.22	275.21
3	May	995.62	788.01	268.23
4	June	1110.24	972	285.23
5	July	1569	899	319.24
6	August	1367.74	1080.12	269.23
7	September	1044.43	875.11	278.22
8	October	1231.33	990.02	319.72
9	November	1345.56	1081.22	311.22
10	December	1713.24	1277.11	310.11
	Mean	1227.252	951.924	291.587

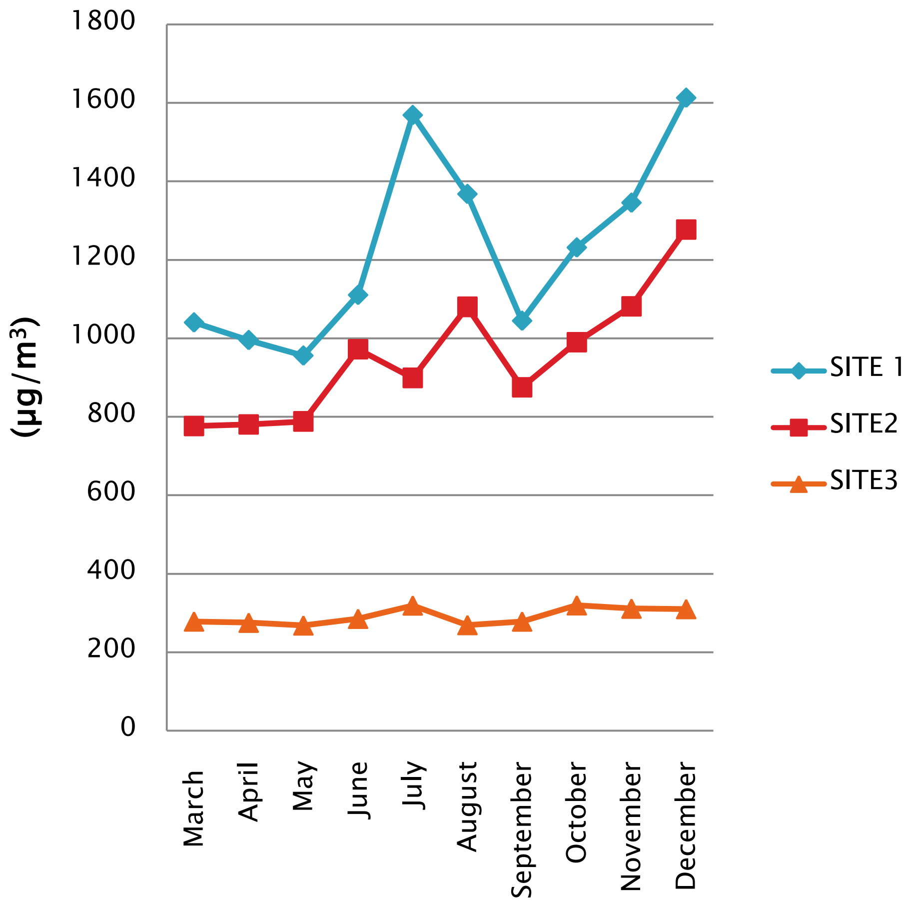


Fig. 3. Monthly variation in SPM levels (µg/m^3) for ten months of the year 2011

Table 4. Monthly SO_2 levels ($\mu g/m^3$) from March upto December, 20112

S.No.	Month	SO_2 ($\mu g/m^3$)		
		Site I / (FS)	Site II / (WF)	Site III/ (DH)
1	March	108.1	99.34	21.44
2	April	106.12	105.64	23.6
3	May	122.88	105.43	26.9
4	June	128.4	107.34	28.2
5	July	121.2	98.22	22.64
6	August	118.16	101.33	31.12
7	September	115.11	99.44	30.64
8	October	138.24	110.43	33.44
9	November	119.64	107.43	31.22
10	December	140.34	118.64	32.12
	Mean	121.82	105.32	28.13

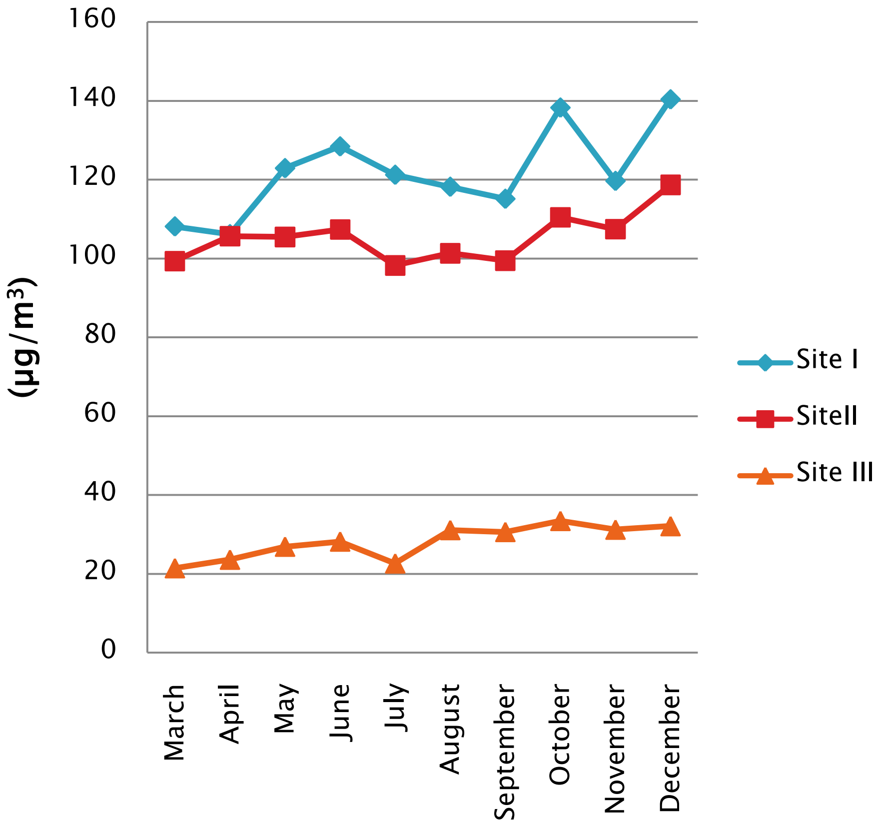


Fig. 4. Monthly variation in SO_2 levels (µg/m^3) from March upto December, 2011

Table 5. Monthly estimates of NO_2 levels (μg/m^3) for the ten months of the year 2011

S.No.	Month	NO_2 (μg/m^3)		
		Site I /(FS)	Site II /(WF)	Site III / (DH)
1	March	100.56	95.64	26
2	April	105.61	100.64	22
3	May	107.16	99.46	13
4	June	124.95	99.46	21
5	July	103.11	95.46	24
6	August	133.64	103.46	17
7	September	122.45	98.18	13.65
8	October	126.43	110.64	19
9	November	135.62	118.43	21
10	December	145.44	125.24	18
	Mean	120.49	104.06	19.46

