Air Pollution Removal by Urban Trees in Khulna City

The Thesis Submitted to the Department of Urban and Regional Planning, Khulna University of Engineering & Technology (KUET), in Partial Fulfilment of the Requirement for the Degree of

**Bachelor of Urban and Regional Planning (BURP)**



**Session: 2015-2016**

**Submitted by**

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**Department of Urban and Regional Planning**

**Khulna University of Engineering & Technology**

June, 2017

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Abstract

Air Pollution occurs when harmful substance introduce in earth’s atmosphere. It causes harms to living organisms and damage the natural or built environment. Trees remove gaseous air pollution through uptake via leaf stomata in the leaf, gases diffuse into intercellular spaces and may be absorbed by water films to form acids or react with inner-leaf surfaces. Trees also remove pollution by intercepting airborne particles. The most renowned method to analyze removal of pollution by trees in a particular area is UFORE-D method. This method finds Dry Deposition of Air Pollution, Which quantifies the hourly amount of pollution removed by the urban forest and associated percent improvement in air quality throughout a year. Pollution removal is calculated for O3, SO2, NO2, CO, PM2.5 and PM10 based on field, pollution concentration, and meteorological data. This study integrates UFORE-D model in order to estimate air pollution removal by urban trees in Khulna city, Bangladesh and to provide strategies for air pollution control for Khulna city. In this study tree cover is calculated by using remote sensing of Landsat 5 TM 32-Day NDVI Composite 2013-2015. Pollution concentration and other meteorological data is collected from CAMS (The Continues Air Monitoring Station is a project of Department of Environment) Khulna. Applied for the first time in Bangladesh, the model shows that trees, removed about 23.48 tons of pollutants during the first seven months of 2015 (from January 2015 to July 2015): about 0.56 ton for CO; 2.16 tons for NO2; 2.24 tons for O3; 14.35 tons for PM10 and 4.17 ton for SO2. The amount of pollutant removed and monetary value is high, but percent pollution removal is small. Thus our study argues that urban trees are important element to reduce air pollution, but are not the main solution to air pollution problem. Thus the study argues that air pollution reduction strategy should focus on prevention measures rather than mitigation measures like tree plantation. However, increase in tree plantation is required for mix of services obtained from urban tree.

***Keywords:*** *Air Pollution, UFORE-D, Pollution Concentration, Meteorological data, CAMS, Pollution Removal by Trees, Tree Plantation*

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Operational Terms and Definitions

**Air**:

The atmosphere of Earth is the layer of gases, commonly known as air. This layer is a mixture of gases, mainly nitrogen (78%) and oxygen (21%). Argon, water vapor, carbon dioxide and methane are among the other gases present in small amounts. The atmosphere helps to protect our planet from asteroid impacts and solar radiation (BBC, 2017).

**Air Pollution:** Clean air is made up of nitrogen, oxygen and argon, with traces of other gases such as carbon dioxide (EPA VICTORIA, 2016). Air pollution occurs when harmful substances including particulates and biological molecules are introduced into Earth's atmosphere. It may cause diseases, allergies or death in humans (Patel, Chaudhary, & Sen, 2014).

**Air Pollutants:** Any substance in air that could, in high enough concentration, harm animals, humans, vegetation, and materials. Such pollutants may be present as solid particles, liquid droplets, or gases (BuisnessDictionary, 2017). Potentially, air pollutants can be found in air anywhere - outdoors and indoors. Air pollutants can be divided into three groups:

* Criteria pollutants (Such as Carbon monoxide, Lead, Nitrogen dioxide, Ozone, Particles, Sulfur dioxide)
* Air toxics (Emits from motor vehicle emissions, solid fuel combustion, industrial emissions, and materials such as paints and adhesives in new buildings.)
* Biological pollutants (Found from microbiological contamination, e.g. molds, the skin of animals and humans and the remains and dropping of pests such as cockroaches)

(Australian Government -Department of Environment and Energy, 2017)

**Air Pollution Removal by Trees:**

Trees can remove gaseous air pollution either through uptake via leaf stomata or the plant surface. Once inside the leaf, gases diffuse into intercellular spaces and may be absorbed by water films to form acids or react with inner-leaf surfaces (W.H., 1990). Trees can also remove pollution by intercepting airborne particles. Some particles can be absorbed into the tree, though most that are intercepted are retained on the plant surface. The intercepted particle is often re-suspended to the atmosphere, washed off by rain, or dispersed through leaf fall (DEFR, 2010). In 1994, trees in New York City removed an estimated 1,821 metric tons of air pollution at an estimated value to society of $9.5 million. Air pollution removal by urban forests in New York was greater than in Atlanta (1,196 ton; $6.5 million) and Baltimore (499 ton; $2.7 million) (Nowak & Crane, The Urban Forest Effects (UFORE) model: quantifying urban forest structure and functions, 2000).

**Air Pollutant Flux:**

Pollutant flux (F) is calculated as a product of the deposition velocity and the air pollutant concentration (Hirabayashi, Kroll, & Charles.N. & Nowak, i-Tree Eco Dry Deposition Model Descriptions, 2015).

𝐹 = 𝑉𝑑 \* 𝐶 \* 3600

**Air Pollutant Concentration:**

Air pollutant concentrations, as measured or as calculated by air pollution dispersion modeling, must often be converted or corrected to be expressed as required by the regulations issued by various governmental agencies. Regulations that define and limit the concentration of pollutants in the ambient air or in gaseous emissions to the ambient air are issued by various national and state environmental protection and occupational health and safety agencies. Such regulations involve a number of different expressions of concentration. Some express the concentrations as ppm (parts per million by volume) and some express the concentrations as mg/m3 (milligrams per cubic meter)(Citizendium, 2013)**.**

**Air Quality Improvement by Trees**

Percentages of air pollutants removal by tree cover.

**Canopy Resistance**

The canopy surface resistance, rc (sm-1), describes the resistance of vapor flow through the transpiring crop and evaporating soil surface. Where the vegetation does not completely cover the soil, the resistance factor should indeed include the effects of the evaporation from the soil surface (CRA-CIN, 2009).

**Deposition of Pollutants:**

In aerosol physics, Deposition is the process by which aerosol particles collect or deposit themselves on solid surfaces, decreasing the concentration of the particles in the air. It can be divided into two sub-processes: dry and wet deposition (Revolvy, 2017). Deposition of air pollutants is an important loss of gases and aerosol particles from the atmosphere. At the same time, deposition processes of different air pollutants can cause various harmful effects both on ecosystems and built environment. Deposition of an air pollutant affects its atmospheric concentration as well as the state of the environment or human health (Tananyag, 2017).Airborne particles and gas molecules can be deposited when they pass close to a surface. Most plants have a large surface area per unit volume, increasing the probability of deposition compared with the smooth, manufactured surfaces present in urban areas. For example, 10-30 times faster deposition has been reported for sub micrometer (<mm) particles on synthetic grass compared with glass and cement surface (Roupsard, Ameilh, Coppalle, & Branger, 2013).

**Dry Deposition:** Gravitational sedimentation of particles during periods without precipitation. These particles include: aerosols, sea salts, particulate material, and adsorbed/reacted gases captured by vegetation (Davis, 2017) . Dry deposition refers to acidic gases and particles. About half of the acidity in the atmosphere falls back to earth through dry deposition. The wind blows these acidic particles and gases onto buildings, cars, homes, and trees. Dry deposited gases and particles can also be washed from trees and other surfaces by rainstorms. When that happens, the runoff water adds those acids to the acid rain, making the combination more acidic than the falling rain alone. (Lane, 2003)

**Deposition Velocity:** It is the rate of deposition of pollutants. The deposition velocity is often described as the reciprocal of resistance to deposition (Davidson, Wu, & Y.-L., 1990). The deposition velocity is generally determined by performing experiments. The deposition velocity generally increases with:

* Solubility of pollutant
* Particle diameter and density
* Wetness and roughness of surface
* Wind speed and turbulence (Dr. Ashok Kumar, 2017)

**Dry Deposition Velocity:** The rate of deposition of pollutants during periods without precipitation. It is denoted as ‘Vd’. Deposition velocity is defined from F = VC, where F is flux density or Pollutant flux, V is deposition velocity and C is concentration. Deposition velocities (*Vd*) for CO, NO2, SO2, and O3 are calculated as the inverse of the sum of the aerodynamic resistance (*Ra*), quasi-laminar boundary layer resistance (*Rb*), and canopy resistance (*Rc*) (Hirabayashi, Kroll, & Charles.N. & Nowak, i-Tree Eco Dry Deposition Model Descriptions, 2015).

**Leaf Area Index:**

Leaf area index (LAI) is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area (LAI = leaf area / ground area, m2 / m2) in broadleaf canopies (Watson, 1947).

**Stomatal Resistance**

The opposition to transport of quantities such as water vapor and carbon dioxide to or from the stomata (pores) on the leaves of plants (OKE, 1987).

**Tree:**

In botany, a tree is a perennial plant with an elongated stem, or trunk, supporting branches and leaves in most species. In some usages, the definition of a tree may be narrower, including only woody plants with secondary growth, plants that are usable as lumber or plants above a specified height (Qerkini, 2015). In dictionary tree is a plant having a permanently woody main stem or trunk, ordinarily growing to a considerable height, and usually developing branches at some distance from the ground (Dictionary.com, 2017).

**Urban Tree:** The trees and associated organisms existing within a city (The Free Dictionary By Farlex, 2017). It is mainly the urban forestry. Urban forestry is the care and management of single trees and tree populations in urban settings for the purpose of improving the urban environment. Urban forestry advocates the role of trees as a critical part of the urban infrastructure (Patel, Chaudhary, & Sen, 2014).

**UFORE Model:**

The Urban Forest Effects (UFORE) is a computer model implemented in SAS (Statistical Analysis Software) that utilizes field-surveyed urban forest information, location specific data, weather data, and air pollutant measurements to quantify urban forest structure and numerous forest-related effects (Hirabayashi, Kroll, & Nowak, Urban Forest Effects-Dry Deposition (UFORE –D)). The UFORE model uses standard field, air pollution, and meteorological data to quantify urban forest structure and numerous forest-related effects in various U.S. cities (Nowak & Crane, The Urban Forest Effects (UFORE) model: quantifying urban forest structure and functions, 2000).

**UFORE Method:**

In UFORE Method there are five models. Such as: UFORE-A: Anatomy of the Urban Forest, which quantifies urban forest structure based on field data. UFORE-B: Biogenic Volatile Organic Compound (VOC) Emissions, Which quantifies hourly urban forest VOC emissions based on field and meteorological data, and O3 and CO formation based on VOC emissions. UFORE-C: Carbon Storage and Sequestration, Which calculates total stored C, and gross and net C sequestered annually by the urban forest based on field data. UFORE-D: Dry Deposition of Air Pollution, Which quantifies the hourly amount of pollution removed by the urban forest and associated percent improvement in air quality throughout a year. Pollution removal is calculated for O3, SO2, NO2, CO, PM2.5 and PM10 based on field, pollution concentration, and meteorological data. UFORE-E: Energy Conservation, Which estimates effects of trees on building energy use and consequent emissions of carbon from power plants (i-Tree).

**Urban Mixing Height**

The mixing height is the height of vertical mixing of air and suspended particles above the ground. It changes with day-night and seasons. Extrapolation from ground-layer concentration to total pollution within the boundary layer assumes a well-mixed boundary layer, which is common in the daytime (unstable conditions) (Colbeck, Harrison, & R.M., 1985).

# Acronyms and Abbreviation

**ADB** - Asian Development Bank

**AQS -** Air Quality Standard

**BB** - Bangladesh Bank

**BRAC** - Bangladesh Rural Advancement Committee

**BAI** - Bark Area Index

**BDT -** Bangladesh Taka (Bangladeshi Currency)

**CAMS** - Continuous Air Monitoring Stations

**CNG** - Compressed Natural Gas

**COPD** - Chronic Obstructive Pulmonary Disease

**DoE** - Department of Environment

**DPF** - Diesel Particulate Filter

**GFW -** Global Forest Watch

**GIS -** Geographical Information System

**IHME** - Institute for Health Metrics and Evaluation

**JICA** - Japan International Cooperation Agency

**KDA** - Khulna Development Authority

**KML -** Keyhole Markup Language

**KCC** - Khulna City Corporation

**LAI -** Leaf Area Index

**NASA -** National Aeronautics and Space Administration

**NFPA -** National Fire Protection Association

**NDVI -** Normalized Difference Vegetation Index

**PM -** Particulate Matter

**PPM -** Parts Per Million

**PPB -** Parts Per Billions

**PPP** - Purchasing Power Parity

**SAS -** Statistical Analysis Software

**TSP -** Total Suspended Particles

**UFORE -** The Urban Forest Effects

**UFORE-D -** The Urban Forest Effects- Dry Deposition of Air Pollution

**UMH -** Urban Mixing Height

**USA -** United States of America

**USEPA -** United States Environmental Protection Agency

**WB -** World Bank

**WUC -** The World Urban Campaign

**WHO -** World Health Organization

# Abbreviation

**Acr -** Acre

**Ft -** Feet

**Gm**  - Gram

**gm-2h-1 -** Gram Per Square Per Hour

**gm-3h-1 -** Gram Per Cube Per Hour

**h -** Hour

**ha -** Hector

**km -** Kilometer

**km2 -**Square Kilometer

**m -** Meter

**m2 -** Meter Square

**ms-1 -** Meter Per Second

**ms-2 -** Meter Per Second Square

**ppm -** Parts Per Millions

**ppb -** Parts Per Billons

**s -** Second

**sm-1 -** Second per meter

**t -** Ton

**μg/m3 -** Microgram per Meter Cube

**$ -** Dollar

**$/t -** Dollars Per Ton

# INTRODUCTION

## Background

Air lets our living planet breathe—it's the mixture of gases that fills the atmosphere, giving life to the plants and animals that make Earth such a vibrant place. Broadly speaking, air is almost entirely made up of two gases (78 percent nitrogen and 21 percent oxygen), with a few other gases (such as carbon dioxide and argon) present in absolutely minute quantities (Woodford, 2017). Air pollution occurs when harmful substances including particulates and biological molecules are introduced into Earth's atmosphere. It may cause diseases, allergies or death in humans; it may also cause harm to other living organisms such as animals and food crops, and may damage the natural or built environment. Human activity and natural processes can both generate air pollution. Air pollution occurs for different types of pollutants increasing in the air. These pollutants are Sulfur oxides (SOx), Nitrogen oxides (NOx), Nitrogen dioxides (NO2), Sulfur dioxides (SO2), Carbon monoxide (CO), Ozone(O3), Particulates (PM2.5, PM10), Volatile organic compounds (VOC), Ammonia (NH3), Chlorofluorocarbons (CFCs) etc. Toxic metals such as lead and mercury especially their compounds, odors and radioactive pollutants. There are various locations, activities or factors which are responsible for releasing pollutants into the atmosphere. These sources can be classified into two major categories. They are man-made source and natural source. Man-made pollution source includes power plants, motor vehicles, Controlled burn practices in agriculture and forest management, Fumes from paint, hair spray, varnish, aerosol sprays and other solvents, Waste deposition in landfills, Military resources, such as nuclear weapons, toxic gases, germ warfare and rocketry. Natural source includes Dust from natural sources, usually large areas of land with little or no vegetation, Methane, emitted by the digestion of food by animals, for example cattle, Radon gas from radioactive decay within the crust, Smoke and carbon monoxide from wildfires, Vegetation, in some regions, emits environmentally significant amounts of Volatile organic compounds (VOCs) on warmer days, Volcanic activity, which produces Sulfur, chlorine, and ash particulates etc. (Air Pollution, 2017).Air pollution is a significant risk factor for a number of pollution-related diseases and health conditions including respiratory infections, heart disease, and COPD, stroke and lung cancer. The World Health Organization estimated in 2014 that every year air pollution causes the premature death of some 7 million people worldwide (GENEVA, 2014). Annual premature European deaths caused by air pollution are estimated at 430,000 (Europian Parliament, 2016). In December 2013 air pollution was estimated to kill 500,000 people in China each year (Moore, 2014). India has the highest death rate due to air pollution (Harris, 2014). Across the European Union, air pollution is estimated to reduce life expectancy by almost nine months (BBC, 2005). Urban outdoor air pollution is estimated to cause 1.3 million deaths worldwide per year. Children are particularly at risk due to the immaturity of their respiratory organ systems (WHO , 2016). A 2007 review of evidence found ambient air pollution exposure is a risk factor correlating with increased total mortality from cardiovascular events (Chen, J.Villeneuve, & Goldberg, 2008). Research has demonstrated increased risk of developing asthma and COPD from increased exposure to traffic-related air pollution (U, A.H, M, Fisher, & Jongste, 2010) (Andersen, et al., 2011). In December 2015, medical scientists reported that cancer is overwhelmingly a result of environmental factors, and not largely down to bad luck (Gallagher, 2015). In 2011, a large Danish epidemiological study found an increased risk of lung cancer for patients who lived in areas with high nitrogen oxide concentrations. In this study, the association was higher for non-smokers than smokers (Raaschou-Nielsen, et al., 2011). A recent study in Europe has found that exposure to ultrafine particles can increase blood pressure in children. (Pieters, et al., 2015). Air pollution exposure also affects the central nervous system (Bos, De Boever, Int Panis, & Meeusen, 2014). Air pollution costs the world economy $5 trillion per year as a result of productivity losses and degraded quality of life, according to a joint study by the World Bank and the Institute for Health Metrics and Evaluation (IHME) at the University of Washington. (Common Dreams, 2016) The world's worst short-term civilian pollution crisis was the 1984 Bhopal Disaster in India (Chakrabarti, 2004). Nanoparticles found in vehicle exhaust fumes can build up in damaged blood vessels and stay in the blood system for months, potentially raising the risk of a heart attack or a stroke (RT QUESTION MORE, 2017). Cities concentrate many problems that can affect human wellbeing. They hold the majority of human activities and the associated air pollution emissions (Per Bolunda, 1999) Trees play an important role in reducing air pollution. Trees remove gaseous air pollution primarily by uptake via leaf stomata, though some gases are removed by the plant surface. Once inside the leaf, gases diffuse into intercellular spaces and may be absorbed by water films to form acids or react with inner-leaf surfaces. Trees also remove pollution by intercepting airborne particles. Some particles can be absorbed into the tree, though most particles that are intercepted are retained on the plant surface. The intercepted particle often is re-suspended to the atmosphere, washed off by rain, or dropped to the ground with leaf and twig fall (Smith & H., 1990). Growth of city trees can cut air pollution (Kinver, Growth of city trees can cut air pollution, says report - BBC News, 2016). Several studies have quantified the amount of air pollution removal by urban forests (Freer-Smith, 1997) (McPherson, 1999) (Yang, McBride, Zhou, & Sun, 2005). For Example (Nowak, Crane, & Stevens, 2006) studied air pollution removal and air quality improvement by urban forests for several cities in the United States. Using assumed urban forest structure values such as leaf area index, estimated mean removal of PM10 by trees in Los Angeles, United States was 8.0 g m−2 (Yang, McBride, Zhou, & Sun, 2005) discuss the role of urban forests on air quality in Beijing and found that pollution removal rates by its urban forest were greater than those for cities in the United States (McPherson, 1999) analyzed the benefits and costs of managing municipal urban forests for multiple benefits and services, including air quality. A study across the Chicago region determined that trees removed approximately 17 tons of carbon monoxide (CO), 93 tons of Sulfur dioxide (SO2), 98 tons of nitrogen dioxide (NO2), and 210 tons of ozone in 1991 (Nowak, McPherson, E-Gregory, Rowntree, & A., 1994). The “air pollution” kills nearly 15,000 Bangladeshis each year according to Mr. Paul Martin, a bank environmental specialist in Dhaka 2001. This is released in the World Bank report saying Bangladesh could save between $200 million and $800 million per year. These amounts translate to about 0.7% to 3.0% of the gross national product if air pollution is reduced in just four major cities of Bangladesh. An on-line forum called South Asia in 2001 mentioned that 6.5 million people in four large cities of Bangladesh suffer each year. Another at least 8.5 million cases have been observed with minor illnesses that did not require severe treatment. The major disease in Bangladesh is not diarrhea as often perceived. In reality it is acute respiratory infection caused mainly from the polluted air according to South Asia, 2001.Researchers anticipated that the densely populated cities like Bangkok, Dhaka, Manila, Mexico City, New Delhi, etc. are the rapidly growing cities in the world. These are often entombed with air pollution from several kinds of vehicles such as trucks, taxis, buses, and motorcars in addition to the uncontrolled industrial discharge (Mahmood, 2011). Bangladesh is one of the least developed nations in the world. Since 1971 there has been some growth in the industrial sector. Industries are mainly concentrated in major urban metropolitan areas such as Dhaka, Rajshahi, seaports of Chittagong and Khulna, inland port city of Narayanganj, and other divisional towns. Khulna is the 3rd largest industrial city of Bangladesh. (Mahmood, 2011). Khulna is the third biggest metropolitan city of Bangladesh and already called a medium industrial zone of Bangladesh. Because of available of river, raw products and transport there are many industries are existed in this division. Khalishpur, Noapara are the main industrial area where the factory emitted a huge amount of smoke called CO2. The air environment of Khulna has been deteriorating rapidly during the last couple of years especially due to migration of highly polluting 2-stroke engine banned vehicles from Dhaka. In this city there is lack of solid waste management system. Almost every time we have seen that the wastes have been dumped in the road side (Goldar, 2017).

