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ABSTRACT

Thesis: *"Linear Regression Modeling of Selected Analytes From the Balad Air Sampling Program"*

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Joint Base Balad (JBB) / Logistics Support Area Anaconda (LSA Anaconda) utilized burn pits from 2003-2009 to facilitate and manage solid waste disposal. The base transitioned in phases from burn pit to incinerator use from June 2007 to October 2009. The Air Force Institute for Operational Health and the U.S. Army Center for Health Promotion and Preventive Medicine began an ambient air sampling program to determine pollutant emissions generated from the JBB burn pit. Ambient air sampling periods were: January – April and October – November 2007, May – June 2009, and March – May 2010. Data from the Balad Air Sampling Program are analyzed to explore possible temporal trends in ambient air quality for selected analytes from the VOC, PAH, Dioxin and Furan chemical groups during the transition from burn pit to incinerator operation. The results from linear fixed effect regression model indicate that benzo[a]pyrene observed a positive correlation between analyte log concentration and the

sampling periods, suggesting that the overall ambient air quality at JBB decreased with Benzo[a]pyrene's increased log concentration value over time. Whereas, the analyte log concentrations for tetraCDD, benzene, *n*-heptane, cadmium and lead observed a negative correlation (decrease in log concentration over the sample periods) suggesting that the overall ambient air quality at JBB increased with the analyte's between log concentration values during the transition from burn pit to incinerator operation.

Linear Regression Modeling of Selected Analytes from the Balad Air Sampling Program

by

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A thesis submitted to the Faculty of the Department of Preventive Medicine and Biometrics, Uniformed Services University of the Health Sciences in partial fulfillment of the requirements of the degree

of

MASTER OF SCIENCE IN PUBLIC HEALTH, 2012

DEDICATION

I dedicate this Master of Science in Public Health thesis to my wife, Mydee and our sons Matthew Joshua and Timothy James. Thank you for providing the inspiration and passion to pursue my dreams.

In loving memory of my father, Tito. Your life lessons continue to provide me with a firm foundation. You are always with me.

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ABBREVIATIONS

AFCCC	Air Force Combat Climatology Center
AFIOH	Air Force Institute for Operational Health
ASD(HA)	Assistant Secretary Defense for Health Affairs
ANOVA	Analysis of Variance
AOR	Area of Responsibility
BaP	Benzo[a]pyrene
BMP	Best Management Practice
CAS	Chemical Abstracts Service
CASF	Contingency Aeromedical Staging Facility
COB	Contingency Operating Base
DOD	Department of Defense
DOEHRS	Defense Occupational Environmental and Health Readiness System
EPA	Environmental Protection Agency
EPC	Exposure Point Concentration
FOB	Forward Operating Base
GAO	U.S. Government Accountability Office

HRA	Health Risk Assessment
IARC	International Agency for Research on Cancer
IOM	Institute of Medicine
JBB	Joint Base Balad
JP-8	Jet Propellant – 8
LOAEL	Lowest Observed Adverse Effect Level
LOD	Limits of Detection
LSA	Logistic Support Activity
MRL	Minimum Risk Level
NCMI	National Center for Medical Intelligence
OSHA	Occupational Safety and Health Administration
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PEL	Permissible Exposure Limits
PET	Polyethylene terephthalate

PM	Particulate Matter
POL	Petroleum, Oil and Lubricant
SEM	Standard Error Mean
SVOC	Semi-volatile Organic Compound
TWA	Time Weighted Average
VOC	Volatile Organic Compound
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USAPHC	U.S. Army Public Health Command
USCENTCOM	U.S. Central Command
UXO	Unexploded Ordnance

Chapter One: Introduction

Statement of Problem

Open air burning of material waste (e.g. household solid waste, commercially produced solid waste) in barrels and open burn pit(s) is a common method of primary waste management in rural areas of the United States as well as many areas of third world and developing countries. [1] The "open burning" of various material wastes poses a health and environmental concern to the public as well as local and federal foreign environmental regulatory agencies. The U.S. Environmental Protection Agency (EPA) defines "open burning" as a "unenclosed combustion of materials in an ambient environment".[2] According to the *Medical Preventive Medicine: Mobilization and Deployment*, the United States generates approximately 4 to 6 pounds of waste per person/day.[3] Solid waste material may comprise various materials to include:

"…any garbage, refuse, sludge, and other discarded material including solid, liquid, semisolid or gaseous material resulting from industrial, commercial, agriculture operations and community activities"[4]