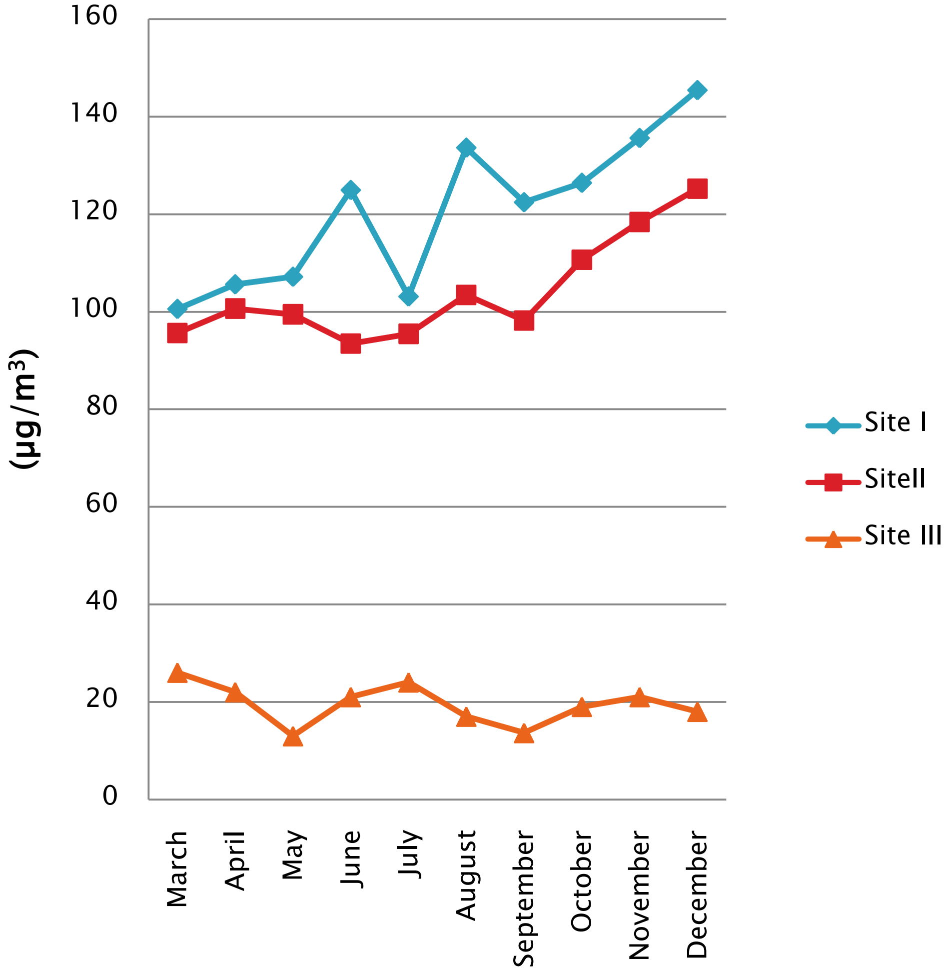


Fig. 5. Month wise fluctuations in NO_2 levels (µg/m^3) from March upto December, 2011

Table 6. Mean values of RSPM, NRSPM, SPM, and their NAAQS (INDIA) & MoE (Japan) Standards.

S. No	Parameter (µg/m^3)	SiteI / (FS)	Site II/ (WF)	SiteIII / (DH)	NAAQS (INDIA) (µg/m^3)		MoE, Japan standards (2005) (µg/m^3)	
					Annual average*	24 hours**	Daily average	Hourly values
1	RSPM	660.802	511.35	128.55	50	75	na	Na
2	NRSPM	566.45	467.05	163.03	Na	na	na	Na
3	SPM	1227.25	951.92	291.58	70	100	100	200
4	SO_2	121.82	105.32	28.13	15	30	115	286
5	NO_2	120.49	104.6	19.46	15	30	115-170	170

*Annual Arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval.

** 24 hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days.

Note: 1ppm = 2860 µg/m^3

Na = not available

National Ambient Air Quality Standards (NAAQS)

Ministry of Environment, (MoE) Japan

POLLINATION STUDY

Composition of hymenopteran pollinators on mustard and almond

The composition of species of Hymenoptera pollinators on both mustard and almond flowers recorded among different selected study sites are depicted in Table 7 and Table 8. A total of 5 species belonging to 2 families were recorded on mustard. Darbagh, Harwan / (DH) harboured 5 species, while Wuyan field (WF) and factory site (FS) had 4 species each. *Vespa orientalis* belonging to family Vespidae was absent at Wuyan field (WF) and factory site (FS).

In almond, a total of 6 species belonging to 2 families were recorded at the different study sites. Darbagh, Harwan (DH) registered 6 species, while Wuyan field (WF) and factory site (FS) recorded 4 species each. *Xylocopa sp.* and *Megachile sp.* belonging to families Apidae and Megachilidae were absent at Wuyan field (WF) and factory site (FS), suggesting that diversity of hymenopteran pollinators was low at factory site (FS) and high at Darbagh, Harwan (DH).

Besides Hymenoptera, pollinators belonging to orders Lepidoptera, Diptera, Hemiptera and Coleoptera were also observed to visit differentially on both the species as shown in Table 9 and Table 10.

Number of hymenopteran pollinators on mustard and almond

Individual number of hymenopteran pollinators/ individuals observed on mustard and almond at different study sites are recorded in Table 11 and Table 12. A total number of 181 individuals of different recorded species of hymenopteran pollinators were observed on mustard. At Darbagh, Harwan (DH), maximum of 98 individuals of hymenopteran pollinators were recorded while at factory site (FS) only 34 were recorded. The contribution of Wuyan field (WF) was 49 individuals. This suggests that density or size of hymenopteran pollinators was low at factory site (FS) and high at Darbagh, Harwan (DH). Amongst the 5 species *Apis cerana indica* belonging to family Apidae was the most abundant at all study sites.

In almond total number of 93 individuals of different recorded species of hymenopteran pollinators was observed. Maximum individuals (50) of hymenoptera pollinators were recorded at Darbagh, Harwan (DH), while at factory site (FS) only 19 individuals were counted. The contribution of Wuyan field (WF) was 24. This indicated that density or size of hymenopteran pollinators was low at factory site (FS) and high at Darbagh, Harwan (DH). In almond also among the 5 species *Apis cerana indica* (Apidae) was the most abundant at all study sites.

Pollination efficiency

Along three selected study sites of each species, diverse and variable arrays of visitors were observed to visit the blossomed inflorescences. At least 15 insect species belonging to orders Hymenoptera, Lepidoptera, Diptera and Hemiptera were observed. However, *Apis cerana indica* accounted for the highest number and duration of visits for all the populations studied, which represented 36.13% of the overall floral visit and thus was considered a major pollinator for both the species.

Significant differences in insect *Apis cerana indica* abundance were observed among different sites. The lowest values of insect abundance were observed at factory site (FS) for both the selected plants and the highest values of insect abundance were observed at Darbagh, Harwan (DH). As expected, data on floral visitation rate or pollination efficiency of dominant pollinator was in accordance with the floral visitors' abundance, i.e., at Darbagh, Harwan (DH) the highest visitation rates were observed for both *B. campestris and P. amagdylus*. These results are presented in Table 13 and Table 14. significant differences were observed in mean number of flowers visited per plant/bee among the different sites, ranging from 3.1 at factory site (FS) to 11.8 at Darbagh, Harwan (DH).The mean number of flowers foraged at per plant per honeybee for *B. campestris* at factory site (FS), Wuyan field (WF) and Darbagh, Harwan (DH) were 3.1, 5.2 and 11.8 while for *P. amagdylus*, the mean flower number foraged at per plant per honeybee were 2.1, 2.9 and 5.3 respectively. The mean time that an individual honeybee spent foraging per flower did not vary greatly among different populations. There was only about 4s difference between the highest mean flower foraging time at Darbagh, Harwan (DH) and lowest at factory site (FS). The mean honeybee foraging times per flower for *B. campestris* at factory site (FS), Wuyan field (WF) and Darbagh, Harwan (DH) was 10.51s, 11.41s and 14.48s, while for *P. amagdylus* it was 10.17s, 10.70s, and 13.58s. at factory site (FS), Wuyan field (WF) and Darbagh, Harwan (DH) respectively. A significant difference was observed in the time that an individual honeybees spent foraging per plant and the mean foraging times per plant at factory site (FS), Wuyan field (WF) and Darbagh, Harwan (DH) for *B. campestris* were 32s, 46s, 61s, and while for *P. amagdylus,* it was 27s, 31s, 52s, at factory site (FS), Wuyan field (WF) and Darbagh, Harwan (DH) respectively.

Seed set and other parameters that reflect reproductive success of plants

The density and diversity of pollinator insects affected the seed set and reproductive success of mustard and almond (Tables 15 and Table 16).The number of ovules that were successfully transformed into seeds, i.e.,% age seed set in mustard was quite fairly high at Darbagh, Harwan (DH), (94.44%) as compared to 50% at factory site (FS).

Almost similar trend was observed for almond also, the highest %age seed set at Darbagh, Harwan (DH), (90 %) and lowest of 50% at factory site (FS).

In addition to %age seed set, the density and diversity of pollinator insects affected the other parameters like number of pods, seeds per pod and seed weight per plant of mustard and seed weight of almond (Table 17 and Table 18). The average number of pods, seeds per pod and seed weight per plant was highest at Darbagh, Harwan (DH), (1800, 13.75 and 148.5gm respectively) and lowest at factory site (1143.6, 6.25 and 28.59 gm respectively).

Average seed weights of almond was highest for Darbagh Harwan (DH) (25.38 gm) and lowest for factory site (FS) (14.1 gm).