Though air pollution is an important factor that influences quality of life of urban dwellers. This study focuses on the air quality improvement by urban trees. Here the amount of air pollution removed by urban trees and air quality improvement of the Khulna city has been showed. And finally some scope of tree plantation in different areas of Khulna city to improve the quality of air and remove more air pollutants while planning in this city is shown.

## Objectives of the Study

The objectives of this study are:

* To analyze current air pollution situation in Khulna city.
* To measure air pollution removal by urban trees in Khulna city.
* To provide strategies for air pollution control for Khulna city.

## Research Questions of the Study

* What is the current air pollution situation in Khulna, and how does it compare with standards?
* What is the necessity of urban tree and air pollutants removal in development thinking?
* How much pollution does urban trees of Khulna remove?
* Is further pollution removal possible by further tree plantation?
* Can a model be prepared for making further study on air pollution removal by urban trees convenient?

## Rationale of the Study

Air pollution is a significant problem of urban area that can reduce quality of life of urban people. Air pollution is a major cause of premature death, respiratory diseases and so on. Due to transportation and manufacturing activity, pollution level in urban area is higher than other areas. And with the ongoing rapid urbanization and industrialization process, this problems is going to magnify in the future.

The population size and density makes large number of people vulnerable to air pollution related problems. Air pollution under desirable limit is an important attribute of a livable urban area. Thus air pollution is a standard of SDG 11, the only SDG goal related with city.

This creates a necessity for analyzing air pollution situation for any city. The comparison of pollution level with the standards of the country is necessary to understand possible harmful effect of air pollution in the area. Thus this study is essential in the planning, development process of urban area and betterment of urban dwellers. This study does this analysis that address the air pollution scenario of Khulna city and compares it with standard.

Trees are a main source of air pollution removal. With numerous services of trees, they are a major source of pollution removal from an areas atmosphere.

This study analyses the amount of air pollution removal by urban trees in Khulna city. This vital service received by urban trees with other numerous service can increase the significance of tree plantation and maintenance of trees in urban planning. Furthermore, tree plantation planning can be undertaken to reduce air pollution level if it is above desired air pollution level. And that is possible when air pollution level and removal is studied.

## Scope of the Study

The scope of this study includes:

* To investigate current pollution, meteorological situation in Khulna.
* To compare pollution level with country standards.
* To determine the tree cover in Khulna.
* To analyze air pollution removal by urban trees in Khulna.
* To quantify monetary value of air pollution service provided by trees.
* To recommend plantation for extra removal of pollutants.
* To prepare model for further study of air pollution removal by urban trees.

## Limitations of the Study

* Problem of data validation: the data used in this study is complex, and there is only one source of data. Data of CAMS project is used in air pollution related research by Department of Environment of Bangladesh. However, for Khulna, there is no other data source for pollution related data. Thus validation of pollution data isn’t possible.

Furthermore, there has been no study conducted on Khulna about air pollution removal by urban trees. Thus the validation of results isn’t possible.

However, as the data source is reliable and widely used, this study puts confidence in the quality of data.

* The model used in this model is one of the most sophisticated in this field, but due to immense complexity of the air pollution removal process, the model draws many assumed values in order to make this process possible. For example, the pollution removal rate changes with the type of tree species. Considering all variations is certainly more accurate, but adds immense complexity in the study. Considers value of most common vegetation type cuts of this complexity while keeping the result inside the acceptable accuracy. This simplification is used in places of this study to increase its convenience.
* The model requires very high quality meteorological data for an extended period of time. But the meteorological data collection of Bangladesh is not very sophisticated. Thus extrapolation or interpolation of data was required.
* Data such as urban mixing height calculation is desired for this study. But no such study has been conducted in Bangladesh to determine mixing height as it requires specific machinery and process. Thus the values were obtained from literature.
* This study uses remote sensing technology based value for vegetation cover. Due to the resolution of remote sensing data, the obtained value might slightly differ from the actual tree cover.

# LITERATURE REVIEW

## Air Pollution Discussion

### Description of Major Air Pollutants

The major air pollutant includes Carbon Monoxide, Nitrogen Dioxide, Sulfur Dioxide, Ozone, Particulates.

**CO**

Carbon monoxide (CO) is a colorless, odorless, and tasteless gas that is slightly less dense than air. It is a product of incomplete combustion of fuel such as natural gas, coal or wood. Vehicular exhaust is a major source of carbon monoxide (Department of Environment of Government of Bangladesh, 2012).

**NO2**

Nitrogen Dioxide is one of several Nitrogen Oxides. It is a well-known precursor to acid rain, which can reduce agricultural production and damage the environment (UNEP, 2012). NO2 is also a precursor for the formation of particulates and O3 in the atmosphere, which are both known to increase premature mortality. The CAMS data of Environment Department of Bangladesh has data lack within 3 year time series of NO2 that makes it hard to analyze the impact of this pollutant in Bangladesh (Department of Environment of Government of Bangladesh, 2012).

**SO2**

Sulfur dioxide (SO2) has health impacts as a gas and also acts as a precursor to the formation of particulates and acid rain in the atmosphere. SO2 emissions occur primarily from combustion of Sulfur containing fuel (coal, diesel). In Bangladesh, diesel vehicles and brick kilns are the most important sources because of the presence of Sulfur in commercially available diesel and coal.

**O3**

Ozone (O3) in high concentrations at the ground level can be a significant health hazard, resulting in premature mortality. O3 can also reduce agricultural productivity significantly by hindering plant growth. Unlike particulates, NOx or SO2, O3 is not directly emitted by any source, but is produced in the atmosphere when emissions of volatile organic compounds and

NOx from different sources react in the presence of sunlight.

**Particulate Matter**

Atmospheric particulate matter also known as particulate matter (PM) or particulates – are microscopic solid or liquid matter suspended in the Earth's atmosphere (Seinfeld & Spyros, 1998). Sources of particulate matter can be man-made or natural. They have impacts on climate and precipitation that adversely affect human health. Particles with a diameter between 2.5 and 10μm (PM10) and fine particles with a diameter of 2.5μm or less (PM2.5).

It is widely accepted that particulate matter is the major pollutant of concern internationally and in Bangladesh (ADB, 2006).

### Air Quality Standard

Table 2.1: Air Quality Standard in Bangladesh

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Pollutant** | **Averaging time** | **Bangladesh Standard (µg/m3)** | **WHO guideline (µg/m3)** | **US standard (µg/m3)** |
| **Carbon Monoxide (CO)** | 1 hour | 40,000 (35 ppm) | 30,000 | 40,000 |
| **Nitrogen Oxides** | Annual | 100 (0.053 ppm) | - | - |
| **Coarse Particulates (PM10)** | Annual | 50 | 20 | - |
| **Ozone (O3)** | 1 hour | 235 (0.12 ppm) | - | 235 |
| **Sulfur dioxide** | Annual | 80 (0.03 ppm) | - | 78 |
| 24 hour | 365 (0.14 ppm) | 20 | 365 |

Source: DoE Bangladesh, 2012

### Sources of Air Pollution in Bangladesh

In order to control air pollution, it is necessary to understand the sources of air pollution, since one of overall air pollution control approaches is to reduce emission.

Table 2.2: Major Sources of Air Pollutants

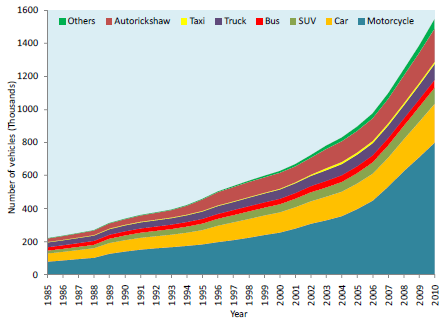
|  |  |
| --- | --- |
| **Pollutant** | **Sources** |
| **Carbon Monoxide (CO)** | Motor vehicle exhaust, kerosene, power plants with internal combustion engines or wood/biomass burning stoves. |
| **Sulfur Dioxide (SO2)** | Coal-fired power plants, brick kilns, petroleum refineries, Sulfuric acid manufacture, and smelting Sulfur containing ores. |
| **Nitrogen Dioxide (NO2)** | Motor vehicles, power plants, and other industrial, commercial, and residential sources that burn fuels (e.g. diesel generators). |
| **Ozone (O3)** | Vehicle exhaust and certain other fumes (hydrocarbons). Formed from other air pollutants in the presence of sunlight. |
| **Particulate Matter (PM)** | Diesel engines, motor vehicles, power plants, brick kilns, industries, windblown and road dust, wood/ biomass stoves, open burning. |

Source: USEPA, 2017

**Motor vehicles**

Combustion of fuels in motor vehicles is, undoubtedly, the most important source of air pollution in the largest of the urban centers, i.e. in Dhaka and Chittagong. Fuel combustion not only produces fine particulates directly, which have severe health effects, but also emits NOx and SOx, which are important precursors to producing further particulates in the atmosphere.4 NOx and HC emitted from vehicles can also undergo transformation in the atmosphere to produce ozone (as well as a range of other secondary pollutants), another pollutant with direct adverse health impacts. Also, vehicles emit closer to the human population and thus have a direct effect on human health in urban areas (DoE, 2012).

In recent years, motor vehicles are growing rapidly.



Source: BRTA, 2016

Figure 2.1: Vehicle Growth in Bangladesh During 1985-2010

**Brick kilns**

Brick kilns are a major source of air pollution throughout Bangladesh. Brick kilns are major sources of PM, SOx, CO, VOC (VOCs are precursors to O3) and acidic gases (e.g. HF, HCl etc.). Brick making is also one of the largest GHG emissions source in Bangladesh, with large CO2 emissions from the combustion of coal and wood (Department of Environment of Government of Bangladesh, 2012).

**Industries**

While the brick industry requires a separate section because of its large contribution to air pollution, contribution from other industrial sources are not negligible. The major polluting industries in this regard are the cement, steel, parboiling rice mills, and glass plants. All three are directly linked to building and infrastructure construction (as is brick), which is a natural consequence of the state of growth in Bangladesh. Since such growth is expected in the future, it is important to control emissions from these sources in order to keep the air quality at a reasonable level. There are currently gaseous emissions standards governing emissions from these industries, but enforcement is so lax that only a few people are aware of their existence. (Department of Environment of Government of Bangladesh, 2012)

**Biomass Burning**

The World Health Organization (WHO) estimates that 2.4 billion people worldwide rely on burning biomass fuels (e.g., fuel wood, animal dung, crop residues) for cooking and heating their homes. Biomass is extensively used in rural areas of Bangladesh, primarily for cooking. Biomass contributes to more than half of the total primary energy needs in Bangladesh. Biomass burning, especially in traditional cooking stoves, results in significant air pollution, which is harmful especially to the women and young children who often spend most of their time in the kitchen with a high level of particulates concentration. In rural Bangladesh, majority of people rely on solid biomass fuel; and firewood, crop residue dung, and tree leaves accounts for about 97% of total household energy use (Department of Environment of Government of Bangladesh, 2012).

**Construction and Vehicular Activities**

Dust is one of the major problems in most urban areas and some rural areas in Bangladesh, especially during the dry seasons (i.e. winter, spring, and late autumn). While coarse suspended particulates are not as lethal as their finer counterparts, they can still be a health hazard, especially increasing incidences of morbidity among the population. Construction and vehicular activities primarily give rise to dust in urban areas. Large urban metropolises (Dhaka and Chittagong and, to a lesser extent, the divisional and the district headquarters) have benefited from a boom in the real estate sector, but this also equates to an increase in construction activities. Since there are no specific guidelines or rules on storage and transport of construction materials, it is very common that the construction sites are all very dusty. Even the roads catering for the construction traffic are also dusty because there are no requirements of covering the construction material during transport. In addition, most of the construction (especially excavation and soil transport which are particularly dust generating) take place during the winter, which is dry and further conducive to air pollution (Department of Environment of Government of Bangladesh, 2012).

**Power Sector**

Although electricity utilities are a major source of air pollution in many developed and developing countries, their contribution to air pollution in Bangladesh has not been large. As opposed to the USA, Australia, China or India, where coal is the major primary source to produce electricity, Bangladesh has only one coal-fired power plant. Most of its electricity is produced from natural gas, which is much cleaner than coal, both in terms of local air pollution and global air pollution (Department of Environment of Government of Bangladesh, 2012).

### Effects of Air Pollution

Air pollution has adverse impacts on human health, material, agricultural production, ecosystems and regional and global climate, thus adversely affecting quality of life and economic output. Most of the evidence base for these health impacts is from developed countries, where physiological and toxicological studies confirmed the adverse impacts of the pollutants. Extensive research efforts during the past decades have resulted in successful quantification of some of these health impacts with respect to a change in the ambient pollutant (Hurley, et al., 2005).

Carbon Monoxide is toxic to Hemoglobin animals (both invertebrate and vertebrate, including humans) when encountered in concentrations above about 35 ppm (Detect Carbon Monoxide, 2017).

Table 2.3: Health Impact of Different Levels of CO

|  |  |
| --- | --- |
| **Level of CO** | **Health Effects, and Other Information** |
| **0 PPM** | Normal, fresh air. |
| **9 PPM** | Maximum recommended indoor CO level |
| **10-24 PPM** | Possible health effects with long-term exposure. |
| **25 PPM** | Max TWA Exposure for 8 hour work-day |
| **50 PPM** | Maximum permissible exposure in workplace |
| **100 PPM** | Slight headache after 1-2 hours. |
| **200 PPM** | Dizziness, nausea, fatigue, headache after 2-3 hours of exposure. |
| **400 PPM** | Headache and nausea after 1-2 hours of exposure. Life threatening in 3 hours. |
| **800 PPM** | Headache, nausea, and dizziness after 45 minutes; collapse and unconsciousness after 1 hour of exposure. Death within 2-3 hours. |
| **1000 PPM** | Loss of consciousness after 1 hour of exposure. |
| **1600 PPM** | Headache, nausea, and dizziness after 20 minutes of exposure. Death within 1-2 hours. |
| **3200 PPM** | Headache, nausea, and dizziness after 5-10 minutes; collapse and unconsciousness after 30 minutes of exposure. Death within 1 hour. |
| **6400 PPM** | Death within 30 minutes. |
| **12,800 PPM** | Immediate physiological effects, unconsciousness. Death within 1-3 minutes of exposure. |

Source: National Fire Protection Association (NFPA) Standards, 2017

The table below shows health impact of different air pollutant.