The open air combustion of material waste has been shown to emit many different chemical byproducts, to include the following: soot and particulate matter (PM) that is visible as smoke plume; carbon monoxide (CO); methane (CH_4); volatile organic compounds (VOCs); semivolatile organic compounds (SVOCs); metals (e.g. lead, arsenic); polycyclic aromatic hydrocarbons (PAHs);

dioxins (PCDDs) and furans (PCDFs).[2] Airborne emission of these potential harmful analytes is due to the low combustion temperature and oxygen-depleted conditions associated with open burning; often resulting in incomplete combustion and increased pollutant emissions. In addition, air emissions released from the open burning of household waste are released at ground level which prevents an effective method of dilution from dispersion.[5] Contaminant dispersion has been found to be temporally related to the period during the day and in what season the burning occurs. A spatial relationship also exists regarding airborne dispersion, in that local/regional atmospheric effects can be significantly different than in other areas.

From a public health perspective, improper management and disposal of solid waste material could result in groundwater, air and soil contamination with unwanted chemicals as well as attract vectors (Insects, rodents, etc.) for diseases. In deployed environments, numerous factors may impact the management of solid waste materials. Some of these factors include a lack of waste stream segregation, insufficient disposal infrastructure and inadequate or an absence of incinerator or landfill facilities.[6] The management of solid waste in current operational areas of Afghanistan and Iraq has been contingent upon the "footprint" and "maturity" of the operational bases.[7] Base camps located in the vicinity of urbanized areas may have an established solid waste management infrastructure that may assist in the removal of household and commercial material waste piles accumulating in forward operating bases (FOBs) prior to being ignited and disposed of in the burn pit (open burn) area. Additionally, in contingency operations, which are defined by the Secretary of Defense as “any military operation in which members of the armed forces may become involved in military actions against an opposing military force,”[8] the disposal of waste materials through segregation and recycling methods may not be feasible since these solid wastes may require transportation to other suitable and less hostile locations. The management and control of waste materials under these deployed conditions may warrant field disposal methods such as burial and open burning.[6] The composition of waste materials in the deployed areas of Southwest Asia include water bottles, polystyrene foam from food containers, electronic components (e.g. computers, cell phones, portable storage devices) and batteries.[6] The abundance of these materials in a deployed environment adds to the difficulty of effectively sorting and separating harmful wastes in a burn pit area.

The most common plastics introduced in the solid waste stream include polystyrene, polyethylene, and polyethylene terephthalate (PET). The analyte emissions of organic air toxics from open burning generate particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide, VOCs and polycyclic aromatic hydrocarbons, all of which may pose hazards to the health of humans.[9] Furthermore, open burning of the deployed waste streams mentioned may generate dioxins, furans (PCDDs / PCDFs), polychlorinated biphenyls (PCBs) and metals such as lead and mercury.[9, 10]

Recently, the use of burn pits in austere and deployed environments have been the focus of media attention, Assistant Secretary Defense for Health Affairs

(ASD (HA)) as well as congressional inquiries and legislation.[8, 11] The Joint Particulate Matter Working Group was chartered in 2005 by the (ASD(HA)) in order to identify possible health issues attributed with particulate matter (PM).[7] Complaints of eye and respiratory symptoms made by service members exposed to burn pit smoke in deployed environments raised concern among members of Congress that burn pit activities may be associated with these adverse effects.[11, 12] Subsequently, the May 2010 *Epidemiological Studies of Health Outcomes among Troops Deployed to Burn Pit Sites* report stated that service members living or operating in the near vicinity of burn pits can be potentially exposed directly to combustibles by inhalation or ingestion and indirectly by dermal deposition.[11] The report indicated that potential acute health effects of exposure to burn pit combustibles may include eye, throat and sinus irritation, acute bronchitis, dermatitis and allergic rhinitis, in addition to an acute exacerbation of pre-existing medical conditions such as asthma.[11, 13] Additionally, the 2010 report stated that possible long term health effects may include chronic obstructive pulmonary disease (COPD), emphysema and cancer.[11, 13, 14]