Seed Viability

The viability of seeds of mustard and almond that were collected from three different sites varied from 62.22% (FS) to 90% (DH) for mustard and from 50% (FS) to 83.33% (DH) for almond (Table 19 and Table 20). Seeds collected from Darbagh, Harwan (DH) revealed greatest germination capability and reproductive success while seeds gathered from factory site (FS) exhibited lowest germination capability and reproductive success.

Table 7: Species composition / (presence, + and absence, -) of hymenopteran pollinators on mustard flowers during the Study Period

S.No.	Family	Species	Site I / (FS)	Site II/(WF)	Site III/(DH)
1	Apidae	*Apis cerana indica*	+	+	+
2	Apidae	*Apis malifera*	+	+	+
3	Apidae	*Andrena armata*	+	+	+
4	Apidae	*Bombus haemorrhoidalis*	+	+	+
5	Vespidae	*Vespa orientalis*	–	–	+

Table 8: Species composition (presence, + and absence, -) of Hymenoptera Pollinators on almond flowers during the Study Period

S.No.	Family	Species	Site I/ (FS)	Site II/ (WF)	Site III/ (DH)
1	Apidae	*Apis cerana indica*	+	+	+
2	Apidae	*Apis malifera*	+	+	+
3	Apidae	*Andrena armata*	+	+	+
4	Apidae	*Bombus haemorrhoidalis*	+	+	+
5	Apidae	*Xylocopa sp.*	–	–	+
6	Megachilidae	*Megachile sp.*	–	–	+

Table 9: Uncounted pollinators other than Hymenoptera observed on mustard flowers at all study sites during the study period

S. No.	Order	Species
1	Diptera	*Fannia canicularis* *Surphus spp*
2	Coleoptera	*Harmonia spp* *Phycodecta spp*
3	Lepidoptera	*Colias hyale*

Table 10: Uncounted pollinators other than Hymenoptera observed on almond flowers at all study sites during the study period

S.No.	Order	Species
1	Diptera	*Fannia canicularis* *Surphus spp.* *Scaeva spp.*
2	Coleoptera	*Harmonia spp*
3	Lepidoptera	*Colias hyale*
4	Hemiptera	*Elymana spp.*

Table 11: Individual number of hymenopteran pollinators on mustard flowers during the Study period

S.No.	Family	Species	Site I/ (FS)	Site II/ (WF)	Site III/(DH)
1	Apidae	*Apis cerana indica*	12	18	32
2	Apidae	*Apis malifera*	12	15	28
3	Apidae	*Andrena armata*	8	12	20
4	Apidae	*Bombus haemorrhoidalis*	2	4	10
5	Vespidae	*Vespa orientalis*	0	0	8

Table 12: Individual number of hymenopteran pollinators observed on almond flowers during the Study period

S.No.	Family	Species	Site I/ (FS)	Site II/ (WF)	Site III/ (DH)
1	Apidae	*Apis cerana indica*	8	9	20
2	Apidae	*Apis malifera*	5	7	11
3	Apidae	*Andrena armata*	3	4	7
4	Apidae	*Bombus haemorrhoidalis*	3	4	7
5	Apidae	*Xylocopa sp.*	0	0	3
6	Megachilidae	*Megachile sp.*	0	0	2

Table 13: Comparative Pollination efficiency of dominant pollinator (*Apis cerana indica*) on mustard

Sites	Mean No. of flowers visited/ bee/ plant	Mean time spent per flower foraging (sec.)	Mean time spent per flower/plant (sec.)
I / (FS)	3.1	10.51	32
II / (WF)	5.2	11.41	46
III / (DH)	11.8	14.48	61

Table 14: Comparative Pollination efficiency of dominant pollinator (*Apis cerana indica*) on almond

Sites	Mean No. of flowers visited/ bee/ plant	Mean time spent per flower foraging (sec.)	Mean time spent per flower/plant (sec.)
I / (FS)	2.1	10.17	27
II / (WF)	2.9	10.70	31
III / (DH)	5.3	13.58	52

Table 15: Comparative Seed Set of mustard flower

Sites	No. of ovules/flower	No. of Seeds/flower	%age seed set
I / (FS)	12.5	6.25	50
II / (WF)	12.5	9.1	72.8
III / (DH)	14.5	13.75	94.82

Table 16: Comparative Seed Set of almond flower

Sites	No. of ovules/flower	No. of Seeds/flower	%age seed set
I / (FS)	1	0.5	50
II / (WF)	1	0.6	60
III / (DH)	1	0.9	90

Table 17: Comparison of reproductive success of *Brassica campestris* L. during the study period (Average values)

S.No.	Plant reproductive success	Site I/ (FS)	Site II/ (WF)	Site III/ (DH)
1	Plant height (cm)	108.55	115	129.55
2	Number of racemes per plant	31.1	40.5	50
3	Number of pods per plant	1143.6	1399.6	1800
4	Pod length (cm)	4.8	5	5.5
5	Number of seeds per pod	6.25	9.1	13.75
6	Number of seeds per plant	7147.5	12739.09	24750
7	Weight of 1 seed (gm)	0.004	0.005	0.006
8	Seed weights per plant (gr)	28.59	83.69	148.5

Table 18: Comparison of Seed weights of *Prunus amygdalus* Batsch during the study period (average values)

S.No.	Weight of almond(gm)	Site I/ (FS)	Site II/ (WF)	Site III/ (DH)
1	Weight of 10 unshelled almond	14.1	16.92	25.38

Table 19: Comparative Seed viability of mustard flower

Sites	No. of seeds taken	No. of viable seeds	%age seed viability
I/ (FS)	90	56	62.22
II/ (WF)	90	60	66.66
III/ (DH)	90	81	90

Table 20: Comparative Seed viability of almond flower

Sites	No. of seeds taken	No. of viable seeds	%age seed viability
I/ (FS)	30	15	50
II/ (WF)	30	19	63.33
III/ (DH)	30	25	83.33

PHOTO GALLERY

Chimney of the cement factory realizing smoke at Khrew (Factory site)

Dust spreading from vehicles around the factory

Conveyor carrying crushed stones from the crushers

Cement dust deposition on the vegetation (*Ailanthus altisema)*

Cement dust covering the vehicles transporting cement from the factory

Bees visiting wild *Lonicera sp.* For nuctar and pollen collection

Bees gathering pollen from wild flowers of *Eremurus himalaicus*

Bees visiting ornamental *Rosa sp.*

Bees visiting crop plant of cucurbitaceae and helping in its pollination

Hymenopteran visiting the flowers of egg plant (solanaceae)

Lepidopteran visiting the flowers of *Jasminium sp.*

Hymenopteran visiting dandelion (*Taraxacum officinale*)

Wild bee visiting the mustard flowers

Mustard pod of Darbagh Harwan or control site showing almost full seed set

Mustard pod of Factory site showing aborted seeds (fairly low seed set) due to lack of pollination

Comparison of seed viability test between almond collected from factory site and that of Darbagh Harwan

Chapter – 6

DISCUSSION

The spontaneous discharge of atmospheric pollutants due to industrialization, population explosion and urbanization result in injury and damage. The intensity and nature of the damage depends on the concentration of pollutants and the duration of exposure (dose) that has immediate (acute) and long (chronic) term effects on the quantity and quality of agricultural products (Shaibu-Imodagbe, 1991).The consequential effects of these pollutants on the receptor leads to biochemical and physiological modifications at the cellular level as well as whole plant, animal and ecosystem levels and can also lead to disturbance in plant pollinator relationship which may in turn cause considerable changes in agricultural output. Almost all the built-up units of a cement factory e.g., crushers, raw mill, kiln, coal mill, cement mill are point sources of pollution emission. In addition some other activities associated with post-manufacturing stages like open air handling, loading and unloading etc. result in leakage of dust into the environment, that are called fugitive sources of emissions. A variety of pollutants are emitted by automobiles. These include carbon monoxide (CO), sulfur dioxide (SO_2), particulates and volatile organic compounds (VOCs). Poorly maintained roads and absence of vegetation also adds to the havoc caused by air pollution.

Emissions of Carbon dioxide take place during cement manufacturing because of decarbonisation of Calcium carbonate and Magnesium carbonate and burning of fossil fuels. Oxidation of Sulphur in fuel generates SO_2 (Sulphur dioxide) and combination of Oxygen and Nitrogen at high temperature in the burning zone generate Nitrogen oxides. The cement manufacturing process thus results in emission of following pollutants:-

Particulate matter (respirable and non respirable), Nitrogen oxides, Sulphur oxides, Carbon monoxide, Volatile organic compounds (VOCs) and Green House Gases (GHG). Other substances include, Acidic compounds, Heavy metals, Cadmium, Lead, Mercury and Nickel. It is because of emission of such and other dangerous pollutants that the cement industry finds place in the red category club i.e. the most polluting industry (Ministry of Environment and Forest, Government of India and Central Pollution Control Board). Vehicles are another important source of these deadly pollutants of air.