Table 2.4: Health Impact of the Criteria Air Pollutants

|  |  |  |
| --- | --- | --- |
| **Pollutant** | **Health Effects** | **Other Welfare Effects** |
| **Carbon Monoxide (CO)** | Headaches, reduced mental alertness, heart attack, cardiovascular diseases, impaired fetal development, and death. | Contribute to the formation of some secondary pollutants. |
| **Sulfur Dioxide (SO2)** | Eye irritation, wheezing, chest tightness, shortness of breath, lung damage. | Contribute to the formation of acid rain, visibility impairment, plant and water damage, aesthetic damage. |
| **Nitrogen Dioxide (NO2)** | Susceptibility to respiratory infections, irritation of the lung and respiratory symptoms (e.g. cough, chest pain, difficulty breathing). | Contribute to the formation of smog, acid rain, water quality deterioration, global warming, and visibility impairment. |
| **Ozone (O3)** | Eye and throat irritation, coughing, respiratory tract problems, asthma, lung damage, leading to premature mortality. | Plant and ecosystem damage. Material (rubber) damage |
| **Particulate Matter (PM)** | Eye irritation, asthma, bronchitis, lung damage, cancer, heavy metal poisoning, cardiovascular effects, leading to premature mortality. | Visibility impairment, atmospheric deposition, aesthetic damage. |

Source: USEPA, 2017

The table below is based on major studies conducted on air pollution and its impact. It includes the yearly health impact, monetary value.

Table 2.5: Health Impacts and Associated Monetary Impact of Air Pollution

| **Study** | **Region** | **Yearly Health Impacts/Benefits** | **Monetary value-M$** | **Comments** |
| --- | --- | --- | --- | --- |
| **(Carter, 1997)** | 4 cities | Reduction to WHO standard avoids 14,850 premature deaths (Dhaka 10,800) 6.54 mil hospital admissions or medical treatments (Dhaka 4.74 mil) | 185~810 | Fairly old estimate |
| **(Khaliquzzaman, et al., 2007)** | Urban Areas | 20% - 80% reduction avoids 1,200 – 3,500 premature deaths |  |  |
| **(Aktar & Shimada, 2005)** | Country-wide (indoor) | 20% - 80% reduction avoids 7,600 – 30,400 premature deaths |  | For indoor air pollution |
|  | AQS attainment avoids 1,210 premature deaths | 97.0 | Mortality impact from time series data |
| **ADB 2005** | 3 major cities | 20% reduction avoids  1,070 premature deaths  18,300 chronic bronchitis  Total AQS attainment avoids  3,340 premature deaths  57,100 chronic bronchitis | -  30.2  62.3  -  94.2  194.3 | Mortality costs appear to be underestimated, or morbidity costs over-estimated. US studies show avoided premature death benefits govern the total benefits |
| 18 minor cities | 20% reduction avoids  190 premature deaths  1,780 chronic bronchitis  Total AQS attainment avoids  200 premature deaths 1,830 chronic bronchitis | -  5.3  6.0  -  5.5  6.2 |  |
|  | Dhaka | 30%~50% reduction from brick kilns avoids  200~332 premature deaths 1,870~3,110 chronic bronchitis | -  7.3~12.1 8.2~13.6 |  |
| **(Wadud & Waitz, 2011)** | Dhaka | CNG conversion avoided  4,260 premature deaths | -  500 | Impact-pathway approach with AQ models used, CRF for long term exposure |
| **AP COSTS Daily star** | Dhaka | 3,580 premature deaths | 60~270 | Source unclear |

### Tree as Air Pollution Reduction Measure

There are few arguments discussed below to describe importance of trees as a means of air pollutants reduction:

**Limitations of Prevention Measures**

All the air pollution control measures in Bangladesh are prevention centric. But due to limitations in governance, weak institutions, data limitations, many of these strategies can’t be ensured in Bangladesh. For example, Bangladesh has no pollution measurement mechanism for its industries. Thus emission of pollutants can’t be imposed very soon here.

**Priority in Industrialization**

Moreover, as an economically growing country, Bangladesh gives priority to industrial expansion. As economic law, strict pollution standards can reduce competitiveness of industries of Bangladesh. Thus it’s not very probable that Bangladesh will take measures to reduce pollution of industries very strictly.

**Lack of Consciousness About Pollution Reduction**

Many source of air pollutant emission is a result of lack of consciousness and priority. For example, construction practices are a major source of PM emission. But the majority parties related with construction in Bangladesh won’t consider air pollution as a major issue. If otherwise, much pollution prevention might have been possible.

These arguments support the fact that, pollution emission in Bangladesh is not going to reduce significantly in short time. To control pollution, it is necessary to consider mitigation measures. Meaning, even if pollutants gets emitted in air, there should be measures to reduce the pollutants.

**Tree as Pollutant Remover**

Trees removes almost all the major air pollutants. Especially, reduction of average reduction of PM near a tree can be between 7% and 24% (Kinver, Growth of city trees can cut air pollution, 2016). It is a main natural source that removes air pollution.

**Controllable approach**

Just like tree, rainfall, water bodies are other means of natural pollution mitigation. But rainfall is a complete natural process that occurs in certain seasons. Artificial rainfall is possible, but in no way a practical means.

Water bodies removes pollution from air. But increasing water body isn’t a practical solution in case of Bangladesh, where government is failing to even protect existing water bodies.

Tree plantation is perhaps the most suitable approach to address the problem. Tree doesn’t require much space. In our climatic condition, tree doesn’t take heavy maintenance. Tree has multi-dimensional benefits, air pollution removal is just one of the benefits. Thus tree plantation benefits in different ways.

Because of these arguments, it can be said that tree can be viewed as an important mode for air pollutant control measure.

### Preventive Strategies to Reduce Air Pollution

Strategies to reduce air pollution includes past strategies, widespread approaches, and proposed strategies by DoE.

**Past Preventive Strategies to Reduce Air Pollution in Bangladesh**

1. **Phasing out of lead from petrol**: phasing out of lead from petrol in 1999 is one of the major success stories in air pollution regulations in Bangladesh. Motor vehicle was the main source of lead pollution.
2. **Ban on two-stroke three-wheelers in Dhaka**: ban on two-stroke three-wheeler in Dhaka was another major step to reduce air pollution. Two-stroke three-wheeler were a major source of PM emission in Dhaka due to their incomplete and inefficient combustion mechanism. They were replaced with four-stroke three-wheeler CNG baby taxies.
3. **Promoting CNG conversion of vehicles:** promoting CNG conversion of vehicles was another step as usage of CNG over petroleum has several environmental and fiscal benefits. It includes reduction in GHG emission.
4. **Ban on older vehicles:** Ban on older vehicles is another step to reduce emission. A small percentage of older vehicle that are not subject to emission standards results in significant pollution. However, unlike previous successful attempts, this strategy hasn’t been successful. Successive governments hasn’t been able to ban older bus, truck etc.
5. **Vehicle emission standard:** Bangladesh has a vehicle emission standard since 1977, but it was tighten in 2005. This includes ban on any vehicle that emits excess pollution.
6. **Policies to reduce emission from brick kilns:** brick kilns around cities are a major source of air pollution in large and small cities. The Brick Burning Act of Bangladesh in 1989 banned use of wood in brick kilns. Since the regulation, brick kilns has changed fuel type significantly which has reduced pollution. However, regulations like improved kiln technology and high chimney are still not successfully applied all over country.
7. **Ban on high Sulfur coal:** Indian coal containing more than 1% Sulfur is banned in Bangladesh. But as they’re cheap energy source, they’re still being imported.
8. **Improved Cooking Stoves (ICS):** introduction of improved cooking stoves is a very important and essential step in management of indoor air pollution (IAP), and also improves cooking efficiency and reduces cooking time. Programs has been taken by Local Government, NGOs, and donor agencies to increase usage of ICSs.

### Pollution Control Approaches

There are two main strategies to reduce air pollution: Command and Control (CAC) and Market Based Instruments (MBI).

1. Command and Control: it sets a uniform maximum emission limit – often known as standards – for the emitting units, then monitors and enforces the set standards. This is the most widespread method for controlling harmful emission in both developed and developing countries. It can include incorporation of specific technology such as use of catalytic converters in every vehicles.

Bangladesh has enacted vehicle emission standards.

1. Two most commonly used MBIs are:
   1. Emission taxes: SO2 and NOx emission charges in several European countries. Emission taxes discourage emission of a pollutant by imposing a financial payment for it.
   2. Emission trading (also known as Cap and Trade, Tradable permits) based on the Coase theorem (Coase, 1960).

Both these methods are successfully applied in many countries, but successful application of these method in Bangladesh is hard because of some major limitations. Lack in data about pollution emission, lack of study on the process of pollutants, weak institutional framework is among the limitations.

### Proposed Strategies to Control Air Pollution by DoE

1. Improve public transport
2. Strengthen vehicle inspection and maintenance
3. Ban old vehicles
4. Encourage Diesel to CNG switch through incentives
5. Emission based annual registration fees
6. Emission based annual tariff
7. Comprehensive land use plan for industry locations
8. Import of quality coal
9. Better construction management
10. Landscaping and gardening

## Significance of Urban Trees in Urban Development Thinking

As human population has grown, so has the number of people living in cities, towns and villages on all continents. More than half the population currently live in cities, and 3 billion more people is expected to be added by 2050. Urbanization is liked with economic growth, employment generation and development. But the environment of urban area is often more polluted than rural area. Air pollution is higher in urban area as the emission is higher due to transportation, factories etc. At the same time, there is less tree, water body in urban area to compensate those pollution. To ensure better living condition for major population of earth, urban environment needs to be carefully controlled.

### The World Urban Campaign

“The World Urban Campaign (WUC) is an advocacy and partnership platform to raise awareness about positive urban change in order to achieve green, productive, safe, healthy, inclusive and well planned cities. Its goal is to place Urban Agenda at the highest level in development policies. It is coordinated by UN-Habitat and driven by a large number of committed partners – currently 180 partners and networks – from around the world” (UN-Habitat, 2012).

There are six thematic areas in WUC:

1. A Green City
2. A Resilient City
3. A Productive City
4. A Planned City
5. A Safe and Healthy City
6. An Inclusive City

The planning of cities will have significant implication for how resilient, resource-efficient and environmentally sound they’ll be in future. A green city means promoting sustainable development through a carbon efficient built environment.

### Sustainable Development Goals

Within the framework of the 2030 Agenda for Sustainable Development, there is a dedicated goal on cities, SDG 11. The goal is about making cities more inclusive, safe, resilient and sustainable. The goal has 10 targets under it, illustrating the measurable standard to reach the goal. The 6th standard is about environmental impact of cities, and the second indicator of this target (indicator 11.6.2) is about Annual mean levels of fine Particulate matter (PM2.5 and PM10) in cities (United Nations, 2016).

According to the indicator, there are 3 kind of threshold (Sachs, Traub, & Delacre, 2016).

Green: Percentage PM2.5 below 10.

Yellow: Percentage PM2.5 10 – 20.

Red: Percentage PM2.5 more than 20.

Source: United Nations Statistics, 2017

Figure 2.2: Current State of Countries According to PM2.5 Indicator

### New Urban Agenda

The New Urban Agenda is framework adopted by world leaders that lays out how cities should planned and managed to best promote sustainable urbanization in the United Nations Conference on Housing and Sustainable Urban Development at 21st October 2016. There are a number of areas on which leaders has committed to work on. One of the areas is promoting safe, accessible and green public spaces. The Agenda calls for planning to increase public space, parks, gardens, plantation in urban area. Sustainable urban design plays a key role in ensuring the livability and prosperity of a city (United Nations, 2016).

## UFORE-D: Dry Deposition of Air Pollutants Model

Urban Forest Effects (UFORE) model is the model used to assess different urban tree services. The UFORE model with dry deposition component (UFORE-D) is used in software like i-Tree Eco, which is widely used platform for assessing air pollution removal by urban trees. The pollutants includes carbon monoxide (CO), nitrogen dioxide (NO2), ozone (O3), sulfur dioxide (SO2), and particulate matter less than 10 microns (PM10) and particulate matters less than 2.5 microns (PM2.5).

### Case Study of Application of UFORE-D Model

**Case Study 1: Strasbourg city, France**

This study was conducted by Wissal Selmi, Christiane Weber, Emmanuel Rivière, Nadège Blond, Lotfi Mehdi and David Nowak. In their study i-Tree Eco model was used in order to estimate air pollution removal by urban trees in Strasbourg city, in North East France. The city’s population reached about 275 000 inhabitants in 2011 (INSEE, 2011). The climate of Strasbourg is continental with an average monthly temperature of 2◦C in January and 19◦C in June. The mean annual precipitation is 665 mm (Metro France website: http://www.meteofrance.com/accueil). Applied for the first time in this French city. Though i-Tree model requires several types of data. They input tree structure information to the model along with local weather and pollution data. Used boundary layer height data to estimate percent air quality improvement due to the pollution removal by trees. They determine tree cover by sampling in four steps managed by municipal services in Strasbourg city. Hourly weather data and pollution data, hourly meteorological data were collected from the Metro France and the National Oceanic and Atmospheric Administration (NOAA, 2016). Where one station is located at Strasbourg city. Boundary layer data were obtained from the nearest monitoring station. The hourly pollution concentration data for ozone (O3); sulfur dioxide (SO2); nitrogen dioxide (NO2); carbon monoxide (CO); PM10 and PM2.5 were obtained from the regional Air Quality Agency (ASPA) in charge of the air pollution monitoring in the Alsace Region. These data were measured in six monitoring stations located within the study area over a one year period. The study shows that about 88 tons of pollutants during one year period from July 2012 to June 2013 was removed by trees in the study area. About 1 ton for CO; 14 tons for NO2; 56 tons for O3; 12 tons for PM10 ; 5 tons for PM2.5 and 1 ton for SO2. The comparison between simulated pollution removal rates and local emissions shows that public trees of Strasbourg reduce about 7% of the emitted PM10 in the city’s atmosphere; however, effect on other air pollutants was small. Their study limitations were the model parameters were adjusted depending on local collected tree data and locally measured meteorological and air pollution data. Thus, their study reveals that urban trees are a significant element to reduce air pollution but are not the only solution to this problem. They recommended to associate planting and managing urban forest resources including the urban environment characteristics such as built structures, street design, location of local sources etc. (Selmi, et al., 2016).

**Case Study 2: Guangzhou city, China**

This study was done by C.Y.Jim and Wendy Y.Chen (Department of Geography, Hong Kong). The study area was focused on the central built-up part of Guangzhou city, which is major subtropical city in South China and the provincial capital of Guangdong. Which has a significant proportion of 73.6 km2 covered by green spaces which amounts to 31.1% of the study area, of which 16.37 km2 is composed of tree cover (Guangzhou Landscape Bureau, 2002). The primary air pollutants in that area are SO2, NOx, and total suspended particulates (TSP). SO2 is a principal air pollutant due to mass use of fuels high in sulfur content. Their research assesses the capability and monetary value of the ecosystem service in Guangzhou city in South China. They did continuous sampling manually at optimized monitoring points to collect air pollution data for the whole city. They observed dry deposition of air pollution to quantify air pollutant removal. Total removal of main air pollutants by urban trees in Guangzhou’s was 312.03 Mg in 2000.The amount of SO2, CO2 and TSP 20.26, 42.24 and 245.04 Mg/y respectively in their study. Amongst the three pollutants, TSP as the major air pollutant in the study period had the largest removal (C.Y. Jim, 2008). For valuing ecosystem services the marginal cost for NO2 was set according to the latest emission cost issued by the State Environmental Protection Administration (2004) of China. The marginal costs for SO2 and TSP were set according to published estimates. The adopted values were RMB600/Mg for SO2, RMB600/Mg for NO2 and RMB185/Mg for particulates (Ouyang & Wang, 1997) & (Xiao, Ouyang, Zhao, & Wang, 2000). RMB stands for Renminbi which is the Chinese currency, at an exchange rate of US$1.00=RMB8.26. The service value of SO2, CO2 and TSP was 12.16, 25.34 and 45.33 RBM respectively. The total value of air pollutant removal generated by urban trees in Guangzhou is estimated at RMB 90.19 thousand in 2000.The total value is lower than the empirical results of cities with a similar size city. The monetary value of this ecosystem service in Guangzhou is lower than similar studies in developed countries, because the marginal cost for air pollutant removal in China is much lower. For example, the value of air pollutant removal by trees per year was about US$5.9 million in New York and US$3.1 million in Philadelphia studied by (Nowak & Dwyer, Understanding the benefits and costs of urban forest ecosystem., 2000) . The main limitations of the present study were the unavailability of more detailed meteorological and air quality data also the complexity of dry deposition of air pollutant process. Their recommendation was to give focus on the preservation of urban nature, and ecological repair and rehabilitation in large cities such as Guangzhou in order to improve urban environmental quality. Also to strengthen public understanding of the less known benefits of urban trees, and provide clues for green space design and management (C.Y. Jim, 2008).