AIR ANALYSIS

The suspended particulate matter (SPM) in air affects the flora and fauna of the region. It has also been associated with health impairment and increase in mortality, morbidity and asthma (Dockery and Popes, 1994). The site wise estimations of SPM pollution indicated that factory site (FS) (the site in the immediate surroundings of the factory) recorded maximum SPM levels and exhibited an increasing trend from Darbagh, Harwan (DH) through Wuyan field (WF) till highest at the point source or factory site (FS). This was likely to be due to industrial activities near the cement factory such as, SPM (RSPM + NRSPM) released from the cement factory and from the mini cement plants positioned in the vicinity of karewas , which crush limestone rock used in the production of cement, the extensive quarring operations for the limestone rock in the high ground surrounding of the karewas particularly from the Northern side of the region, other activities of the factory, like, mining, loading, unloading, emissions released from the kiln etc . This can be also due to soaring density of vehicles around the factory, particularly that of diesel vehicles, deficiency of vegetation, narrow road geometry, poorly maintained roads and high rate of combustion of coal and domestic fuels (Kulandisamy *et al.,* 2001).The emission from diesel engines have more SPM than emission from petrol vehicles (Doyal, 2000). Significant amounts of SPM are emitted by vehicles during combustion process, mechanical processes (Brake wear and Tyre wear) as well as by re-suspending the dust from road surfaces.

The occurrence of lowest levels of SPM at Darbagh, Harwan (DH) can be attributed to the absence of factory, fairly lower vehicular traffic in comparison to other two sites, well maintained roads, presence of more vegetation and low rate of combustion of coal and other domestic fuels.

SPM profile (Table 3) indicated that the area in the immediate surroundings of the cement factory (the most affected region) experienced high SPM concentration during December. The concentration of SPM at Darbagh, Harwan (DH) was highest in October. Comparatively stable weather conditions of winter may account for build up concentration of ambient air pollutants during winter. This justification is supported by the demonstrations of Ravindra *et al.,* 2003 and 2005. Higher concentrations of SPM in the month of October may be attributed to the prevalence of anti – cyclonic conditions, which is characterized by calm or light winds and restricted mixing depth due to stable or inversion atmosphere rate, resulting in little dispersion or dilution of pollutants which in turn, helps in the buildup of SPM concentration (Ruj and Reddy, 2003).

Lower levels of SPM at some stages in spring and summer months can be attributed to the prevalence of wind due to which dispersion of the pollutants takes place.

Sulfur dioxide (SO_2) is emitted from the combustion of fossil fuels. The average concentration of SO_2 was found to be highest at factory site (FS) and lowest at Darbagh, Harwan (DH). The occurrence of highest value of SO_2 at factory site (FS) are reflecting abundant burning of coal and fuel wood for residential heating and high vehicular density mostly of diesel vehicles (Trucks, buses, Tipper etc). SO_2 emissions are higher from diesel vehicles than petrol vehicles. The vehicles while crossing the factory road emit significant amounts of SO_2 which result in elevated concentrations of SO_2 at factory site (FS). Burning of coal (fuel) for the manufacturing of cement in the kilns of factory also add to the SO_2 concentration.

The lowest concentration of SO_2 was recorded at Darbagh, Harwan (DH), which may be attributed to the absence of industrial and commercial complexes at this site. There is limited movement of vehicles in that area. This site has minimum anthropogenic activity than other two sites.

The monthly profile of SO_2 levels indicated that highest levels of SO_2 (140.34 µg/m^3) at factory site (FS) and (118.64 µg/m^3) at Wuyan field (WF) were recorded in the month of December. Prevalence of relatively higher levels of SO_2 during winter can be ascribed to the burning of more coal (fuel) for the manufacturing of cement in the kilns of factory and also by the burning of more coal by the employees residing in nearly quarters in cold weather conditions. Burning of more coal by the local people and the military personal also helps in the built up of SO_2 in winter. Prevalence of anti- cyclonic conditions in December adds on more SO_2 in the atmosphere. Lower levels of SO_2 were recorded during summer months which can be ascribed to the prevalence of high wind currents due to which dispersion of the pollutants takes place and burning of less coal and fuel wood for heating purpose. Similar observations were made by Reddy and Ruj (2003) as they were working on the ambient air quality status in an industrial area.

Nitrogen dioxide (NO_2) is emitted from the combustion of fossil fuels and also from the oxidation of NO. The average values of NO_2 concentration during the study period were dissimilar at the three monitoring sites (Table 5). The site-wise profile of NO_2 revealed that the mean value of NO_2 were highest at factory site (FS) (120.49 µg/m^3), which may be attributed partially to the industrial activities and also to the heavy vehicular source mostly of diesel vehicles. Similar observations were recorded by Gupta *et al.,* 2002. Although all motor vehicles emit NO_2, the majority of NO_2 emissions occur from diesel vehicles (USEPA, 2006). The high concentrations of NO_2 are known to result in photochemical smog with O_3 concentrations, which adversely affects human health and plant life Singh *et al*. (1997) and Reddy *et al.* (2004). Lowest concentration of NO_2 was recorded at Darbagh, Harwan (DH) which can be attributed to absence of industrial unit there, lesser vehicular density at this site and dispersion of pollutants due to prevalence of windy conditions at this site.

The monthly profile of NO_2 levels indicated that highest levels of NO_2 (145.44 µg/m^3) at factory site (FS) and (125.24 µg/m^3) at Wuyan field (WF) were recorded in the month of December, which may be due to atmospheric disturbances in the area. At Darbagh, Harwan (DH) or control site comparable levels of NO_2 were recorded from March to August, which can be due to slightly higher vehicular density during these months due to peak tourist season. Lowest levels of NO_2 (100.56 µg/m^3) at factory site (FS) were recorded in the month of March and summer months and (95.46 µg/m^3) at Wuyan field (WF) in July due to wash out of NO_2 by intermittent precipitation and prevalence of high speed winds due to which better dispersion of NO_2 takes place. At Darbagh, Harwan (DH) or control site lowest levels of NO_X (13 µg/m^3) was recorded in May, which can be due to intermittent precipitation that dilute the NO_2 concentration in the atmosphere.

Pollinator population structure and probable impacts of air pollution on the process of pollination

Great truths, according to Wilson (1997), are sometimes so pervasive and exist in such plain view as to be invisible. One of them is the supremacy on the land of flowering plants and insects. In addition to their overpowering biomass, nearly a quarter million species of plants and quarter million insects stand described by the biologists to date, together composing a full two – thirds of all kinds of organisms known to exist on the planet. It is the consequence of evolution, the process in natural selection during build rich ecosystems. The interaction between plants and insects has been going on for long time. It began over 100 million years ago with the origin of the flowering plants and accelerated with their superiority in the world's vegetation during the early coenozoic era. Some 40 million years later much of their co evolution was mutualistic, species , more often whole complexes of species came to seal obligatory partnerships with their insect counter parts. Such relationships are among the central topics of ecology. Ants, for example, among the most abundant of insects that spread the seeds of plants, protect them from herbivores, and enrich the soil in which they grow. Nature, as we learn, is kept productive and flexible by uncounted thousands of such partnerships**.** If the last pollinator species adapted to a plant is deleted by pesticides or habitat disorder or air pollution, the extinction of the plant will soon follow. Besides their co evolutionary importance the wild animals as pollinators of cultivated and non–cultivated plants has a great role in capital generation in the human society. Pollination is thus a vital process carried out by insects, mostly independent of man. Most important crops depend on pollination by insects, and of these insects, bees are by far the most important. The bees are of two categories, wild bees and domesticated honey bees. Honey bees of the genus Apis have been cultured by man for many centuries in various regions of the world, where they occur naturally.

During the present investigation it was found that the diversity of hymenopterans for both the selected plants was high at Darbagh, Harwan (DH) or pollution free site and low at factory site (FS) or polluted site (Table 7 and Table 8). During their count, the incidence of occurrence/ abundance of these pollinators/pollen collectors, appeared that *Apis cerana indica* represented itself as the most dominant population at all the three sites and was found to be getting declined as one moved consecutively from Darbagh, Harwan (DH) towards the most polluted site i.e. factory site (FS). The incidence of occurrence or density or individual number of hymenoptera pollinators on mustard and almond flowers at different study sites during the study period was significantly low at the site located at the point source and appeared to exhibit a gradual increase towards Darbagh, Harwan (DH). Presence of more species at control site and less at polluted sites and decline in the pollinator number as one moved from the control towards the point source can be attributed to the stress of prevalence of cement dust in the atmosphere of these polluted sites.

According to Heliovaare and Vaisanen (1993), numeric changes in the insect species observed in the field are difficult to interpret in relation to casual factors, since insect populations fluctuate widely and may be due to life–history phenomenon, intraspecific and interspecific interactions, and unpredictable abiotic (e.g., air pollution) stress factors.

Although air pollution has not been directly associated to the phenomenon of colony collapse disorder (CCD), where honeybees are abandoning healthy hives, it is definitely a stress on the honeybee and other important pollinators and is partly responsible for the decline in their numbers. Since 2006, when CCD became evident, environmentalists have been in fear over the declining number of honeybees and the direct effect this has on the world's crops. As honeybees are one of the most important pollinators of humankind's food supply, pollinating 80 percent of the world's crops, this is indeed a reason for alarm.

Honeybees have poor vision and are dependent on their sense of smell in locating their food. They go to flowers as well as the flower buds of fruit trees and crops for the pollen and nectar they depend on. With the increase in smoke and other exhausts in the air, the spread of the flowers' scent is impeded. As the flower scent travels with the wind, it encounters pollutants and is stopped. The scent of a flower used to travel up to 4,000 feet in the 1800s, but in the 2000s, this number is greatly reduced. In highly polluted cities, a flower scent will only travel 1,000 feet, according to the Washington Post. Natural News reports that the scent is only traveling 200 to 400 feet in highly polluted areas.

Honeybees and other pollinators searching for flowers are not finding them due to air pollution. These bees are then not capable to bring food to their hives. The outcome of this is a hive not reproducing at its normal rate, as well as the flowers not reproducing due to lack of pollination. It becomes a cycle resulting in fewer honeybees, less flowers and ultimately less food for humans. Their sense of smell being is compromised by air pollution and as such honeybees may be finding it harder to mate and to protect themselves as well. This would also cause their numbers to decline.

During the course of this investigation the percentage seed set and reproductive success (averages of number of pods, seeds per pod and seed weight per plant) of mustard showed marked variation at different study sites. The highest values were recorded for the Darbagh, Harwan (DH) and the lowest at the factory site (FS). Same trend was followed for the almond also. Besides these parameters, seed viability, i.e., Seeds collected from Darbagh, Harwan (DH) revealed greatest germination capability and reproductive success while as seeds from factory site (FS) revealed lowest germination capability and reproductive success for both mustard and almond. This may be attributed to highest density and diversity of pollinators at Darbagh, Harwan (DH) and lowest density and diversity of pollinators at factory site (FS). Pollinator diversity and pollination efficiency in Canada has recently been identified to be influenced by air pollution. Bees and flora tend to be bioaccumulators of heavy metals. Bees are being analyzed for their arsenic content in British Columbia as a biological indicator species of atmospheric pollution from the smelters in nearby Washington State. Pollen loads collected by honey bees and other bees may reflect the known concentration of soil-borne heavy metals (Sawidis, 1997). Pollen is being suggested as a biological indicator due to its high sensitivity to pollution stress. Metals build up on plant surfaces or within tissues as a result of dry deposition or root uptake. Pollen germination and tube growth is very sensitive to toxic compounds and these pollen parameters have been found to provide a far more sensitive method for detecting injury by air pollutants than the production of visible leaf damage or other vegetative symptoms (Cox 1988). All these factors lead to less reproductive success and less seed and fruit production.

The number of seeds produced or percentage seed set is a good indicator of the effectiveness of the pollinator as well as a measure of female fertility if compatible pollen is abundant (Ritzinger and Lyrene 1998). Seed number increases with the increased bee density. These results are consistent with earlier studies that found that blueberry fruits produce a small number of seeds when insect pollinators are excluded (Lang and Danka 1991, Froborg 1996, Sampson and Cane 2000).

Pollinator visitation rates or frequency or pollination efficiency of dominant pollinator was high at Darbagh, Harwan (DH) and low at factory site (FS) which is most probably attributable to high abundance of pollinators at Darbagh, Harwan (DH) and vice versa . This parameter is an important quantitative component affecting pollination success (Bond 1994; Herrera 2000). Therefore, the decline in total visitation rate to mustard and almond flowers at a site close to factory compromise pollen transfer and eventually limit fruit production.

Chemical signals play vital role in ecological communications but are susceptible to perturbation by air pollution. In polluted air loads, signals may travel shorter distances before being destroyed by chemical reactions with pollutants, thus losing their specificity. With this the essential process of pollination seems likely to be affected (McFrederick et al., 2008). Scent molecules include reduced carbon, and this carbon is vulnerable to atmospheric oxidation by compounds such as ozone (O_3), the hydroxyl radical (HO), and the nitrate radical (NO_3) (Fuentes *et al*., 2000). The oxidation of biogenic scent molecules produce secondary compounds, some of which may have alike chemical structure, in spite of coming from unlike parent compounds (Fuentes *et al.*, 2000; McFrederick *et al*., 2008). This disturbance of scent signals hastens the damage and also changes the uniqueness of the scent plume, both of which can affect the probability of detection by intended or unintended recipients. Pinto *et al*., 2008, suggested that O_3 may reduce the abilities of insects to use volatile compounds as info chemicals. Pollinators utilize floral scents to navigate at both long and short spatial scales (Dobson, 1994). Over short distances (within 1 m), pollinators such as bees may use floral fragrances to choose whether flowers are worthwhile enough to visit or not (Dobson, 2006; Raguso, 2001), whereas night-flying moths have been shown to orient to flowers by scent alone (Dobson, 1994). Thus the impact of air pollution on floral scents can be severe. For relatively clean air only 10% of the original scent is lost to reaction with pollutants at a distance of 250 m from the source, whereas in polluted air 65–75% of the scent is lost to reaction with pollutants at the same distance (McFrederick *et al*., 2008). The sharp decline in signal magnitude could have an effect on both the pollinators and the plants that rely on them.

Vegetative as well as the reproductive development of the plant was found to be enhanced at Darbagh, Harwan (DH) and reduced at factory site (FS). There was great variation in plant height, flower size, number of racemes per plant, number of pods per plant, pod length and many other parameters at factory site (FS) due to presence of anthropogenic stresses prevailing there. At Darbagh, Harwan (DH) these parameters were almost constant due to absence of lethal stresses. Flower formation at (FS) was reduced as compared to (DH). According to Smith (1981), Pollution in particular inhibits or reduces flower formation. If the reproductive output of a plant resource is limited, any vegetative shortcoming will result in reproductive damage as well and there will be fewer visits of pollinators to the flowers. This will result in less pollination and less productivity.

Besides, there was great variability in density of flowers of mustard and almond at factory site (FS) and almost constant density of flowers was observed at Darbagh, Harwan (DH) due to stress factors prevailing there. This also leads to decrease in density and diversity of pollinators which in turn leads to less visitation rates, lower seed set and seed viability as dense flower patches are more attractive for social bees (*A.cerana* and *A. dorsata*) and they prefer mass flowering crops (steffan – Dewenter and Tscharntke 1999). It was reported by Klein *et al.* (2003) that social bees are attracted in large numbers when coffee flowers were abundant.

The viability of seeds of both the selected plants was highest at Darbagh, Harwan (DH) and lowest at factory site (FS). This can be attributed to less density, diversity and visitation rates of pollinators at factory site and high density and diversity and visitation rates of pollinators at Darbagh, Harwan (DH). Seed yield or %age seed set was also high there and low at factory site (FS). Due to lack of cross pollinators there is reduction in seed number, seed size, and production in subsequent generation (Delaplane & Mayer 2000). Former studies on the effects of pollinator insects to seed set of Cruciferae had been reported. In male sterile oilseed rape (*B. napus*), production of the species were increased by honey bee pollination (Westcott& Nelson 2001; Steffan-Dewenter 2003). Correspondingly, in sarson (*B. campestris*), insects pollination enhances the seed yield, caused formation of well-shaped, larger grain, and more viable seed (Khan & Chaudory 1995).