**Case Study 3: Cities of United States**

This study was conducted by David J. Nowak, Daniel E. Crane and Jack C. Stevens in USA's 55 city. Their work was supported by funds through the USDA Forest Service’s RPA Assessment Staff, and State and Private Forestry’s, Urban and Community Forestry Program. They used dry deposition of air pollution model for air pollution removal by trees. Though this model require several data , the hourly weather data was taken from nearby airports for 1994 and Hourly pollution concentration data (1994) from each city were obtained from the US Environmental Protection Agency (EPA). Mixing heights was taken from nearby stations and interpolated to produce hourly values using the EPA’s PCRAMMIT program (US EPA, 1995). Minimum boundary-layer heights were set to 150 m during the night and 250 m during the day based on estimated minimum boundary-layer heights in cities. Pollution removal (O3, PM10, NO2, SO2, CO) varied among cities with total annual air pollution removal by US urban trees which was estimated at 711,000 metric tons ($3.8 billion value). This study shows that pollution removal is only one of various ways that urban trees affect air quality. It reveals that management of urban tree canopy cover could be a viable strategy to improve air quality and help meet clean air standards (David J. Nowak & Stevens, 2006).

**Case Study 4: Santiago Metropolitan Region, Chile**

This study was conducted by Francisco J. Escobedo and David J. Nowak in the 967.2 km2 Santiago Metropolitan Region in central Chile, Where according to World Bank report 1994 the average annual precipitation of 375 mm most of which is concentrated during the winter months. They evaluate how the spatial heterogeneity of the urban forest influences air pollution removal at the socioeconomic sub region scale. Air pollution removal for July 1997 to June 1998 and July 2000 to June 2001 were estimated using measured urban forest structure data from three socioeconomic sub regions in Santiago, Chile. They established three socioeconomic sub regions based on methods from Escobedo (2004). They used Urban Forest Effects (UFORE) model (David J. Nowak & Stevens, 2006); (Nowak D. C., 2000) to estimate the amount of air pollution removal by Santiago’s three urban forest sub regions. They used 2002 field data and meteorological and pollution concentration data from July 2000 to June 2001.The hourly meteorological data was taken from the La Platina weather station located in the south. Mixing heights provided by CENMA were obtained from methods using Seibert et al. (2000). To measure atmospheric pollution concentrations in the three modeling sub regions for the periods July 1997 to June 1998 and July 2000 and June 2001 the MACAM-2 (Red de Monitoreo Automática de Contaminants Atmosféricos) monitoring station network hourly pollution data were used. Urban forest effects on pollutant dry deposition were quantified using the UFORE model. In addition, pollution concentration and weather data from July 1997 to June 1998 were used to compare air quality improvement differences for the Santiago Metropolitan Region between analysis years. Air pollution removal per square meter of tree cover was greatest in the low socioeconomic sub region. Pollution removal during 1997–1998 was different from 2000 to 2001 due to pollution concentration differences. The annual air quality improvement by pollutant for Santiago’s three different sub regions during 2000–2001 was 6.1%, 2.1%, 1.9%, 0.02% and 1.5% by PM10, O2, SO2, CO and NO2 respectively in high sub-region. Their study limitations was because of lack of weather data and model limitations. However their results can be used to design management alternatives at finer administrative scales such as districts and neighborhoods that maximize the pollution removal rates by the urban forest in a sub region. And says to take policies while making region wide recommendations that affect the functionality of urban forest structure must consider spatial heterogeneity and scale (Escobedo & Nowak, 2009).

### Data Limitations and Application of UFORE-D Model in context of Khulna city

**Creating Calculation Model Instead of Submitting to i-Tree Platform**

i-Tree Eco platform is an automatized platform for tree service determination. i-Tree uses dry deposition model, termed as UFORE-D model for air pollution removal. Other UFORE models is used to determine other benefit received by tress. i-Tree automatize analysis of US, but for areas outside US, they take up to 6 months for providing results. They also require strict data standards for analysis. This data requirement makes it unsuitable for countries like Bangladesh where proper data is often missing or not produced at all. Thus this study had to make a calculation model to analyze the pollution removal. This also allowed this study to be completed in significant less time.

**Application of Remote Sensing for Determination of Tree Cover**

Determination of tree cover was done with remote sensing. The original method excludes remote sensing technology. The determination of tree cover was assumed from total number of trees. But application of remote sensing to determine tree cover is a much used method that can enable faster production of data with sound accuracy. Thus this study uses remote sensing to determine tree coverage.

Generation of tree inventory

i-Tree platform and study requires intensive surveying of urban trees and making tree inventory. Even the sampling survey can take up to 1 year depending upon the size of the city. This inventory data then can be used to produce many different tree service results. But to determine the air pollution removal, only tree cover data is required. Thus this study doesn’t perform intensive tree surveying and generation of inventory. Instead this study determines tree cover with remote sensing technology that makes the methodology much less time consuming and appropriate for determination of air pollution removal.

**Obtaining Data from Literature**

Many data used in i-Tree methodology and case study is obtained from literature as the convenience. But some data required by i-Tree like urban mixing height is often not available in developing countries like Bangladesh as they require costly machinery and complex process to determine them. This limitation makes tree pollution study impossible for these countries. But this study uses data from valid source in these cases (i.e.: urban mixing height, opaque cloud cover, stomatal resistance). This change makes this study possible in places where there is limitation of data while keeping the result in acceptable accuracy

# KHULNA CITY AS STUDY AREA

## Study Area Khulna City

The study area is Khulna city. It is a divisional city and the 3rd largest industrial city of Bangladesh. It is the prime hub for administrative, institutional, commercial and academic activity in South-Western Bangladesh.

Khulna Municipality was established in 1884 during the British colonial regime. The area within which municipal limits was 12.02 square kilometers. Due to migration of Muslims after 1947, population increased in Khulna significantly. The impact of such migration was revealed in 1951 census, when Khulna population rose to about 42,000, nearly four times than it had just 5 years ago (KDA Master Plan, 2002).

During late 1950s, and early 1960s Khulna became an important center for industrial development. With the establishment of a second seaport of the country at Mongla, just about 20 miles south of Khulna town, the city gained further momentum. Many new industries were setup at Khulna and commercial activities increased manifolds, and thus, the city became center point of jute industries and jute trade in Bangladesh.

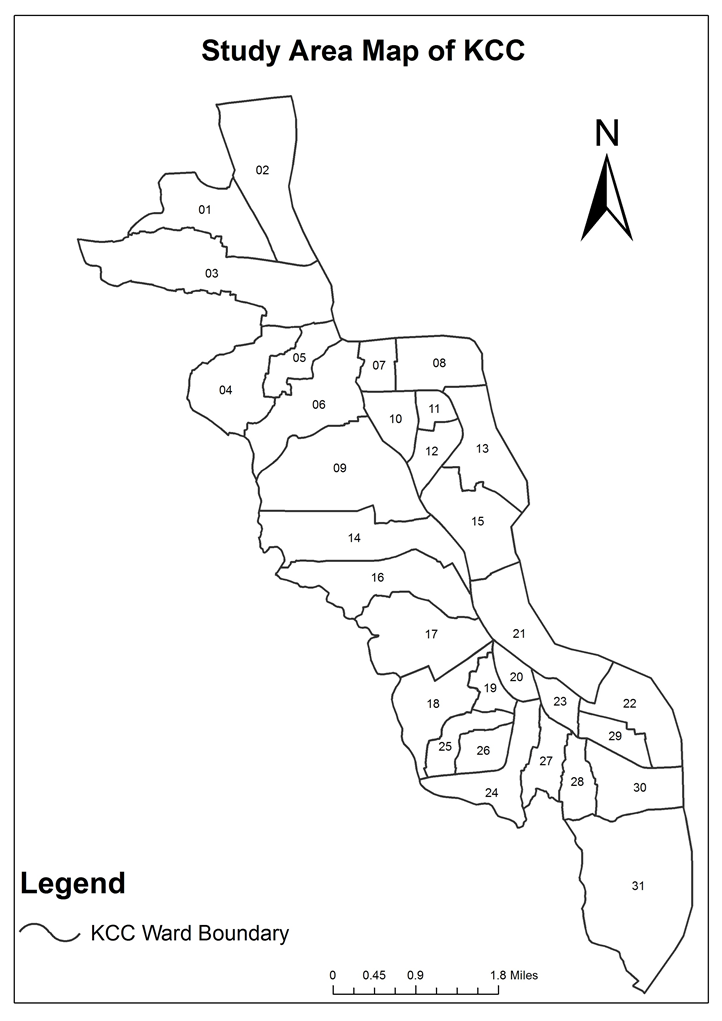
Khulna became a metropolitan city in 1984 with population more than 1 million through the Khulna Municipal Corporation Ordinance of 1984. Later in 1990, it was declared as a City Corporation by National Assembly bill.

The city has a population of about 1.5 million in 45.65 square kilometers area. Population growth rate of Khulna is about 4.13 percent per year. The population of Khulna had grown mainly because of rural urban migration and natural population growth. However, a large portion of Khulna’s population falls into economically active group, which increases its potential for future industrial growth. However currently, income of about 66 percent of people in Khulna city is below Tk. 5,000. With 30 percent people below poverty line (Khan, 2006).

### Location of Khulna city

Khulna city is located on the banks of the Rupsha and the Bhairab rivers. It lies between 22047´16´´ to 22052´ north latitude and 89031´36´´ to 89034´35´´ east longitude. The city is 4 m above the Mean Sea Level (MSL). Khulna is bounded by the Bhairab River and Fultala Thana on the north, by the Rupsha River on the east and south and on the west by Dumuria Thana.

Khulna city is divided into 31 wards. This study analyzes tree cover percentage and pollution removal separately for 31 wards and later shows the comparison of tree air pollution removal.



Map of KCC as Study Area

Figure 3.1: Map of Khulna City Corporation

Because of physiographic setting, Khulna has grown along the west bank of the river Bhairab in a linear pattern. Because of the non-availability of buildable land on the west, the westward growth of the city has been restricted, making the city a narrow strip of urbanized land, 16 km in north-south and a maximum of 4 km in east-west.

The areas with higher buildup percentage has lower amount of tree cover in Khulna, while there are areas where tree cover is still high.

The tree authorities associated with air pollution is Department of Environment, Khulna. Urban tree plantation is maintained by Divisional Forest Office, Khulna.

# STATE OF AIR POLLUTION IN KHULNA CITY

Though population has increased continuously, industrial growth of Khulna has declined with time. Significant economic activity of Khulna includes shrimp farming, jute processing etc. Thus the air pollution level in Khulna is comparatively low. Thus the air pollution related problem is not considered significant though Khulna has just 6.35% tree. The only significant polluter is the brick kilns situated outside the Khulna city. Industrial activity is assumed to accelerate with better connectivity due to construction of Padma bridge. Due to low tree coverage, future increased industrial activity poses a threat of air pollution related problems.

Below is the table of average pollutant concentration level in Khulna city. Local meteorological data was collected from Khulna Environmental Department, and from secondary data source. The data included concentration of SO2.

Table 4.1: Different Pollutants Concentration Level in Khulna City

| **Date** | **SO2 (ppm)** | **NO2 (ppm)** | **CO (ppm)** | **O3 (ppm)** | **PM2.5 (μg/m3)** | **PM10 (μg/m3)** |
| --- | --- | --- | --- | --- | --- | --- |
| Dec, 12 | 0.002145 | 0.02222023 | 3.05 | 0.00 | 107.8566 |  |
| Jan, 13 | 0.001521 | 0.02164208 | 3.683883 | 0.006585 | 190.0934 |  |
| Feb, 13 | 0.002078 | 0.01699642 | 2.27166 | 0.009778 | 105.9161 | 168.6422 |
| Mar, 13 | 0.002276 | 0.0184234 | 2.200349 | 0.009918 | 77.60951 | 139.5169 |
| Apr, 13 | 0.002001 | 0.01824157 | 1.358734 | 0.011629 | 47.15373 | 96.73874 |
| May, 13 | 0.002174 | 0.02273731 | 1.492089 | 0.008829 | 34.06763 | 65.33418 |
| Jun, 13 | 0.001941 | 0.02439624 | 1.244152 | 0.005838 | 32.79 | 78.36982 |
| Jul, 13 | 0.002413 | 0.01868708 | 1.124372 | 0.005021 | 23.74804 | 49.33116 |
| Aug, 13 | 0.016833 | 0.01946969 | 1.041637 | 0.004039 | 17.75964 | 50.69685 |
| Sep, 13 | 0.030663 | 0.02448983 | 1.059084 | 0.002748 | 47.80523 | 112.8698 |
| Oct, 13 | 0.003185 | 0.00991 | 1.131683 | 0.001629 | 34.36233 | 81.12858 |
| Nov, 13 | 0.009266 | 0.01127077 | 1.274908 | 0.003986 | 120.5118 | 255.327 |
| Dec, 13 | 0.00713 | 0.01528239 | 1.3857 | 0.002993 | 181.2639 | 380.6951 |
| Jan, 14 | 0.007214 | 0.01470423 | 1.283887 | 0.001797 | 224.2358 | 369.551 |
| Feb, 14 | 0.004059 | 0.01412608 | 0.857365 | 0.006085 | 102.0304 | 316.4433 |
| Mar, 14 | 0.004353 | 0.01354792 | 0.50004 | 0.009278 | 133.8011 | 250.1244 |
| Nov, 14 | 0.002789 | 0.01296977 | 0.582842 | 0.003908 | 63.54551 | 19.50345 |
| Dec, 14 | 0.004248 | 0.01239162 | 0.420475 | 0.002269 | 60.63043 | 44.55365 |
| Jan, 15 | 0.009977 | 0.01181346 | 0.626661 | 0.00503 | 59.42707 | 56.91167 |
| Feb, 15 | 0.012383 | 0.01123531 | 0.668986 | 0.007916 | 62.88245 | 38.79376 |
| Mar,15 | 0.012171 | 0.01065715 | 0.518132 | 0.011402 | 63.85874 | 43.68569 |
| Apr, 15 | 0.014912 | 0.010079 | 0.546073 | 0.012453 | 64.22845 | 29.36451 |
| May, 15 | 0.013981 | 0.00950085 | 0.327793 | 0.006596 | 43.21919 | 46.19435 |
| Jun, 15 | 0.014898 | 0.00892269 | 0.342584 | 0.005313 | 35.86779 | 36.47317 |
| Jul, 15 | 0.016149 | 0.00834454 | 0.350607 | 0.004389 | 28.51638 | 58.66677 |

Source: DoE Khulna, 2017

### State of NO2, O3, SO2, CO, and PM10 in Khulna

Khulna is not heavily industrialized area. The main industries around Khulna includes brick kilns, two power plant (not coal based), shrimp manufacturing industry in Khulna divisions, Jute mill etc. Number of vehicles in Khulna is also very minor compared to other major cities like Dhaka, Chittagong in Bangladesh.

Due to this lack of industrial activity, air pollutant release in Khulna is very low. Due to this factor, all the pollutants except Particulates is below the standard level in Khulna.

Data Source: DoE Khulna, 2017

Figure 4.1: NO2 Concentration Level Compared to Standard

Data Source: DoE Khulna, 2017

Figure 4.2: SO2 concentration Level Compared to Standard

Data Source: DoE Khulna, 2017

Figure 4.3: CO concentration Level Compared to Standard

Data Source: DoE Khulna, 2017

Figure 4.4: O3 Concentration Level Compared to Standard

Though the level of NO2, O3, SO2, CO is low in Khulna, Particulates matters is over the standard all the time except the rainy season. April to October is the time when the concentration is close to standard. But during October to March, the concentration is much higher.

Data Source: DoE Khulna, 2017

Figure 4.5: Coarse Particulates Concentration Compared to Standard

# METHODOLOGY

This study has been divided into 5 stages:

* Background Study
* Local Meteorological, Pollution and Tree Coverage Data Collection
* Analyzing Air Pollution Removal by Urban Trees in Khulna City
* Providing Recommendation Based on Findings
* Preparation of Model for Further Study

## Background Study

Background study was a significant part of this study. The background study started with the goal of understand tree service. But then the focus shifted and narrowed down to air pollutant removal by urban trees. Establishing methodology for the study was perhaps the most effort consuming part of this study. Due to data shortage and other limitations, changes had to be made to calculate some terms stated in UFORE-D model.

Understanding the terms, processes was another part of background study. The study deals with many complex terms related with multi-dimensional field.

### Literature Review

Literature review included review of journal articles, scholarly publications, books, websites etc. Though no literature on tree air pollution removal was been found in case of Bangladesh, there were rich international literature on related topics. Help has been drawn from many of these literatures which are referenced at the end of this report.

### Selection of UFORE-D Model

UFORE-D model is made by David J Nowak, who is a leading scholar in the field of tree air pollution removal studies. This is the most used and contemporary method to estimate tree air pollution removal. All most all the study on air pollution removal by urban tree found during literature review of this study follows methodology of UFORE-D Model. i-Tree Eco, a leading platform to study tree service follows this model to quantify air pollutant removal.

## Study Area Selection

The study area for this study is Khulna City Corporation.

* Coordinates & GIS Map
* Land use

## Local Meteorological, Pollution and Tree Coverage Data Collection

The local meteorological, pollution and tree cover data was collected from Khulna Environmental Department. The data is generated through CAMS project.

### CAMS - Continuous Air Monitoring Station

The Continues Air Monitoring Station is a project of Department of Environment funded by WB (World Bank). The first CAMS started operating in Dhaka Shangshad Bhaban in 2002. The other CAMS in Dhaka (BRAC) has been operating since 2008. A CAMS has also been operating in Chittagong since 2006 and two more in Khulna and Rajshahi since 2008.

The data for this study has been collected from the CAMS Khulna.

### Local Metrological and Pollution Data

Collected local pollution data included concentration of SO2, NO2, CO, O3, PM10, and PM2.5. Local metrological data included rainfall, wind speed and temperature.

Further data about percent cloud cover was collected from World Weather Online, an online platform of weather data.

## Analyzing Air Pollution Removal by Urban Trees in Khulna City

### UFORE-D Dry Deposition Model

The description of the model is detailed in sections below.

### Air Pollutant Flux Calculation for CO, NO2, SO2, O3 and PM10

Pollutant flux is calculated as a product of the deposition velocity and the air pollutant concentration.

Where,

*F* = Pollutant flux (gm-2h-1)

*Fmin* = Minimum pollutant flux (gm-2h-1)

*Fmax* = Maximum pollutant flux (gm-2h-1)

*Vd* = Deposition velocity (ms-1)

*Vd,min* = Minimum deposition velocity (ms-1)

*Vd,max* = Maximum deposition velocity (ms-1)

*C* = Air pollutant concentration (gm-3)

### Deposition Velocity Calculation for CO, NO2, SO2, O3

Deposition velocities (Vd) for CO, NO2, SO2 and O3 are calculated as the inverse of the sum of the aerodynamic resistance (Ra), quasi-laminar boundary layer resistance (Rb), and canopy resistance (Rc) (Baldocchi, Hicks, & Camara, 1987).

Where,

*Vd* = Deposition velocity (ms-1)

*Ra* = Aerodynamic resistance (sm-1)

*Rb* = Quasi-laminar boundary layer resistance for a type of air pollution (sm-1)

*Rc* = Canopy resistance (sm-1)

The minimum and maximum of Vd are estimated as follows (Lovett, 1994).

In daytime,

For NO2

*Vd,min* = 0.001

*Vd,max* = 0.005

For O3

*Vd,min* = 0.001

*Vd,max* = 0.008

For SO2

*Vd,min* = 0.002

*Vd,max* = 0.01

Else (in the nighttime)

*Vd,min* = Vd

*Vd,max* = Vd

### Deposition Velocity Calculation for PM10

Equation for deposition velocity of PM10:

Where,

*Vd,PM10,avg* = Average deposition velocity for PM10 = 0.0064ms-1 (Lovett, 1994)

*Vd,PM10,min* = Minimum deposition velocity for PM10 = 0.0025ms-1 (Lovett, 1994)

*Vd,PM10,max* = Maximum deposition velocity for PM10 = 0.01ms-1 (Lovett, 1994)

*LAIPM10* = Leaf area index for particle deposition = 6

*BAI* = Bark area index

*LAI* = Leaf area index

### Aerodynamic Resistance Calculation

The aerodynamic resistance (Ra) is calculated as (Killus, et al., 1984):

Where,

*u (z)* = Mean wind speed at height z (ms-1)

*u\** = Friction velocity (ms-1)

**Friction Velocity Calculation**

Depending on the stability of atmosphere (i.e. neutral, unstable, and stable), *u\** is described as below:

The stability of atmosphere can be determined by Monin-Obuhkov stability length, which can be empirically estimated based on the pasquill stability class.

Pasquill = A:

Where,

L = Monin-Obuhkov stability length

z0 = Roughness length

**For Neutral atmosphere (L=0)**

Where,

k = von Karman constant = 0.42

z = Mean wind speed at height z (ms-1)

d = displacement height (m)

**Unstable atmosphere (L<0)**

When the atmosphere is unstable, such as during daytime when the air convection occurs, *u\** is calculated as (Killus, et al., 1984).

Where,

*ψM*= Stability function for momentum

Stability function for momentum is calculated as (Ulden, A.P., & Holtlag, 1985).

Where *x* is calculated as (Dyer, A.J., & Bradley, 1982)

**Stable atmosphere:**

When the atmosphere is stable, u\* is calculated as (Venkatram & A, 1980):

Where,

*CDN* = Neutral drag coefficient (dimensionless)

*CDN* is calculated as (US EPA 1995)

*u0* is calculated as (US EPA 1995)

Where,

*βm* = Dimensionless constant = 4.7

*g* = Acceleration due to gravity = 9.81 ms-2

*T* = Air temperature (K)

*Θ\** is calculated as (US EPA 1995)

Where,

*N* = Fraction of opaque cloud cover

### Quasi-laminar Boundary Layer Resistance Calculation

Quasi-laminar boundary layer resistance (Rb) is calculated as (Pederson, et al., 1995):

*Sc* = Schmidt number

*Pr* = Prandtl number

### Canopy Resistance Calculation for CO

Removal of CO by vegetation is not directly related to transpiration, the canopy resistance for CO in in-leaf periods is set to a constant based on (Bidwell, R., & D., 1972)

### Canopy Resistance Calculation for NO2, O3 and SO2

The canopy resistances for NO2, O3, and SO2 can be calculated as:

Where,

*rs* = Stomatal resistance

*rm* = Mesophyll resistance

*rsoil* = Soil resistance

*rt* = Cuticular resistance

### Air Quality Improvement Calculation

**Hourly air quality improvement in city**

Hourly air quality improvement per unit tree cover due to dry deposition of air pollutants,

Where,

F = Pollutant flux (gm-2h-1)

Mtotal = Total air pollutant mass per unit tree cover (gm-2h-1)

H = Urban mixing height (m)

C = Air pollutant concentration (gm-3h-1)

Hourly air quality improvement for total tree cover, Itotal (%) is calculated as:

Where,

Tc = Total tree cover in the city (%)

**Air pollution concentration change calculation**

Change in air pollutant concentration can be calculated as

Where,

∆C = Air pollutant concentration change (ppm for CO, NO2, SO2 and O3 and µgm-3 for PM10 and PM2.5)

C = Air pollutant concentration (ppm for CO, NO2, SO2 and O3 and µgm-3 for PM10 and PM2.5)

### Calculation of Urban Mixing Height

Usually Sound Wave technology is used to determine mixing height by weather department. But no study has been done to determine mixing height in Bangladesh.

To calculate mixing height, this study follows method specified in (Benarie, 1975).

Were,

χ = annual mean pollutant concentration, averaged over the whole area, g/m3

S = surface m2

L = total annual wind path over the area = 365\*86400m

U = the mean surface wind velocity ms-1

H = mixing height

E = integral source strength, the pollution emission

### Calculation of Total Tree Cover in Khulna City

The tree cover of Khulna City Corporation was determined by Global Forest Watch. The data of global forest watch is produced by collaboration of renowned scientist and corporations like Hansen, Google and NASA. The data of global forest watch is used in scholarly articles, by UN, in Google Earth platform etc. Thus this study chooses data of global forest watch data rather than determining tree cover with Remote Sensing technology.

Global forest watch uses Landsat NDVI image data from 2001 to 2015 to calculate forest cover. The data resolution is 30m, which can result in less accurate results in small area. Sentinel 2 data provides 10m resolution data for our study area. But the only the data between 2015 to 2017 may is available for use. The pollution data used in this study ranges from 2013 to 2015. Thus Sentinel data can’t be used for the study. Thus the study uses Global Forest Watch data instead of applying remote sensing.

Global Forest Watch (GFW) is an interactive online forest monitoring and alert system designed to empower people everywhere with the information they need to better manage and conserve forest landscapes. Global Forest Watch uses cutting edge technology and science to provide the timeliest and most precise information about the status of forest landscapes worldwide, including near-real-time alerts showing suspected locations of recent tree cover loss. GFW is free and simple to use, enabling anyone to create custom maps, analyze forest trends, subscribe to alerts, or download data for their local area or the entire world (GFW, 2017).

### Monetary Value Calculation of Removed Pollution

Monetary value of pollution removal by trees is estimated using the median externality values for the United States for each pollutant (Murray, F., L., & P.A., 1994) (Ottinger, et al., 1990) adjusted to 2007 dollars based on the producer price index (US Dept. of Labor 2008). The externality values are: CO=$1,407/t, NO2=$9,906/t, PM10=$6,614/t, SO2=$2425/t. Externality value for O3 was set to equal the value for NO2.

## Providing Recommendation Based on Findings

After analysis, the results were discussed and recommendations were provided accordingly. As urban air pollution isn’t a local context, discussion incorporated case of other cities of Bangladesh.

## Preparation of Model for Further Study

As data shortage and other limitations makes Bangladesh unsuitable for i-Tree Eco platform, a methodological and calculation model has been prepared to make further study on this topic much more convenient. The goal of this part was to create a model that acknowledges the limitations, thus provide possible methodology and data requirements. Inputting data in the model will calculate results with much more convenience, which this study didn’t had.

## Schematic Diagram of Work Methodology

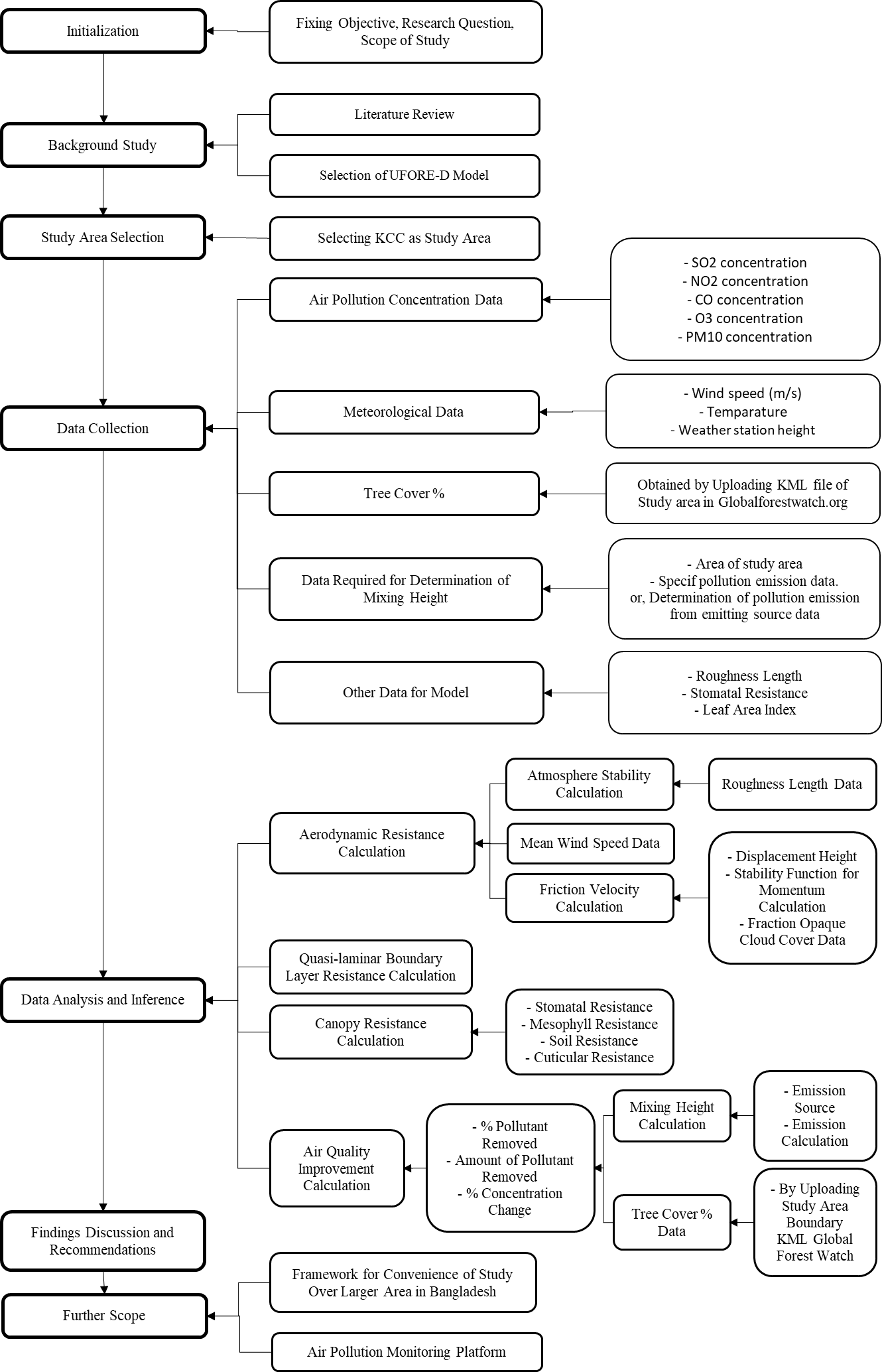


Figure 5.1: Schematic Diagram of the Workflow

# AIR POLLUTION REMOVAL BY URBAN TREES IN KHULNA CITY

## Aerodynamic Resistance Calculation

The aerodynamic resistance (Ra) is calculated as (Killus, et al., 1984):

Here,

Roughness length z0 is set as 2 from literature (Dorman & Sellers, 1989).

The data of mean wind speed at height z was collected from Department of Environment, Khulna. The source of data is CAMS project of DoE Bangladesh.

The height of weather station, z which is 9.75 m.

Displacement height or the zero plane displacement height of a vegetated surface is the height at which the is the height at which the wind speed would go to zero if the logarithmic wind profile was maintained from the outer flow all the way down to the surface.

d = 0.67\*canopy height.

For this study, average canopy height was set as 12 m.

Thus d = 8.04 m.

**Stability of atmosphere of study area**

As value of L is negative, so the atmosphere of study area is unstable. Thus, *u\** is calculated as (Killus, et al., 1984):

Where *x* is calculated as (Dyer, A.J., & Bradley, 1982)

Stability function for momentum is calculated as (Ulden, A.P., & Holtlag, 1985)

The value of aerodynamic resistance is same for all pollutants. The calculated value is given below.

Table 6.1: Results of Aerodynamic Resistance for all Pollutants

|  |  |  |  |
| --- | --- | --- | --- |
| **Month** | **Ra (sm-1)** | **u(z)** | **u\*** |
| Dec, 12 | 4.178671 | 2.7 | 0.808258 |
| Jan, 13 | 4.083397 | 2.8 | 0.827116 |
| Feb, 13 | 4.085494 | 2.8 | 0.826692 |
| Mar, 13 | 4.096483 | 2.8 | 0.824474 |
| Apr, 13 | 4.082918 | 2.8 | 0.827213 |
| May, 13 | 1.298175 | 8.8 | 2.601686 |
| Jun, 13 | 1.719432 | 6.6 | 1.964279 |
| Jul, 13 | 1.335442 | 8.5 | 2.529084 |
| Aug, 13 | 1.402436 | 8.1 | 2.40827 |
| Sep, 13 | 1.787057 | 6.4 | 1.889948 |
| Oct, 13 | 2.126762 | 5.4 | 1.588069 |
| Nov, 13 | 4.387357 | 2.6 | 0.769813 |
| Dec, 13 | 4.752971 | 2.4 | 0.710596 |
| Jan, 14 | 3.933493 | 2.9 | 0.858637 |
| Feb, 14 | 4.562852 | 2.5 | 0.740205 |
| Mar, 14 | 4.073975 | 2.8 | 0.829029 |
| Nov, 14 | 5.703565 | 2.0 | 0.592164 |
| Dec, 14 | 4.842538 | 2.4 | 0.697453 |
| Jan, 15 | 4.224863 | 2.7 | 0.799421 |
| Feb, 15 | 4.073975 | 2.8 | 0.829029 |
| Mar,15 | 3.564728 | 3.2 | 0.947462 |
| Apr, 15 | 2.376485 | 4.8 | 1.421193 |
| May, 15 | 1.83986 | 6.2 | 1.835708 |
| Jun, 15 | 1.933412 | 5.9 | 1.746883 |
| Jul, 15 | 2.924905 | 3.9 | 1.154719 |

Th value of Aerodynamic resistance depends on wind speed, displacement height, roughness length. Thus the value changes with time. The value is used to calculate pollutant flux.

## Quasi-laminar Boundary Layer Resistance Calculation

Quasi-laminar boundary layer resistance (Rb) is calculated as (Pederson, et al., 1995):

Where,

*Sc* = Schmidt number = 1 for O3

0.76 for CO

0.98 for NO2

` 1.15 for SO2

*Pr* = Prandtl number = 0.72

The value of u\* is taken from calculation of aerodynamic resistance.

Table 6.2: Results of Quasi-Laminar Boundary Layer Resistance

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | Rb (sm-1) | | | |
| **NO2** | **O3** | **SO2** | **CO** |
| Dec, 12 | 4.783383 | 4.848244 | 5.321692 | 4.037633 |
| Jan, 13 | 4.674322 | 4.737704 | 5.200357 | 3.945575 |
| Feb, 13 | 4.676722 | 4.740137 | 5.203027 | 3.947601 |
| Mar, 13 | 4.689301 | 4.752886 | 5.217022 | 3.958219 |
| Apr, 13 | 4.673773 | 4.737147 | 5.199746 | 3.945112 |
| May, 13 | 1.48604 | 1.50619 | 1.653274 | 1.25436 |
| Jun, 13 | 1.968258 | 1.994947 | 2.18976 | 1.661398 |
| Jul, 13 | 1.528699 | 1.549427 | 1.700734 | 1.290368 |
| Aug, 13 | 1.605388 | 1.627156 | 1.786053 | 1.355101 |
| Sep, 13 | 2.045669 | 2.073408 | 2.275883 | 1.726741 |
| Oct, 13 | 2.434534 | 2.467545 | 2.708509 | 2.05498 |
| Nov, 13 | 5.02227 | 5.090369 | 5.587461 | 4.239276 |
| Dec, 13 | 5.440792 | 5.514567 | 6.053083 | 4.592549 |
| Jan, 14 | 4.502724 | 4.56378 | 5.009448 | 3.80073 |
| Feb, 14 | 5.22316 | 5.293984 | 5.81096 | 4.408847 |
| Mar, 14 | 4.663536 | 4.726772 | 5.188357 | 3.936471 |
| Nov, 14 | 6.52895 | 6.61748 | 7.2637 | 5.511059 |
| Dec, 14 | 5.543321 | 5.618486 | 6.16715 | 4.679093 |
| Jan, 15 | 4.83626 | 4.901837 | 5.380518 | 4.082266 |
| Feb, 15 | 4.663536 | 4.726772 | 5.188357 | 3.936471 |
| Mar,15 | 4.080594 | 4.135925 | 4.539812 | 3.444412 |
| Apr, 15 | 2.720396 | 2.757283 | 3.026542 | 2.296275 |
| May, 15 | 2.106113 | 2.134671 | 2.343129 | 1.777761 |
| Jun, 15 | 2.213204 | 2.243214 | 2.462271 | 1.868156 |
| Jul, 15 | 3.34818 | 3.39358 | 3.724974 | 2.826184 |

Quasi-Laminar boundary layer is calculated using value obtained from Aerodynamic layer calculation and some other constants. This also changes with time and is required to calculate pollution flux.