Chapter – 7

CONCLUSIONS

In conclusion, it may be pointed out that the status of air pollution in Khrew area, factory site (FS) and Wuyan field (WF) is critical and in Darbagh, Harwan (DH) is of very low level. The dominant pollutants of air (RSPM, NRSPM, SPM, SO_2 and NO_2) had the highest concentration at factory site (FS) and lowest at Darbagh, Harwan (DH). Intermediate values were recorded for Wuyan field (WF). Reasons for higher concentration of these pollutants at factory site (FS) may be built-up units of a cement factory e.g., crushers, raw mill, kiln, coal mill, cement mill etc., soaring density of diesel vehicles around the factory, deficiency of vegetation cover, narrow road geometry, poorly maintained roads and high rate of combustion of coal and domestic fuels. The occurrence of lowest levels of these pollutants at Darbagh, Harwan (DH) can be attributed to the absence of industrial and commercial complexes, fairly lower vehicular traffic in comparison to other two sites, well maintained roads, presence of more vegetation and low rate of combustion of coal and other domestic fuels.

- ❖ Usually higher concentrations of these pollutants was observed during winter months due to prevalence of anti – cyclonic conditions, which is characterized by calm or light winds and restricted mixing depth due to stable or inversion atmosphere rate, resulting in little dispersion or dilution of pollutants which in turn, helps in the build up of these pollutants.

- ❖ Lower levels of these pollutants was observed at some stages in spring and summer months which can be attributed to the prevalence of wind due to which dispersion of the pollutants takes place wash out of these pollutants by intermittent precipitation.

- ❖ The density and diversity of hymenopteran pollinators, visitation rates of these pollinators, seed set, reproductive success and seed viability of mustard and almond was lowest at factory site (FS) and high at Darbagh, Harwan (DH).This may be due to following reasons:

- ❖ Presence of stress of atmospheric pollution at factory site (FS) and absence of such kind of stress at Darbagh, Harwan (DH).
- ❖ Air pollution kills flower fragrance and these pollinators have poor eye sight, which makes scent particularly important. Pollinators face troubles in finding sufficient food and as a result their population declines.
- ❖ Decrease in their population translates into decreased pollination and keeps away flowering plants from proliferation.
- ❖ Great variability in density of flowers of mustard and almond at factory site (FS) and almost constant density of flowers at Darbagh, Harwan (DH) due to stress factors prevailing there also leads to decrease in density and diversity of pollinators which in turn leads to less visitation rates, lower seed set and seed viability because dense flower patches are more attractive for social bees (*A.cerana* and *A. dorsata*) and they prefer mass flowering.
- ❖ Air exhausts spread on soil thereby, deteriorating the soil quality. Soil is nesting place for many pollinators, like, *Andrena sp.* which are important pollinators of selected plants. Deterioration of soil quality due to factory exhausts leads to decline in number of these soil nesting bees.

BIBLIOGRAPHY

Agarwal, S. B., Agarwal, M., Nandi, P. K. and Rao, D. N. 1987. Effect of sulphur dioxide and Ekalux (EC 25) singly and in combination on the photosynthetic pigments of *Oryza sativa* plants. *J. Environ. Biol.* **8**(4): 315-321.

Aizen – Marcelo, A., Garibaldi, S. A, Cunningham and Klein, A. M. 2009. How much does agriculture depend on pollinators? Lessons from long – term trends in crop production. *Ann Bot*, **103** (9): 1579 – 1588.

Anonymous. 2008. Helmholtz Centre for Environmental Research. *Beekeeping Times*.

Armolaitis, K. E., Vaichis, M. V., Kuchialaricheno, L. and Raguotis, A . O. 1996. Influence of cement mill emission on physico-chemical properties of forest soils near the mill. *European Soil Science*. **28**: 212-220.

Barrett, S. C. H., and Kohn, J.R. 1991. Genetic and evolutionary consequences of small population size in plants: implications for conservation. Pages 1-30 *in* D. A. Falk and K. E. Holsinger, editors. *Genetics and conservation of rare plants.* Oxford University Press, New York, New York, USA.

Benoit, L.F., Skelly, J.M., Moore, L. D. and Dochinger, L. S. 1983. The influence of ozone on *Pirtlts strobrls* L. *Cnn J. For. Res.* **13:** 184-187.

Black, V. J., Black, C. R., Roberts, J. A. and Stewart C. A. 2000. Impact of Ozone on the Reproductive Development of Plants. *New Phytologist*, **147**: 421-447.

Bohart, G.E. 1972. Management of wild bees for the pollination of crops. *Annu Rev Entmo*, **17**: 287 – 312.

Bond, W.J. 1994. Do mutualisms matter? Assessing the impact of pollinator and disperser disruption on plant extinction. *Philosophical Transactions of the Royal Society of London, Series B*, **344**: 83–90.

Bosac, C., Black, V. J., Black, C. R., Roberts, J. A. and Lockwood, F. 1993. Impact of O_3 and SO_2 on Reproductive Development in Oilseed Rape (*Brassica napus* L.). I. Pollen Germination and Pollen Tube Growth. *New Phytologist*, **124**(3): 439 - 446.

Buchmann, S. L and Nabhan, G. P. 1996. *The Forgotten Pollinators*. Island Press, Washington, DC, USA

Burd M. 1994. Bateman's principle and plant reproduction: the role of pollen limitation in fruit and seed set. *Botanical Review* **60**: 83-139

Cane .1996. Lifetime momentary value of individual pollinators : proceedings of the sixth International Symposium on Vaccinium Culture, Orono, Maine, USA. *Acta Horticulturae*, **46**: 67-70

Cane, J. H. 2001. Habitat fragmentation and native bees: a premature verdict? *Conservation Ecology*, **5**(1): 3

Cape, J. N. 2007. Secondary air pollutants and forests - new perspectives. *Scientific World Journal*, **7**: 9- 14.

Cox, R. M. 1984. Sensitivity of forest plant reproduction to long range transported air pollutants. Invitro sensitivity of *oenothera parviflora* L. pollen to simulated acid rain. *New Phytologists*, **97**: 63-70

Cox, R. M. 1988. The sensitivity of pollen from various coniferous and broad leaved trees to combinations of acidity and trace metals. *New Phytologists* **109**: 193-201

Crane, E. and Walker. P. 1984. Directory of Important World Honey Sources. *Int. Bee Res. Assoc.*, (IBRA) London, p. 187.

Cunningham, S. A. 2000. Effects of habitat fragmentation on the reproductive eecology of four plant species in mallee woodland. *Conservation Biology*, **14**: 758–768.

Degrandi-Hoffman, G., Thorph, R., Loper, G. and Eisikowitch, D. 1992. Identification and distribution of cross-pollinating honey-bees on almonds. *Journal of Applied Ecology*, **29**: 238-246.

Delaplane, K. S., Mayer, D. F. 2000. *Crop pollination by bees*. Oxon: CABI Publ.

Devaux, C., Klein, E. K., Lavigne, C., Sausse, C. and Messéan, A. 2008. Environmental and Landscape Effects on Cross-Pollination Rates Observed at Long Distance among French Oilseed Rape Brassica napus Commercial Fields. *Journal of Applied Ecology*, **45**(3): 803-812.

Dobson HEM (2006) Relationship between floral fragrance composition and type of pollinator. In: Dudarev N, Pichersky E (eds) Biology of floral scent. CRC, Boca Raton, pp 147–198

Dobson, H. E.M. 1994. Floral volatiles in insect biology. In: Bernays E (ed) Insect–plant interactions, vol 5. CRC, Boca Raton, pp 47–82

Dockery, D. W. and Pope, C. A. 1994. Acute respiratory effects of particulate air pollution. *Annual Review of Public Health*, **1**(5): 107-132.

Dueck, H. G., Wolting, D. R., Moet, F. J. M. and Pasman. 1987. Growth and Reproduction of Silene cucubalus WIB. Intermittently Exposed to Low Concentrations of Air Pollutants, Zinc and Copper. *New Phytologist*, **105** (4): 633-645.

Dupree, C. D., Conroy, L. and Harris, C. R. 2009. Impacts of currently used or potentially useful insecticides for canola agroecosystems on Bombus impatiens (Hymenoptera: Apidae), Megachile rotundata (Hymentoptera:Megachilidae), and Osmia lignaria (Hymenoptera: Megachilidae). *Journal of economic* entomology, **102** (1):177-182.