## Canopy Resistance Calculation

Removal of CO by vegetation is not directly related to transpiration, the canopy resistance for CO in in-leaf periods is set to a constant based on (Bidwell, R., & D., 1972)

The canopy resistances for NO2, O3, and SO2 can be calculated as:

Where,

*rs* = Stomatal resistance

*rm* = Mesophyll resistance

*rsoil* = Soil resistance = 2941 sm-1 in growing season

= 2000 sm-1 otherwise

*rt* = Cuticular resistance

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **NO2** | **O3** | **SO2** |
| rm | 100 sm-1 (Hosker, Jr., R., & S., 1982) | 10 sm-1 (Hosker, Jr., R., & S., 1982) | 0 sm-1 (Wesely & M., 1989) |
| rt | 20,000 sm-1 (Wesely & M., 1989) | 20,000 sm-1 (Taylor, et al., 1988)(Lovett, 1994) | 8,000 sm-1 (Taylor, et al., 1988)(Lovett, 1994) |

**Stomatal resistance calculation**

The value of stomatal resistance changes with tree type (evergreen, deciduous, broadleaf, needle leaf etc.), season etc.

Table 6.3: Results for Canopy Resistance of Different Pollutants

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | **Rc (sm-1)** | | | |
| **NO2** | **O3** | **SO2** | **CO** |
| Dec, 12 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Jan, 13 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Feb, 13 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Mar, 13 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Apr, 13 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| May, 13 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Jun, 13 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Jul, 13 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Aug, 13 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Sep, 13 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Oct, 13 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Nov, 13 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Dec, 13 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Jan, 14 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Feb, 14 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Mar, 14 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Nov, 14 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Dec, 14 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Jan, 15 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Feb, 15 | 257.5107 | 186.5009 | 177.7778 | 50000 |
| Mar,15 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Apr, 15 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| May, 15 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Jun, 15 | 268.5751 | 192.2365 | 182.9819 | 50000 |
| Jul, 15 | 268.5751 | 192.2365 | 182.9819 | 50000 |

The value of stomatal resistance is determined by considering the prominent tree species of the area. The average value of stomatal resistance is similar through the year and the value is 200 sm-1 (Dorman & Sellers, 1989).

## Air pollutant Flux and Deposition Velocity Calculation

Deposition velocity for CO, NO2, SO2 and O3 (Baldocchi, Hicks, & Camara, 1987):

Deposition velocity of PM10:

Where,

*Vd,PM10,avg* = Average deposition velocity for PM10 = 0.0064ms-1 (Lovett, 1994)

*BAI* = Bark area index = 1.7

*LAI* = Leaf area index = 5

*LAIPM10* = Leaf area index for particle deposition = 6

Pollutant flux is calculated as a product of the deposition velocity and the air pollutant concentration.

Table 6.4: Results of Pollutant Flux and Deposition Velocities

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Month** | **Pollutant flux** | | | | | **Deposition velocity** | | | | |
| **NO2** | **O3** | **SO2** | **CO** | **PM10** | **NO2** | **O3** | **SO2** | **CO** | **PM10** |
| Dec, 12 | 0.30 | 0.06 | 0.04 | 0.22 | 3380.90 | 0.0038 | 0.0051 | 0.0021 | 0.00002 | 0.0056 |
| Jan, 13 | 0.29 | 0.12 | 0.03 | 0.27 | 2797.01 | 0.0038 | 0.0051 | 0.0015 | 0.00002 | 0.0056 |
| Feb, 13 | 0.23 | 0.18 | 0.04 | 0.16 | 1939.40 | 0.0038 | 0.0051 | 0.0021 | 0.00002 | 0.0056 |
| Mar, 13 | 0.24 | 0.18 | 0.04 | 0.16 | 1309.81 | 0.0036 | 0.0050 | 0.0023 | 0.00002 | 0.0056 |
| Apr, 13 | 0.24 | 0.21 | 0.04 | 0.10 | 1571.14 | 0.0036 | 0.0050 | 0.0020 | 0.00002 | 0.0056 |
| May, 13 | 0.30 | 0.16 | 0.04 | 0.11 | 988.98 | 0.0037 | 0.0051 | 0.0022 | 0.00002 | 0.0056 |
| Jun, 13 | 0.32 | 0.11 | 0.04 | 0.09 | 1016.36 | 0.0037 | 0.0051 | 0.0019 | 0.00002 | 0.0056 |
| Jul, 13 | 0.25 | 0.09 | 0.05 | 0.08 | 2262.79 | 0.0037 | 0.0051 | 0.0024 | 0.00002 | 0.0056 |
| Aug, 13 | 0.26 | 0.07 | 0.33 | 0.07 | 1626.45 | 0.0037 | 0.0051 | 0.0168 | 0.00002 | 0.0056 |
| Sep, 13 | 0.32 | 0.05 | 0.59 | 0.08 | 5118.74 | 0.0037 | 0.0051 | 0.0307 | 0.00002 | 0.0056 |
| Oct, 13 | 0.14 | 0.03 | 0.06 | 0.08 | 7632.10 | 0.0038 | 0.0052 | 0.0032 | 0.00002 | 0.0056 |
| Nov, 13 | 0.15 | 0.07 | 0.18 | 0.09 | 7408.68 | 0.0037 | 0.0051 | 0.0093 | 0.00002 | 0.0056 |
| Dec, 13 | 0.21 | 0.05 | 0.14 | 0.10 | 6343.99 | 0.0037 | 0.0051 | 0.0071 | 0.00002 | 0.0056 |
| Jan, 14 | 0.20 | 0.03 | 0.14 | 0.09 | 5014.44 | 0.0038 | 0.0051 | 0.0072 | 0.00002 | 0.0056 |
| Feb, 14 | 0.19 | 0.11 | 0.08 | 0.06 | 391.00 | 0.0037 | 0.0051 | 0.0041 | 0.00002 | 0.0056 |
| Mar, 14 | 0.18 | 0.17 | 0.08 | 0.04 | 893.20 | 0.0036 | 0.0050 | 0.0044 | 0.00002 | 0.0056 |
| Nov, 14 | 0.17 | 0.07 | 0.05 | 0.04 | 1140.95 | 0.0037 | 0.0050 | 0.0028 | 0.00002 | 0.0056 |
| Dec, 14 | 0.17 | 0.04 | 0.08 | 0.03 | 777.73 | 0.0037 | 0.0051 | 0.0042 | 0.00002 | 0.0056 |
| Jan, 15 | 0.16 | 0.09 | 0.19 | 0.05 | 875.80 | 0.0038 | 0.0051 | 0.0100 | 0.00002 | 0.0056 |
| Feb, 15 | 0.15 | 0.15 | 0.24 | 0.05 | 588.69 | 0.0038 | 0.0051 | 0.0124 | 0.00002 | 0.0056 |
| Mar,15 | 0.14 | 0.21 | 0.23 | 0.04 | 926.09 | 0.0036 | 0.0050 | 0.0122 | 0.00002 | 0.0056 |
| Apr, 15 | 0.13 | 0.23 | 0.28 | 0.04 | 731.21 | 0.0037 | 0.0051 | 0.0149 | 0.00002 | 0.0056 |
| May, 15 | 0.13 | 0.12 | 0.27 | 0.02 | 1176.14 | 0.0037 | 0.0051 | 0.0140 | 0.00002 | 0.0056 |
| Jun, 15 | 0.12 | 0.10 | 0.29 | 0.02 | 3380.90 | 0.0037 | 0.0051 | 0.0149 | 0.00002 | 0.0056 |
| Jul, 15 | 0.11 | 0.08 | 0.31 | 0.03 | 2797.01 | 0.0036 | 0.0050 | 0.0161 | 0.00002 | 0.0056 |

This table combines the calculated pollutant flux and depositional velocity values for different pollutants that is obtained from values of Aerodynamic Resistance, Quasi-Laminar Boundary layer resistance and Canopy resistance. These values are required to determine pollution removal by trees.

## Air Quality Improvement Calculation

Hourly air quality improvement per unit tree cover due to dry deposition of air pollutants,

Hourly air quality improvement for total tree cover, Itotal (%) is calculated as:

Change in air pollutant concentration can be calculated as

Area of Khulna City Corporation is 37036830 m2 (KCC, 2017).

Total pollution of the area is the product of area (m2), mixing height (m) and concentration (gm-3h-1).

### Calculation of Urban Mixing Height

To calculate total Sulfur emission, this study has selected brick kilns around Khulna as the source of Sulfur pollution. Among the Sulfur polluting sources described in Table 4-2, only brick kilns are present around Khulna City Corporation.

According to DoE, Khulna:

There are 142 brick kilns in around Khulna City Corporation

% Sulphur in Indian coal used as fuel in brick kilns: 0.41

Average brick produced in a brick kiln 45 lakhs

Average coal necessary for production of each lakh brick: 15 ton

Atomic weigh of S = 32

Atomic weigh of O2 = 32

Atomic weigh of SO2 = 64

So 32 gm. of S is produce 64 gm. SO2.

1 gm. S produce 64/32 gm. SO2

(142 \* 45 \* 15 \* 1016047 \* 0.41) gm. S produce 79858246059 gm. SO2

So, the average yearly mixing height of Khulna is 572.77 m

### Calculation of Total Tree Cover in Khulna city

To get the tree cover value for Khulna, upload shape option was chosen from GFW Interactive Map. A KML file of KCC boundary was uploaded to analyze the tree cover. The result showed that the total tree cover in Khulna is 288 ha (

Table 6.5: Tree Cover in Different Wards of Khulna

|  |  |  |  |
| --- | --- | --- | --- |
| **Ward No.** | **Total Area (ha)** | **Tree Cover (ha)** | **%Tree Cover** |
| 01 | 194.00 | 73.00 | 37.62 |
| 02 | 217.00 | 10.00 | 4.60 |
| 03 | 383.00 | 41.00 | 10.70 |
| 04 | 202.00 | 40.00 | 19.80 |
| 05 | 80.00 | 16.00 | 20.00 |
| 06 | 222.00 | 13.00 | 5.85 |
| 07 | 46.00 | 0.00 | 0.00 |
| 08 | 96.00 | 3.71 | 3.86 |
| 09 | 362.00 | 16.00 | 4.42 |
| 10 | 84.00 | 0.74 | 0.88 |
| 11 | 38.00 | 0.00 | 0.00 |
| 12 | 69.00 | 0.00 | 0.00 |
| 13 | 119.00 | 2.23 | 1.87 |
| 14 | 273.00 | 18.00 | 6.59 |
| 15 | 144.00 | 2.97 | 2.06 |
| 16 | 232.00 | 8.17 | 3.52 |
| 17 | 26.00 | 4.46 | 17.15 |
| 18 | 164.00 | 2.23 | 1.36 |
| 19 | 50.00 | 0.75 | 1.50 |
| 20 | 49.00 | 0.00 | 0.00 |
| 21 | 137.00 | 0.00 | 0.00 |
| 22 | 68.00 | 0.74 | 1.09 |
| 23 | 51.00 | 0.00 | 0.00 |
| 24 | 155.00 | 2.23 | 1.44 |
| 25 | 75.00 | 2.97 | 3.96 |
| 26 | 67.00 | 0.74 | 1.10 |
| 27 | 84.00 | 0.00 | 0.00 |
| 28 | 74.00 | 6.69 | 9.04 |
| 29 | 66.00 | 0.00 | 0.00 |
| 30 | 120.00 | 2.97 | 2.47 |
| 31 | 377.00 | 19.00 | 5.04 |
| **Total KCC** | 5324 | 287.6 | Average: 5.3% |

Source: Analysis of Global Forest Watch Data, 2017

Some of values of this analysis shows there is no tree cover in some of the ward. The data source of Landsat image with resolution of 30m. Thus single standing trees, or insignificant amount of trees in ward with high buildup area is being neglected by the tree cover calculation. Though there is some minor percentage of tree cover in those wards, their percent contribution in pollution removal of whole KCC area is insignificant. Thus the limitation of data source doesn’t affect results in significant ways.

### Removal of NO2

Table 6.6: Calculated Results of NO2 Removal

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Month** | **∆C (ppm)** | **Pollution removed (Kg.)** | **Itotal (%)** | **Total pollution (Ton)** |
| Dec, 12 | 0.00003 | 704.945.84 | 0.149 | 471.3 |
| Jan, 13 | 0.00003 | 687.1 | 0.149 | 459.1 |
| Feb, 13 | 0.00003 | 539.6 | 0.149 | 360.5 |
| Mar, 13 | 0.00003 | 561.5 | 0.143 | 390.8 |
| Apr, 13 | 0.00003 | 556.0 | 0.143 | 386.9 |
| May, 13 | 0.00003 | 708.3 | 0.146 | 482.3 |
| Jun, 13 | 0.00004 | 757.5 | 0.146 | 517.5 |
| Jul, 13 | 0.00003 | 582.0 | 0.146 | 396.4 |
| Aug, 13 | 0.00003 | 606.0 | 0.146 | 413.0 |
| Sep, 13 | 0.00004 | 760.0 | 0.146 | 519.5 |
| Oct, 13 | 0.00002 | 319.6 | 0.152 | 210.2 |
| Nov, 13 | 0.00002 | 356.9 | 0.149 | 239.0 |
| Dec, 13 | 0.00002 | 482.6 | 0.148 | 324.1 |
| Jan, 14 | 0.00002 | 467.4 | 0.149 | 311.9 |
| Feb, 14 | 0.00002 | 446.7 | 0.149 | 299.6 |
| Mar, 14 | 0.00002 | 413.0 | 0.143 | 287.4 |
| Nov, 14 | 0.00002 | 406.4 | 0.147 | 275.1 |
| Dec, 14 | 0.00002 | 391.0 | 0.148 | 262.8 |
| Jan, 15 | 0.00002 | 374.6 | 0.149 | 250.6 |
| Feb, 15 | 0.00002 | 356.7 | 0.149 | 238.3 |
| Mar,15 | 0.00002 | 326.1 | 0.144 | 226.0 |
| Apr, 15 | 0.00001 | 311.3 | 0.145 | 213.8 |
| May, 15 | 0.00001 | 294.7 | 0.146 | 201.5 |
| Jun, 15 | 0.00001 | 276.5 | 0.146 | 189.2 |
| Jul, 15 | 0.00001 | 256.6 | 0.145 | 177.0 |

Total amount of NO2removed by urban trees in 7 months of 2015 by urban trees is 2.16 tons. The value (derived from externalities value) of per ton NO2 for 2007 $9906 (Murray, F., L., & P.A., 1994). That makes the value of removed NO2 is $ 25703.22 (inflation adjusted for 2015). In direct conversion in current rate (4th May, 2017) of BDT, the value is BDT 2,097,383.13. However, if we calculated with PPP in 2015, the value is BDT 724,830.93.

Table 6.7: NO2 Removal in 31 Wards of KCC

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Ward No.** | **Avg. Concentration Change (%)** | **Avg. Tons** | **Avg. $ Value** | **Avg. Taka Value** | **Avg. PPP Taka Value** |
| 1 | 0.00013 | 0.14491 | 1723 | 140558 | 48575 |
| 2 | 0.00002 | 0.02000 | 238 | 19402 | 6705 |
| 3 | 0.00004 | 0.08189 | 973 | 79436 | 27452 |
| 4 | 0.00007 | 0.07973 | 948 | 77336 | 26726 |
| 5 | 0.00007 | 0.03189 | 379 | 30933 | 10690 |
| 6 | 0.00002 | 0.02600 | 309 | 25215 | 8714 |
| 7 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 8 | 0.00001 | 0.00742 | 88 | 7199 | 2488 |
| 9 | 0.00002 | 0.03201 | 380 | 31045 | 10729 |
| 10 | 0.00000 | 0.00148 | 18 | 1437 | 497 |
| 11 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 12 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 13 | 0.00001 | 0.00446 | 53 | 4329 | 1496 |
| 14 | 0.00002 | 0.03599 | 428 | 34908 | 12064 |
| 15 | 0.00001 | 0.00594 | 71 | 5766 | 1993 |
| 16 | 0.00001 | 0.01635 | 194 | 15856 | 5479 |
| 17 | 0.00006 | 0.00890 | 106 | 8628 | 2982 |
| 18 | 0.00000 | 0.00446 | 53 | 4330 | 1496 |
| 19 | 0.00001 | 0.00150 | 18 | 1456 | 503 |
| 20 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 21 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 22 | 0.00000 | 0.00148 | 18 | 1437 | 497 |
| 23 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 24 | 0.00001 | 0.00446 | 53 | 4330 | 1496 |
| 25 | 0.00001 | 0.00594 | 71 | 5763 | 1992 |
| 26 | 0.00000 | 0.00148 | 18 | 1437 | 497 |
| 27 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 28 | 0.00003 | 0.01337 | 159 | 12967 | 4481 |
| 29 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 30 | 0.00001 | 0.00594 | 71 | 5765 | 1992 |
| 31 | 0.00002 | 0.03800 | 452 | 36860 | 12738 |
| **Total KCC** | 0.00002 | 0.47023 | 5590 | 456122 | 157630 |

The results of NO2 removal shows that wards with higher amount of tree cover has more NO2 removed from air. However, the percent pollution removal is small.

### Removal of O3

Table 6.8: Results of O3 Removal

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Month** | **∆C (ppm)** | **Pollution removed (Kg.)** | **Itotal (%)** | **Total pollution (Tons)** |
| Dec, 12 | 0.00001 | 132.2 | 0.20 | 64.91 |
| Jan, 13 | 0.00001 | 284.8 | 0.20 | 139.6 |
| Feb, 13 | 0.00002 | 422.9 | 0.20 | 207.4 |
| Mar, 13 | 0.00002 | 416.7 | 0.20 | 210.3 |
| Apr, 13 | 0.00002 | 488.7 | 0.20 | 246.6 |
| May, 13 | 0.00002 | 382.4 | 0.20 | 187.3 |
| Jun, 13 | 0.00001 | 251.7 | 0.20 | 123.8 |
| Jul, 13 | 0.00001 | 217.4 | 0.20 | 106.50 |
| Aug, 13 | 0.00001 | 174.7 | 0.20 | 85.6 |
| Sep, 13 | 0.00001 | 118.4 | 0.20 | 58.2 |
| Oct, 13 | 0.00000 | 72.0 | 0.21 | 34.5 |
| Nov, 13 | 0.00001 | 171.8 | 0.20 | 84.5 |
| Dec, 13 | 0.00001 | 128.5 | 0.20 | 63.4 |
| Jan, 14 | 0.00000 | 77.8 | 0.20 | 38.1 |
| Feb, 14 | 0.00001 | 261.8 | 0.20 | 129.0 |
| Mar, 14 | 0.00002 | 389.9 | 0.20 | 196.8 |
| Nov, 14 | 0.00001 | 166.0 | 0.20 | 82.9 |
| Dec, 14 | 0.00000 | 97.3 | 0.20 | 48.1 |
| Jan, 15 | 0.00001 | 217.2 | 0.20 | 106.7 |
| Feb, 15 | 0.00002 | 342.4 | 0.20 | 167.9 |
| Mar,15 | 0.00002 | 481.8 | 0.20 | 241.8 |
| Apr, 15 | 0.00003 | 533.1 | 0.20 | 264.1 |
| May, 15 | 0.00001 | 284.0 | 0.20 | 139.9 |
| Jun, 15 | 0.00001 | 228.5 | 0.20 | 112.7 |
| Jul, 15 | 0.00001 | 186.7 | 0.20 | 93.1 |

Total amount of O3removed by urban trees in 7 months of 2015 by urban trees is 2.24 tons. The value (derived from externalities value) of per ton O3 for 2007 $9906 (Murray, F., L., & P.A., 1994). That makes the value of removed O3 is $26605.86 (inflation adjusted for 2015). In direct conversion in current rate (4th May, 2017) of BDT, the value is BDT 2,171,038.41. However, if we calculated with PPP in 2015, the value is BDT 750,285.33.

Table 6.9: O3 Removal in 31 Wards of KCC

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Ward No.** | **Avg. Concentration Change (%)** | **Avg. Pollution Removed (tons)** | **Avg. $ Value** | **Avg. Taka Value** | **Avg. PPP Taka Value** |
| 1 | 0.00007 | 0.07901 | 939 | 76638 | 26485 |
| 2 | 0.00001 | 0.01094 | 130 | 10609 | 3666 |
| 3 | 0.00002 | 0.04475 | 532 | 43411 | 15002 |
| 4 | 0.00004 | 0.04354 | 518 | 42231 | 14594 |
| 5 | 0.00004 | 0.01741 | 207 | 16891 | 5837 |
| 6 | 0.00001 | 0.01421 | 169 | 4764 | 4764 |
| 7 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 8 | 0.00001 | 0.00406 | 48 | 1360 | 1360 |
| 9 | 0.00001 | 0.01750 | 208 | 5866 | 5866 |
| 10 | 0.00000 | 0.00081 | 10 | 272 | 272 |
| 11 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 12 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 13 | 0.00000 | 0.00244 | 29 | 818 | 818 |
| 14 | 0.00001 | 0.01967 | 234 | 6595 | 6595 |
| 15 | 0.00000 | 0.00325 | 39 | 1090 | 1090 |
| 16 | 0.00001 | 0.00894 | 106 | 2996 | 2996 |
| 17 | 0.00003 | 0.00486 | 58 | 1629 | 1629 |
| 18 | 0.00000 | 0.00244 | 29 | 818 | 818 |
| 19 | 0.00000 | 0.00082 | 10 | 275 | 275 |
| 20 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 21 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 22 | 0.00000 | 0.00081 | 10 | 272 | 272 |
| 23 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 24 | 0.00000 | 0.00244 | 29 | 818 | 818 |
| 25 | 0.00001 | 0.00000 | 39 | 1089 | 1089 |
| 26 | 0.00000 | 0.00081 | 10 | 272 | 272 |
| 27 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 28 | 0.00002 | 0.00731 | 87 | 2449 | 2449 |
| 29 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 30 | 0.00000 | 0.00325 | 39 | 1090 | 1090 |
| 31 | 0.00001 | 0.02078 | 247 | 6965 | 6965 |
| **Total KCC** | 0.00001 | 0.25707 | 3056 | 249361 | 86176 |

The results of O3 removal shows that wards with higher amount of tree cover has more O3 removed from air.

### Removal of SO2

Table 6.10: Results of SO2 Removal

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Month** | **∆C (ppm)** | **Pollution removed (Kg.)** | **Itotal (%)** | **Total pollution (Tons)** |
| Dec, 12 | 0.000005 | 96.7 | 0.212659 | 45.4 |
| Jan, 13 | 0.000003 | 68.6 | 0.212905 | 32.2 |
| Feb, 13 | 0.000004 | 93.8 | 0.2129 | 44.0 |
| Mar, 13 | 0.000005 | 100.0 | 0.207122 | 48.2 |
| Apr, 13 | 0.000004 | 87.9 | 0.207155 | 42.4 |
| May, 13 | 0.000005 | 98.7 | 0.214194 | 46.1 |
| Jun, 13 | 0.000004 | 87.7 | 0.213099 | 41.1 |
| Jul, 13 | 0.000005 | 109.5 | 0.214097 | 51.1 |
| Aug, 13 | 0.000036 | 763.8 | 0.213922 | 357.0 |
| Sep, 13 | 0.000065 | 1385.1 | 0.212924 | 650.4 |
| Oct, 13 | 0.000007 | 147.3 | 0.21808 | 67.5 |
| Nov, 13 | 0.000020 | 416.9 | 0.212123 | 196.5 |
| Dec, 13 | 0.000015 | 319.4 | 0.21119 | 151.2 |
| Jan, 14 | 0.000015 | 326.4 | 0.213293 | 153.0 |
| Feb, 14 | 0.000009 | 182.2 | 0.211674 | 86.1 |
| Mar, 14 | 0.000009 | 191.3 | 0.207177 | 92.3 |
| Nov, 14 | 0.000006 | 123.5 | 0.208802 | 59.1 |
| Dec, 14 | 0.000009 | 190.1 | 0.210963 | 90.1 |
| Jan, 15 | 0.000021 | 449.8 | 0.21254 | 211.6 |
| Feb, 15 | 0.000026 | 559.3 | 0.212929 | 262.6 |
| Mar,15 | 0.000025 | 538.1 | 0.20843 | 258.1 |
| Apr, 15 | 0.000032 | 668.7 | 0.211412 | 316.3 |
| May, 15 | 0.000030 | 631.1 | 0.212788 | 296.5 |
| Jun, 15 | 0.000032 | 671.7 | 0.212547 | 316.0 |
| Jul, 15 | 0.000034 | 719.4 | 0.210025 | 342.5 |

Total amount of SO2removed by urban trees in 7 months of 2015 by urban trees is 4.17 tons. The value (derived from externalities value) of per ton SO2 for 2007 $2425 (Murray, F., L., & P.A., 1994). That makes the value of removed SO2 is $12139.00 (inflation adjusted for 2015). In direct conversion in current rate (4th May, 2017) of BDT, the value is BDT 990,542.64. However, if we calculated with PPP in 2015, the value is BDT 342,319.88.

Table 6.11: SO2 Removal in 31 Wards of KCC

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Ward No.** | **Avg. Concentration Change (%)** | **Tons** | **Avg. $ Value** | **Avg. Taka Value** | **Avg. PPP Taka Value** |
| 1 | 0.000101 | 0.10918 | 318 | 25926 | 8960 |
| 2 | 0.000012 | 0.01512 | 44 | 3591 | 1241 |
| 3 | 0.000029 | 0.06187 | 180 | 14692 | 5077 |
| 4 | 0.000053 | 0.06018 | 175 | 14290 | 4938 |
| 5 | 0.000054 | 0.02407 | 70 | 5716 | 1975 |
| 6 | 0.000016 | 0.01965 | 57 | 4666 | 1612 |
| 7 | 0.000000 | 0.00000 | 0 | 0 | 0 |
| 8 | 0.000010 | 0.00561 | 16 | 1332 | 460 |
| 9 | 0.000012 | 0.02420 | 70 | 5745 | 1986 |
| 10 | 0.000002 | 0.00112 | 3 | 266 | 92 |
| 11 | 0.000000 | 0.00000 | 0 | 0 | 0 |
| 12 | 0.000000 | 0.00000 | 0 | 0 | 0 |
| 13 | 0.000005 | 0.00338 | 10 | 801 | 277 |
| 14 | 0.000018 | 0.02720 | 79 | 6459 | 2232 |
| 15 | 0.000006 | 0.00449 | 13 | 1067 | 369 |
| 16 | 0.000009 | 0.01236 | 36 | 2935 | 1014 |
| 17 | 0.000046 | 0.00672 | 20 | 1595 | 551 |
| 18 | 0.000004 | 0.00338 | 10 | 802 | 277 |
| 19 | 0.000004 | 0.00114 | 3 | 270 | 93 |
| 20 | 0.000000 | 0.00000 | 0 | 0 | 0 |
| 21 | 0.000000 | 0.00000 | 0 | 0 | 0 |
| 22 | 0.000003 | 0.00112 | 3 | 266 | 92 |
| 23 | 0.000000 | 0.00000 | 0 | 0 | 0 |
| 24 | 0.000004 | 0.00338 | 10 | 802 | 277 |
| 25 | 0.000011 | 0.00449 | 13 | 1067 | 369 |
| 26 | 0.000003 | 0.00112 | 3 | 266 | 92 |
| 27 | 0.000000 | 0.00000 | 0 | 0 | 0 |
| 28 | 0.000024 | 0.01010 | 29 | 2399 | 829 |
| 29 | 0.000000 | 0.00000 | 0 | 0 | 0 |
| 30 | 0.000007 | 0.00449 | 13 | 1067 | 369 |
| 31 | 0.000014 | 0.028726 | 84 | 6821 | 2357 |
| **Total KCC** | 0.000017 | 0.35542 | 1034 | 84397 | 29166 |

The results of SO2 removal shows that wards with higher amount of tree cover has more SO2 removed from air.

### Removal of CO

Table 6.12: Results of CO Removal

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Month** | **∆C (ppm)** | **Pollution removed (Kg.)** | **Itotal (%)** | **Total pollution (Tons.)** |
| Dec, 12 | 0.000024 | 516.8 | 0.000798 | 64763.1 |
| Jan, 13 | 0.000029 | 623.6 | 0.000798 | 78148.3 |
| Feb, 13 | 0.000018 | 384.1 | 0.000798 | 48190.0 |
| Mar, 13 | 0.000018 | 372.5 | 0.000798 | 46677.2 |
| Apr, 13 | 0.000011 | 230.1 | 0.000798 | 28823.6 |
| May, 13 | 0.000012 | 252.6 | 0.000798 | 31652.5 |
| Jun, 13 | 0.000010 | 210.6 | 0.000798 | 26392.9 |
| Jul, 13 | 0.000009 | 190.3 | 0.000798 | 23851.9 |
| Aug, 13 | 0.000008 | 176.3 | 0.000798 | 22096.8 |
| Sep, 13 | 0.000008 | 179.3 | 0.000798 | 22466.9 |
| Oct, 13 | 0.000009 | 191.6 | 0.000798 | 24007.1 |
| Nov, 13 | 0.000010 | 215.8 | 0.000798 | 27045.3 |
| Dec, 13 | 0.000011 | 234.5 | 0.000798 | 29395.6 |
| Jan, 14 | 0.000010 | 217.3 | 0.000798 | 27235.8 |
| Feb, 14 | 0.000007 | 145.1 | 0.000798 | 18187.7 |
| Mar, 14 | 0.000004 | 84.6 | 0.000798 | 10607.6 |
| Nov, 14 | 0.000005 | 98.6 | 0.000798 | 12364.1 |
| Dec, 14 | 0.000003 | 71.1 | 0.000798 | 8919.7 |
| Jan, 15 | 0.000005 | 106.1 | 0.000798 | 13293.7 |
| Feb, 15 | 0.000005 | 113.7 | 0.000798 | 14191.5 |
| Mar,15 | 0.000004 | 87.7 | 0.000798 | 10991.4 |
| Apr, 15 | 0.000004 | 92.4 | 0.000798 | 11584.1 |
| May, 15 | 0.000003 | 55.5 | 0.000798 | 6953.6 |
| Jun, 15 | 0.000003 | 58.0 | 0.000798 | 7267.4 |
| Jul, 15 | 0.000003 | 59.3 | 0.000798 | 7437.6 |

Total amount of COremoved by urban trees in 7 months of 2015 by urban trees is 0.56 tons. The value (derived from externalities value) of per ton CO for 2007 $1407.00 (Murray, F., L., & P.A., 1994). That makes the value of removed CO is $ 951.19 (inflation adjusted for 2015). In direct conversion in current rate (4th May, 2017) of BDT, the value is BDT 77617.19. However, if we calculated with PPP in 2015, the value is BDT 26823.59.

Table 6.13: CO Removal in 31 Wards of KCC

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Ward No.** | **Avg. Concentration Change (%)** | **Avg. Pollution Removed (tons)** | **Avg. $ Value** | **Avg. Taka Value** | **Avg. PPP Taka Value** |
| 1 | 0.000056 | 0.06071 | 103 | 8365 | 2891 |
| 2 | 0.000007 | 0.00832 | 14 | 1146 | 396 |
| 3 | 0.00002 | 0.03410 | 58 | 4698 | 1624 |
| 4 | 0.00003 | 0.03327 | 56 | 4583 | 1584 |
| 5 | 0.00003 | 0.01081 | 22 | 1833 | 634 |
| 6 | 0.00001 | 0.01081 | 18 | 1490 | 515 |
| 7 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 8 | 0.00001 | 0.00309 | 5 | 425 | 147 |
| 9 | 0.00001 | 0.01331 | 22 | 1833 | 634 |
| 10 | 0.00000 | 0.00062 | 1 | 85 | 29 |
| 11 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 12 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 13 | 0.00000 | 0.00185 | 3 | 256 | 88 |
| 14 | 0.00001 | 0.01497 | 25 | 2063 | 713 |
| 15 | 0.00000 | 0.00247 | 4 | 340 | 118 |
| 16 | 0.00001 | 0.00680 | 11 | 936 | 324 |
| 17 | 0.00003 | 0.00371 | 6 | 511 | 177 |
| 18 | 0.00000 | 0.00185 | 3 | 256 | 88 |
| 19 | 0.00000 | 0.00062 | 1 | 86 | 30 |
| 20 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 21 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 22 | 0.00000 | 0.00062 | 1 | 85 | 29 |
| 23 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 24 | 0.00000 | 0.00185 | 3 | 256 | 88 |
| 25 | 0.00001 | 0.00247 | 4 | 340 | 118 |
| 26 | 0.00000 | 0.00062 | 1 | 85 | 29 |
| 27 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 28 | 0.00001 | 0.00556 | 9 | 767 | 265 |
| 29 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 30 | 0.00000 | 0.00247 | 4 | 340 | 118 |
| 31 | 0.00001 | 0.01580 | 27 | 2177 | 752 |
| **Total KCC** | 0.00001 | 0.06071 | 330 | 26949 | 9313 |

The results of CO removal shows that wards with higher amount of tree cover has more CO removed from air.