Eeva, T. J. S. and Koivunen, V. 2004. Effects of heavy metal pollution on red wood ant (*Formica* s. str.) populations. *Environmental Pollution*, **132** (3): 533–539.

Fabienne - Harris, L. and Johnson, S. D. 2007. The consequences of habitat fragmentation for plant–pollinator mutualisms. *International Journal of Tropical Insect Science*, **24** (1):29- 43. Cambridge Univ Press.

FAO. 1993. Harvesting natures diversity. *FAO*, Rome.

Free, J. B. 1993. *Insect pollination of crops*. 2nd edition, Academic press, London.

Froborg, H. 1996. Pollination and seed production in *Vaccinium* and *Andromeda* (Ericaceae).*Can. J. Bot* , **74**: 1363 -1368.

Fuentes, J. D., Lerdau, M., Atkinson, R. Baldocchi, D., Bottenheim, J. W, Ciccioli, P., Lamb, B., Geron, C., Gu, L., Guenther, A., Sharkey, T. D., and Stockwell, W. 2000. Biogenic hydrocarbons in the atmospheric boundary layer. *A review Bull Am Meteorol Soc*, **81**:1537–1575

Gallai, N. *et al*., 2008. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, **68**: 810-821

Gautier-Hion, A. and Maisels, F. 1994. Mutualism between a leguminous tree and large African monkeys as pollinators. *Behavioural Ecology.*

Gupta, H. K., Gupta, V. B., Rao, C. V. C., Gajghate, D. G. and Hasan, M. Z. 2002. Urban Ambient Air Quality and its Management Strategy for a Metropolitian city in India. *Bull. Environ.Contam. Toxicol,* **68**: 347-354.

Gupta, M.C. 1987. The effects of coal-smoke pollutants on the growth yield and leaf Epidermal features of *Abelmoschus esculentus* Moench. *Environmental Pollution,* **43**: 263-270.

HelioVaare, K. and Vaisanen, R. 1993. *Insects and pollution*. CRC Press Boca Raton Ann Arbor, London.

Herrera, C.M. 2000. Flower to seedling consequences of different pollination regimes in an insect-pollinated shrub. *Ecology,* **81**: 15–29.

Hill, S.J., Stephenson, D.W. and Taylor, B.K. 1985. Almond pollination studies, pollen production and viability, flower emergence and cross- pollination tests. *Australian Journal of Experimental Agriculture*, **25**: 697-704.

Hindy, K.T. and Farag, S.A. 1983. Composition of suspended and settled particulate matter from the atmosphere. *Environmental pollution* (series B), **5**: 247-254.

Iqbal, M.Z. and Iqbal Habib. 1995. Impact of dust from the factory at Karachi on the vegetation and soil characteristic. *Research Bulletin of the Punjab University Science,* **45**(1/4): 73-78.

Jacob and Hochheiser. 1958. Method of measurement of air pollution, Nitrogen dioxide. Guidelines for measurement if ambient air pollutants, vol. 1, IS 5182, part 6.

Kearns, C. A. 2001. North American dipteran pollinators, assessing their value and conservation status. *Conservation Ecology* **5**(1): 5

Kearns, C. A., Inouye, D. W. and Waser, N. M. 1998. Endangered mutualism, the conservation of plant-pollinator interactions. *Annuals of Review and Ecological System* **29**: 83-112

Kenmore, P. Krell, R. 1998. Global perspectives on pollination in agriculture and agro-ecosystem management. International workshop on the conservation and sustainable use of pollinators in Agriculture with emphasis on Bees October 7-9 Sao Paulo, Barazil

Kerr, J. T. 2001. Butterfly species richness patterns in Canada, energy, heterogeneity, and the potential consequences of climate change. *Conservation Ecology* **5**(1): 10.

Kevan, P. G. 1997. Honeybees for better apples and much higher yields, Study shows pollination services pays dividends. *Canadian Fruit Grower* **14**: 16

Kevan, P. G. 2003. Pollination for the 21st century: integrating pollinator and plant inter dependence. In: K. Strickler and J.H. Cane [eds] For Nonnative Crops, Whence Pollinators of the Future. Thomas Say Publication of the Entomological Society of America, Lanham, Maryland, U.S.A. pp. 181-204.

Kevan, P. G., and Phillips, T. 2001. The economics of pollinator declines, assessing the consequences. *Conservation Ecology* **5**(1): 8

Khan, B. M., Chaudory, M. I. 1995. Comparative assessment of honey bee and other insects with self-pollination of sarson *(Brassica campestris*) in Peshawar, *Pakistan.* In: Kevan PG (ed). *The Asiatic hive bee: Apiculture, Biology and Role in Sustainable Development in*

Tropical and Subtropical Asia. Ontario: Enviroquest Ltd. p 147-150.

Khan, M. R., and Khan, M. R. 2004. The role of honey bees *Apis mellifera* L. (Hymenoptera: Apidae) in pollination of apple. *Pak. J. Biol. Sci.*, **7**: 359-362.

Klein, A. M., Steffan-Dewenter, I., Tscharntke, T. 2003. Fruit set of highland coffee increases with the diversity of pollinating bees. *Proc R Soc B*, **270**: 955-961.

Knutson, R. D., Taylor, R. G., Penson, B. J. and Smith, G. E. 1990. Economic impacts of reduced chemical use. Knutson and Associates, College Station, Texas pp 30- 31

Kumar, S., Simonson, S.E. and Stohlgren, T.J. 2009. Effects of spatial heterogeneity on butterfly species richness in Rocky Mountain National Park, CO, USA. *Biodiversity and Conservation*, **18**: 739–763.

Kumar. And Singh, V. 1986. Sensitivity of Vignasinesis to SO_2 pollution. *Biovigyanam* **12**(1), 22 –28.

Lang, G. A., and Danka, G. R. 1991. Honey-bee-mediated cross-versus self-pollination of Sharpblue blueberry increases fruit size and hastens ripening. *J. Am. Soc. Hortic.Sci.* **116**: 770 - 773

Lovett, G. M., Tear, T. H., Evers, D. C., Findlay, S. E., Cosby, B. J., Dunscomb, J. K., Driscoll, C. T. and Weathers, K. C. 2009. Effects of air pollution on ecosystems and biological diversity in the eastern United States. *Ann N Y Acad Sci*. **1162**: 99-135.

Lubbers, A. E. and Christensen, N. L. 1986. Intraseasonal variation in seed production among flowers and plants of *Thalictrum thalictroides* (Rununculaceae). *American Journal of Botany*, **73**: 190- 203.0

Maheshwari, J. K. 2003. Endangered pollinators, Newsletter of ISEB India. *Environment News*, **9**: 1

McFrederick, Q. S., Kathilankal, J. C. and Fuentes, J. D. 2008. Air pollution modifies floral scent trails. *Atmos Environ*, **42**: 2336–2348

McFrederick, Q. S., Kathilankal, J. C., Fuentes, J. D., Roulston, T. and Lerdau, M. 2009. Effects of air pollution on biogenic volatiles and ecological interactions. *Oecologia*, **160**:411–420

McGregor, S.E. 1976. *Insect Pollination of Cultivated Crop Plants.* Agric. Handbook No. 496. U. S. Deptt. Agri., Washington, D.C., VIII: 411

Michener, D. M. 2000. *The Bees of the World*. Baltimore: Johns Hopkins Univ Pr.

Mortensen, L. M. 1993. Effects of ozone concentration on the growth of tomato at various light, air humidity and carbon dioxide levels. *Scientia Horticulturae*, **49**: 17- 24.

Nabhan, G. P. and Buchmann, S. L. 1997. Services provided by pollinators. In Natures Services (Ed. G.C. Daily). *Societal Dependence of Natural Ecosystem*. Island Press, Washington, DC, USA, pp133-150.

Natural News. April 16. 2008. Flowers fragnance diminished by air pollution. Leslee Dru Browning.

Nyman, L.P., David, H. B., Patric, J. T. and Joseph, A. 1990. Effects of ozone and sulfur dioxide on two epiphytic orchids. *Environmental and Experimental Botany*, **30**(2) : 207–213.

Oryx. 2007. The decline of the bumble bees and cuckoo bees (Hymenoptera: Apidae: Bombini) of Western and Central Europe. *Fauna & Flora International*, **41**: 79-88.

Packer, L. and Owen, R. 2001. Population genetic aspects of pollinator decline. *Conservation Ecology*, **5**(1): 4.