### Removal of PM10

Table 6.14: Results of PM10 Removal

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Month** | **∆C (μg/m3)** | **Pollution removed (Tons.)** | **Itotal (%)** | **Total pollution (Tons.)** |
| Dec, 12 | 0.374823 | 793.3 | 0.22 | 3577505.2 |
| Jan, 13 | 0.310089 | 6563.5 | 0.22 | 2959653.3 |
| Feb, 13 | 0.215011 | 4551.0 | 0.22 | 2052175.5 |
| Mar, 13 | 0.145211 | 3073.6 | 0.22 | 1385972.2 |
| Apr, 13 | 0.174184 | 3686.8 | 0.22 | 1662504.7 |
| May, 13 | 0.109643 | 2320.7 | 0.22 | 1046490.7 |
| Jun, 13 | 0.112678 | 2385.1 | 0.22 | 1075461.9 |
| Jul, 13 | 0.250864 | 5309.9 | 0.22 | 2394373.7 |
| Aug, 13 | 0.180316 | 3816.6 | 0.22 | 1721028.1 |
| Sep, 13 | 0.567488 | 12011.7 | 0.22 | 5416401.9 |
| Oct, 13 | 0.846130 | 17909.6 | 0.22 | 8075908.1 |
| Nov, 13 | 0.821361 | 17385.3 | 0.22 | 7839500.5 |
| Dec, 13 | 0.703325 | 14886.9 | 0.22 | 6712896.1 |
| Jan, 14 | 0.555925 | 11767.0 | 0.22 | 5306036.1 |
| Feb, 14 | 0.043348 | 917.5 | 0.22 | 413738.1 |
| Mar, 14 | 0.099025 | 2096.0 | 0.22 | 945142.5 |
| Nov, 14 | 0.126491 | 2677.3 | 0.22 | 1207300.4 |
| Dec, 14 | 0.086223 | 1825.0 | 0.22 | 822954.6 |
| Jan, 15 | 0.097096 | 2055.1 | 0.22 | 926730.1 |
| Feb, 15 | 0.065265 | 1381.4 | 0.22 | 622926.5 |
| Mar,15 | 0.102671 | 2173.1 | 0.22 | 979947.8 |
| Apr, 15 | 0.081065 | 1715.8 | 0.22 | 773726.7 |
| May, 15 | 0.130392 | 2759.9 | 0.22 | 1244532.5 |
| Jun, 15 | 0.374823 | 7933.7 | 0.22 | 3577505.2 |
| Jul, 15 | 0.310089 | 6563.5 | 0.22 | 2959653.3 |

Total amount of PM10removed by urban trees in 7 months of 2015 by urban trees is 14.35 tons. The value (derived from externalities value) of per ton PM10 for 2007 $6614.00 (Murray, F., L., & P.A., 1994). That makes the value of removed PM10 is $113,953.89 (inflation adjusted for 2015). In direct conversion in current rate (4th May, 2017) of BDT, the value is BDT 9,298,638.03. However, if we calculated with PPP in 2015, the value is BDT 3,213,499.9.

Table 6.15: PM10 Removal in 31 Wards of KCC

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Ward No.** | **Avg. Concentration Change (%)** | **Avg. Pollution Removed (tons)** | **Avg. $ Value** | **Avg. Taka Value** | **Avg. PPP Taka Value** |
| 1 | 1.59704 | 1723.85455 | 13681889 | 1116442125 | 385829264 |
| 2 | 0.19558 | 238.86935 | 1895858 | 154702032 | 53463202 |
| 3 | 0.45434 | 977.28224 | 7756494 | 632929882 | 218733121 |
| 4 | 0.84043 | 950.43112 | 7543382 | 615539949 | 212723365 |
| 5 | 0.84884 | 380.14628 | 3017145 | 246199033 | 85083489 |
| 6 | 0.24853 | 310.39483 | 2463542 | 201025002 | 69471876 |
| 7 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 8 | 0.16402 | 88.64357 | 703546 | 57409374 | 19840004 |
| 9 | 0.18759 | 382.21612 | 3033573 | 247539548 | 85546756 |
| 10 | 0.03739 | 17.69939 | 140476 | 11462881 | 3961437 |
| 11 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 12 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 13 | 0.07953 | 53.31881 | 423181 | 34531549 | 11933697 |
| 14 | 0.27984 | 429.66676 | 3410179 | 278270621 | 96167053 |
| 15 | 0.08754 | 71.00737 | 563571 | 45987415 | 43696030 |
| 16 | 0.14946 | 195.23040 | 1549505 | 126439577 | 43696030 |
| 17 | 0.72804 | 106.07071 | 841862 | 68695939 | 23740508 |
| 18 | 0.05771 | 53.32840 | 423257 | 34537761 | 11935844 |
| 19 | 0.06366 | 17.93468 | 142344 | 11615269 | 4014100 |
| 20 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 21 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 22 | 0.04619 | 17.69810 | 140466 | 11462050 | 3961150 |
| 23 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 24 | 0.06106 | 53.32693 | 423245 | 34536807 | 11935514 |
| 25 | 0.16807 | 70.96027 | 563197 | 45956915 | 15882169 |
| 26 | 0.04688 | 17.69800 | 140465 | 11461985 | 3961127 |
| 27 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 28 | 0.38370 | 159.55646 | 1266368 | 103335608 | 35711570 |
| 29 | 0.00000 | 0.00000 | 0 | 0 | 0 |
| 30 | 0.10504 | 70.99712 | 563490 | 45980781 | 15890417 |
| 31 | 0.21390 | 453.78334 | 3601588 | 293889546 | 101564770 |
| **Total KCC** | 0.26951 | 5614.40460 | 44560406 | 3636129165 | 1256603461 |

Concentration of PM10 is higher than other pollutants, and the removal of PM10 by trees is also the most significant among pollutants. The results of PM10 removal shows that wards with higher amount of tree cover has more PM10 removed from air.

## Analysis Results

Table 6.16: Air Pollutants Removal by Trees of KCC in 2015

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **In Jan-Jul of 2015** | **NO2** | **O3** | **SO2** | **CO** | **PM10** |
| Pollutant Removed (%) | 0.15 | 0.20 | 0.21 | 0.0008 | 0.22 |
| Concentration Change (ppm) | 0.00001 | 0.00002 | 0.00003 | 0.00004 | 0.1 |
| Amount Removed (tons) | 2.16 | 2.24 | 4.17 | 0.56 | 14.35 |
| Monetary Value (USD) | $25703.22 | $26605.86 | $12139.00 | $951.19 | $113,953.89 |

Pollution removal by trees depends on concentration of pollutants. The concentration of pollutants other than PM10 is much low, so the low removal rate doesn’t matter much. The concentration of PM10 is higher, and trees indeed remove much higher amount of PM10 from air.

While the percent pollution removed by urban trees may not look significant, there is significant impact of this pollution removal. The model considers similar pollution concentration in the total volume of air starting from ground level till mixing height. People of Khulna are mostly affected by the PM10 concentration adjacent to ground level, or human activity level. Trees mostly removes pollution at this level, while not impacting the pollution level of much higher heights of air. This results in significant increase in wellbeing of people as the air pollution of their close proximity is getting reduced. Though the dynamic nature of air balances the concentration of pollutants, trees do result in positive impact.

# RECOMMENDATIONS & CONCLUSION

## Recommendations

The recommendations are described below:

### Higher Need for Increasing Urban Tree Cover

The result of analysis shows that, the amount of pollution removed is very significant. The monetary value of pollution removed is very significant, which encourages for increase of tree cover in Khulna city. The existing tree cover in Khulna is very low, only about 6%. This value should be increased as with many other services of urban tree.

So ward wise which ward has low percentages of tree cover will be prior for tree plantation. In the below there are the ward wise tree cover percentage is given. And priority is set by very high, high, medium, low, and very low.

### Preventive Measure Instead of Mitigation Measure to Reduce Air Pollution

The result shows that percentage of pollution reduction and change in pollution concentration is very insignificant due to pollution removal of urban trees. Even increasing tree cover in significant amount won’t bring PM10 pollution level under standard. Thus it won’t be sufficient to bring air pollution under control if it increases over standard.

To control air pollution, preventive measures (i.e. Reduction in emission) must be taken instead of mitigation measure like tree plantation.

### Preventive Strategies to Reduce Air Pollution in Khulna City

**Include Strategy in Khulna Master Plan:**

According to Khulna Master Plan 2001-2020, In Khulna Nearly eight hundred big and small industries are located in Khulna city and its surrounding areas. Ambient air pollution is not that serious in Khulna comparing with other large cities. But air borne particles (PM) constitute major pollutants which were found in large quantities near bus stations and along the major transportation corridors (Khulna Master Plan, 2001-2020). In this study findings it has been found that the removal of particulate matter (PM10) is significant than other pollutants by existing tree cover. But to get environmentsustainability some advanced preventive measure should be included in Khulna Master Plan’s Environmental management chapter 16 there are some policy recommendation. Among them policy 5 & 7 should be enforced. Policies are:

* Policy -05 : Making legal provisions for gradual relocation of polluting and red industries from densely populated areas of the city
* Policy - 07: Ensuring the strict implementation and enforcement of environmental laws. (Khulna Master Plan, 2001-2020)

**Fit DPF (Diesel Particulate Filter) Mandatorily in Vehicles with Diesel Engine**

DPF\*\*s can be fitted to almost all types of diesel vehicles and equipment. The most of the vehicles in Khulna city use diesel as their fuel. According to BRTA, there are about 5636 total vehicles licensed in 2015 (Sunzid & Azmain, 2016). Though it is industrial metropolitan city many vehicles move here. If DPF is fitted in diesel engine vehicle by making a law for Khulna vehicles in a certain time period. The emission of particulates will reduce in a very significant magnitude.

Most new diesel vehicles are now required to have a factory fitted DPF due to strict emission regulations set by the European Union, however this is a relatively recent development. The majority of diesel vehicles and equipment currently in use in the UK therefore do not have a DPF fitted. Older diesel vehicles and equipment can, however, be fitted with an aftermarket DPF in a process known as ‘retrofit’. This can dramatically reduce both particulate matter and black carbon emissions. This established technology has already been proven in upgrading thousands of older vehicles to today’s low particulate matter emissions standards (Black Carbon Campaign, 2017)

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**\*\***DPF: To achieve very low particulate matter emissions a device known as a diesel particulate filter (DPF) is generally needed. These devices filter out the particulate matter before it is emitted into the air, trapping it within the filter where it is burnt off in a process known as ‘regeneration’.

Source: eBay, 2017

Figure 7.1: Diesel Particulate Filter

**Use of Green Brick Kiln in Khulna**

Nearly 90 percent of the brick-makers have not updated their production process in keeping with new environmental regulations set by the government. According to Environment Ministry in total of 6,637 traditional and modern brickfields only 735 follow the new regulations, says a report by the Bangladesh Centre for Advance Studies (BCAS). The BCAS Executive Director research says 88.65 per cent of brickfields have not obeyed the law. It is illegal for children to work in the brickfields but there are child laborers who are making a living at brick kilns. According to the BCAS, 1,745 of the brickfields in Bangladesh begin operations before obtaining a license (Atik, 2016). Wood or coal is used to fuel the traditional brick kilns. The smoke released from these chimneys damages the ozone layer and pollutes the surrounding area. The government instituted the Brick Making and Brickfield Establishment Act 2013, banning permanent chimney brickfields. According to this Act Wood cannot be used to fuel brick kilns. But in Khulna brick kilns these are not maintained. Five brick kilns of Khornia in Dumuria of Khulna district are burning trees violating environmental law. According to Local people these are due to negligence of Forest Department, Environment Department, District Administration and law enforcers. In the last six months a total of 15 metric tons of woods were burnt and as a result the forest is being deforested in this way (New Nation, 2016). There are 142 brick kilns in Khulna (DoE Khulna, 2017). So a huge amount of trees are being burnt every year in Khulna brick industries.



Bangladesh, Khulna: In this photograph taken on January 18, 2016, a Bangladeshi worker carries bricks at a brick factory on the outskirts of Khulna some 266 kms south of Dhaka.

AFP PHOTO/ Munir uz ZAMAN

Source: Tumbler, 2017

Figure 7.2: Inhumane Working Condition in Brick Kilns



Source: The Daily New Nation, 2017

Figure 7.3: Illegal Log Usage in Brick Kilns

For solution the Green Brick Technology should be adopted for reducing air pollution instead of traditional technology. This technology includes Vertical Shaft Brick Kiln (VSBK) and another is Hybrid Hoffman Kiln (HHK) (Hossain & Abdullah, 2012). It is eco-friendly and energy efficient brick kilns. To support this change to these new brick making technologies, Green Loan Funds of Bangladesh Bank (BB), World Bank (WB), Asian Development Bank (ADB), Japan International Cooperation Agency (JICA) and other foreign Investors are providing financial and technical support (eribd.com, 2017).

**Ban Two Stroke vehicles in Khulna**

Ban two-stroke vehicles in Khulna city. Many two stroke vehicles are seen in Khulna roads. The dirty two-stroke engines, including motorcycles, scooters, and the motorized rickshaws known as tuk-tuks (Atul, Mahindra known in Khulna)

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Source: Tumblr, 2017

Figure 7.4: Some Two Stroke Vehicles

To reduce air pollution a major step was banning two-stroke three-wheeler and replaced with four-stroke three-wheeler CNG baby taxies (DoE, 2012).

**Other Possible Mitigation Measures**

* Instruct the Environmental committee (DoE Khulna): To continue its work on control strategies for major air pollutants.
* Take into account continuous exchange of information on technical and non-technical means of obtaining efficient reduction of air pollution.
* Request the Development Agencies and Authority of Khulna to take this Recommendation into account and to continue its co-operation with the Environment Committee in its work in this field.
* Emission taxes and trading system enforce.
* Create strong relationship with Development Authorities and Environment Management Authorities (Such as among KDA and DoE, Khulna).

## Further Scope of the Study

### Framework for Convenience of Study over Larger Area in Bangladesh

This study introduces methodology that addresses the data limitations of Bangladesh, and provides solution to conduct the study. Thus methodology of this study is applicable all over the country.

Furthermore, a calculation model is prepared under this study that can enable further study in other parts of Bangladesh with convenience.

### Air Pollution Monitoring Platform

It is possible to make a web based monitoring platform that takes required data, conduct analysis and alert authority is pollution after removal by tree is higher than standard.

## Conclusion

Modeling air pollution removal reveals the magnitude of tree effects on improving urban air quality. The effects of public trees in Khulna are relatively small with less than one percent air quality improvement for different pollutants, but depending upon the pollutant, this small percent have substantial health impacts for local residents. The removal of 23.48 tons of pollution reduced in 7 months of 2015 by trees can improve air quality and offset local emissions. How-ever, the change in local air quality is not equally distributed and even though overall pollutant concentration is reduced, it can be increased at the local scale depending on urban forest and street design and local roadside emissions. Urban planners need to consider the impact of urban tree and green spaces on local air quality to create better and more informed plans that ensure air purification and sustain human health in cities.

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# ANNEX A

Table 8.1: Meteorological Data Obtained from DoE Khulna

| **Month** | **SO2 (ppb)** | **NO2 (ppb)** | **CO (ppm)** | **O3 (ppb)** | **PM2.5 (µg/m3)** | **PM10 (µg/m3)** | **Rain (mm)** | **Wind Speed (m/s)** | **Temperature (C°)** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **12.12** | 2.1 | 22.2 | 3.1 | 3.1 | 107.9 |  | 0.1 | 2.7 | 15.6 |
| **1.13** | 1.5 | 21.6 | 3.7 | 6.6 | 190.1 |  | 0.1 | 2.8 | 17.6 |
| **2.13** | 2.1 | 17.0 | 2.3 | 9.8 | 105.9 | 168.6 | 0.2 | 2.8 | 22.0 |
| **3.13** | 2.3 | 18.4 | 2.2 | 9.9 | 77.6 | 139.5 | 0.2 | 2.8 | 26.9 |
| **4.13** | 2.0 | 18.2 | 1.4 | 11.6 | 47.2 | 96.7 | 0.2 | 2.8 | 29.0 |
| **5.13** | 2.2 | 22.7 | 1.5 | 8.8 | 34.1 | 65.3 | 0.6 | 8.8 | 28.6 |
| **6.13** | 1.9 | 24.4 | 1.2 | 5.8 | 32.8 | 78.4 | 0.1 | 6.6 | 29.4 |
| **7.13** | 2.4 | 18.7 | 1.1 | 5.0 | 23.7 | 49.3 | 0.1 | 8.5 | 28.7 |
| **8.13** | 16.8 | 19.5 | 1.0 | 4.0 | 17.8 | 50.7 | 0.1 | 8.1 | 28.2 |
| **9.13** | 30.7 | 24.5 | 1.1 | 2.7 | 47.8 | 112.9 | 0.1 | 6.4 | 28.5 |
| **10.13** | 3.2 | 9.9 | 1.1 | 1.6 | 34.4 | 81.1 | 0.1 | 5.4 | 26.7 |
| **11.13** | 9.3 | 11.3 | 1.3 | 4.0 | 120.5 | 255.3 | 0.2 | 2.6 | 23.8 |
| **12.13** | 7.1 | 15.3 | 1.4 | 3.0 | 181.3 | 380.7 | 0.2 | 2.4 | 19.9 |
| **1.14** | 7.2 | 14.7 | 1.3 | 1.8 | 224.2 | 369.6 | 0.1 | 2.9 | 17.7 |
| **2.14** | 4.1 | 14.1 | 0.9 | 6.1 | 102.0 | 316.4 | 0.2 | 2.5 | 22.6 |
| **3.14** | 4.4 | 13.5 | 0.5 | 9.3 | 133.8 | 250.1 | 0.1 | 2.8 | 23.0 |
| **11.14** | 2.8 | 13.0 | 0.6 | 3.9 | 63.5 | 19.5 | 0.1 | 2.0 | 29.0 |
| **12.14** | 4.2 | 12.4 | 0.4 | 2.3 | 60.6 | 44.6 | 0.1 | 2.4 | 25.0 |
| **1.15** | 10.0 | 11.8 | 0.6 | 5.0 | 59.4 | 56.9 | 0.1 | 2.7 | 25.0 |
| **2.15** | 12.4 | 11.2 | 0.7 | 7.9 | 62.9 | 38.8 | 0.1 | 2.8 | 28.0 |
| **3.15** | 12.2 | 10.7 | 0.5 | 11.4 | 63.9 | 43.7 | 0.1 | 3.2 | 32.0 |
| **4.15** | 14.9 | 10.1 | 0.5 | 12.5 | 64.2 | 29.4 | 0.1 | 4.8 | 34.0 |
| **5.15** | 14.0 | 9.5 | 0.3 | 6.6 | 43.2 | 46.2 | 0.1 | 6.2 | 36.0 |
| **6.15** | 14.9 | 8.9 | 0.3 | 5.3 | 35.9 | 36.5 | 0.1 | 5.9 | 34.0 |
| **7.15** | 16.1 | 8.3 | 0.4 | 4.4 | 28.5 | 58.7 | 0.1 | 3.9 | 32.0 |

Source: DoE Khulna, 2017