Pinto, D. M., Himanen, S. J., Nissinen, A., Nerg, A.-M. and Holopainen, J. K. 2008. Host location behavior of Cotesia plutellae Kurdjumov (Hymenoptera: Braconidae) in ambient and moderately elevated ozone in field conditions. *Environ Pollut*, **156**:227–231.

Piotrowski, W. 1993. Air pollution in Pelesdki National park caused by industrial emission according to the results of technical monitoring. *Sylwan*, **137**(7): 61-65.

Prasad, M.S.U. and Inamdar, J.A. 1991. Effect of cement Kiln dust pollution on growth and yield of *Vigna* spp. *Indian Journal of Ecology*, **18**(2): 91-94.

Raguso, R. A. 2001. Floral scent, olfaction and scent driven foraging behavior. In: Chittka L, Thompson JD (eds) Cognitive ecology of pollination: animal behavior and floral evolution. Cambridge University Press, West Nyack, pp 83–105.

Rao, C.M. and Narayanam, A.1998. Effect of cement dust on rice plant growth. *Journal of Research ANGRAU*, **26**(2): 31-36.

Rathcke, B. and Jules, E. 1993. Habitat fragmentation and plant–pollinator interactions. *Current Science*, **65**: 273– 277.

Ravindra, K., Mor, S. and Kaushik, C.P. 2003. Short term variation in air quality associated with firework event: A case study', *J. Environ. Monlt*. **5**: 260-264.

Ravindra, K., Wauters, E., Taygi, S.K., Mors, S. and Grieken, R.V. 2005. Assessment of air quality after the implementation of CNG as fueld in public transport in Delhi, India. *Environ. Menit. Asses*, In Press.

Reddy, G. S. and Ruj, B. 2003. *Environmental Monitoring and Assessment*. **89**: 153-163.

Reddy, G. S., and Ruj, B. 2002. Ambient air quality status in Ranignaj Asansol area, India. *Indian J.Env.Protect.*, **10**(2): 105-112.

Reddy, M.K., Ramarao, K.G. and Rammahamrao. 2004. Air Pollution Status of Visakapatnam (India)-Indices basis. *Environ Monlt. Assess*, **95**: 1-12.

Ritzinger, R. and Lyrene, P. M. 1998. Comparison of seed number and mass of southern high bush blueberries vs. those of their F1 hybrids with *V. simulatum* after open pollination. *Hort Science*, **33**: 887-888.

Rubatzkky, V. E. and Yamaguchi, M. 2001. *Sayuran Dunia: Prinsip, Produksi dan Gizi.* Bandung: Penerbit ITB

Sachind, D. and Pandey, K. 1983. Atmospheric depositions of nutrients and pollutants in North America: an ecological perspective. *Ecol App*; **4**: 6929-50.

Salaralabai, V.C. and Vivkanandan, M. 1996. Soil application of cement exhaust. *Indian Journal of Germination and Seedlings*.

Salgare, S.A. and Palathingal, T. 1993. Effect of Industrial; pollution on pollen physiology of *Peltophorum ferrugineum* Benth. *J. Environ. Biol.*, **14**(1): 035-039.

Sampson, B. and Cane, J. 2000. Pollination efficiencies of three bee (Hymenoptera: Apoidea) species visiting rabbiteye blueberry. *J. Econ. Entomol*, **93**: 1726-1731.

Saravanan, K. and Appavu, K. 1997. Effect of cement kiln dust deposition on physical properties of soil. *Indian Journal of Environmental health*, **39**(1): 31-36.

Sarkar, D. and Kundu, S. 1996. The effect of air pollution caused by brick kiln in west Dinajpur District (W.B.). *Apropos of surrounding flora .Journal of Natcon,* **8**(1): 27-30.

Satao, R. N., Kene , H. K., Nalmwar, R. V. and Ulemale, R. B. 1993. Effect of cement dust pollution on growth and yield of cotton. *Annals of Plant Physiology*, **7**(1): 73-77.

Sawidis, T. 1997. Accumulation and effects of heavy metals in *Lilium* pollen. Acta Horticulturae, **85**: 621- 633.

Shaibu- Imodagbe, E. M. 1991. The impact of some specific Air Pollutants on agricultural productivity. *The Environmentalist*, **2**(1): 33-38. Springer Netherlands.

Shukla, J. V., Pandey, S.N., Singh, M., Yunus, M., Singh, N. and Ahmad T.J. 1990. Effect of cement dust on growth and yield of *Brassica campestris* L. *Environ. Pollution.* **66**(1): 81-88

Singh, A., Sarin, S.M., Shammugan, P., Shah, N., Attri, A.K. and Jain, V.K. 1997. Ozone distribution in the urban environment of Delhi during winter months. *Atmospheric Environment.* **31**(20): 3421 - 3427.

Singh, B. and Agarwal, M. 2003. Impact of simulated acid rain on the growth and yield of two cultivars of wheat. *Water, Air and Soil pollution,* **152**: 71- 80.

Smith, W. H. 1981. Air pollution and forests, interactions between air contaminants and forest ecosystem. Springer – Verlag, New York.

Socias, I., Company, R., Gomez, A. J. and Alonso, J.M. 2005. Year and enclosure effects on fruit set in an autogamous almond. *Scientia Horticulturae*, **104**: 369-377.

Somerville, D. 2007. *Review of supply of honeybees for the pollination of almonds*. Timber Corp.

Southwick, E. E., Southwick, L. J. 1992. Estimating the economic value of honey bees (Hymenoptera : Apidae) as agricultural pollinators in the United States. *J Econ Entomol*, **85**: 621- 633.

Steffan-Dewenter, I. 2003. Seed set of male-sterile and male-fertile oilseed rape (*Brassica napus*) in relation to pollinator density. *Apidologie*, **34**:227-235.

Steffan-Dewenter, I. and Tscharntke, T. 1999. Effects of habitat isolation on pollinator communities and seed set. *Oecologia*, **121**:432- 440.

Synder, R.G., James Simen, E., Reinert, R.A., Simini, M. and Neck, W.W. 1988. Effects of air quality on foliar injury. Growth, yield and quality of Muskmelon. *Environmental Pollution*, **53:** 187-196.

Themani, L.T., Naik, M.S., Momini, G.A., Krishnan Kachre, S.D., Mary Selvam, A. and Ramana Murty, V. 1980. A study of the gaseous and particulate pollutants in the environment of a thermal power plant project Area. *Water, Air and Soil Pollution*, **13:** 303-316.

Thomson, J. D. 2001. Using pollination deficits to infer pollinator declines: can theory guide us? *Conservation Ecology* **5**(1):6.

Uma, C., Rao, T.V.R and Inandar, J.A. 1994. Impact of cement kiln dust pollution on sun hemp (*Cretalaria junceda* L.) *Phytomorphology*, **44**(3-4): 223-229.

United States Environmental Protection Agency, USEPA, 2006.

Vora, A.B., Bhatnagar, A.R. and Patel, T.S. 1986. Comparative study of dust fall on the leaves in high pollution and low pollution areas of Ahmedabad II. Effect on carbohydrates. *J. Environ. Biol.*, **7**(3): 155-163.

Vuorinen, T., Nerg, A. M. and Holopainen, J. K. 2004. Ozone exposure triggers the emission of herbivore-induced plant volatiles, but does not disturb tri trophic signalling. *Environ Pollut*., **131**:305– 311.

West and Gaeke. 1956. Method of measurement of air pollution, Sulphur dioxide. Guidelines for measurement if ambient air pollutants, vol. 1, IS 5182, part 2.

Westcott, L. and Nelson, D. 2001. Canola pollination: an update. *Bee World*, **82**:115-129.

William, P. H. and Osborne, J. L. 2009. Bumblebee Vulnerability and Conservation Worldwide. *Apidologie*, **40**: 367- 387.

Wilson- Edward, O. 1997. Preface In: Buchmann, S.L. and Nabham, G.P. Written, *The Forgotten pollinators* Island Press/ Shearwater Books. Washington. D.C./Coeval; California.

Wilson, E. O. 1988. *The current state of biodiversity*. National Academic Press, Washington, DC, USA, 3-18.

Winfree, Rachael, Ramiro Aguilar, Diego, P., Gretchen -LeBuhn, and Marcelo, A. Aizen. 2009. A meta-analysis of bees' responses to anthropogenic disturbance. *Ecology*, **90**:2068–2076.

Wolters, J. H. B. and Marten, M. J. M. 1987. Effects of air pollutants on pollen. *Botanical Review*, **53**: 372 - 414.