In 2003, Joint Base Balad (JBB) / Logistics Support Area Anaconda (LSA Anaconda, Iraq) utilized a burn pit to manage their solid waste disposal. During the early deployment stages at JBB (2003-2007), inspection and enforcement of waste materials entering the burn pit were conducted on a limited basis.[15] Accurate waste stream records of the materials being incinerated at the burn pit were not maintained.[15] Materials introduced into the JBB burn pit included: plastics, metal/aluminum cans, rubber, chemicals (e.g. paints, solvents), petroleum, oil, lubricant products, munitions, unexploded ordnance and wood waste. Incomplete combustion by-products with jet fuel (JP-8) (used as the accelerant) were emitted.[15-18] In December 2006, a memorandum generated by the 332nd Air Expeditionary Wing – Bioenvironmental Engineering Fight at Balad Air Base (LSA Anaconda) indicated concerns about the burn pit operations and potential harmful chemicals being dispersed into the ambient environment from the smoke plume . The memo recommended that a more comprehensive air sampling program be implanted to identify the analytes that were being emitted from the burn pit as well as whether or not the concentration levels exceeded any regulatory or military exposure limits.[15-17] The memo claimed that the burn pit was an "acute health hazard for individuals…there is a possibility for chronic health hazards associated with smoke from the burn pit."[15-17] Statements from the 332nd Air Expeditionary Wing memo were based on preliminary air sample analyte concentrations that were erroneously calculated and indicated concentration levels three orders of magnitude over the established regulatory and military limits.[15-17] The 332nd Air Expeditionary Wing memo generated interest from Congress and the media, which resulted in the approval to conduct a comprehensive study on the potential health effects from burn pit emissions.[8, 11] Beginning in 2007, the Air Force Institute for Operational Health (AFIOH) and the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM, now the U.S. Army Public Health Command) instituted an ambient air sampling program to determine the pollutant emissions generated from the JBB burn pit 24 hour-7 day per week operations.[15, 16] The initial air sampling methods were selected based on the expected chemicals present from the combustion of solid waste (plastics, paper, wood, metal cans, etc.), as well as potential airborne generation of polycyclic aromatic hydrocarbons (PAHs), heavy metals, volatile organic compounds (VOCs), and particulate matter ($PM_{2.5}$ and PM_{10}).[15-18] The Balad Air Sampling Program occurred over a four year period with ambient air samples being obtained in 2007, 2009 and 2010.[15, 16, 19, 20] Four distinct sampling stages occurred during the 4-year sampling program: 1) January – April 2007, 2) October – November 2007, 3) May – June 2009 and 4) March – May 2010. Table 1 depicts the sampling protocol utilized by USACHPPM and AFIOH during the Balad air sampling stages in 2007, 2009 and 2010**.**

Method Comparison[8]	**PM - 2.5**[1]	**PM- 10**[2,7]	**TO-9**[3]	**TO-13**[4]	**TO-14**[5]	**TO-15**[6,7]
Sampler	Airmetrics Minivol™	Airmetrics Minivol™	Hi-Volume PS-1	Hi-Volume PS-1	6 liter (L) Stainless Summa Canister	6 liter (L) Stainless Summa Canister
Sample Time	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs	24 hrs
Sample Frequency	7 days	7 days	7 days	7 days	7 days	7 days
Measuring	Particulate matter plus 10 metals	Particulate matter plus 10 metals	Halogenated Dioxins and Furans	Polycyclic Aromatic Hydrocarbons (PAHs)	Volatile Organic Compounds (VOCs)	Volatile Organic Compounds (VOCs)
Collection Period	May-Jun 2009; Mar-May 2010	Jan-Apr 2007; Oct-Nov 2007; May-Jun 2009; Mar-May 2010	Jan-Apr 2007; Oct-Nov 2007; May-Jun 2009; Mar-May 2010	Jan-Apr 2007; Oct-Nov 2007; May-Jun 2009; Mar-May 2010	Jan-Apr 2007; Oct-Nov 2007	May-Jun 2009; Mar-May 2010

Table 1: USACHPPM and AFIOH Balad Air Sampling Protocol[15, 16]

Notes:

[1] $PM_{2.5}$: particulate matter with an aerodynamic diameter of 2.5 micrometers (1 micrometer = 1x10-6 meters) and less.

[2] PM_{10} : particulate matter with an aerodynamic diameter of 10 micrometers (1 micrometer = 1x10-6 meters) and less.

[3-6] Per the U.S. Environmental Protection Agency (U.S. EPA) toxic organic sampling methodology.

[7] U.S. EPA sampling methodology TO-15 was used for the 2009 and 2010 Balad air sampling period in order to capture more VOC analytes; consequently, $PM_{2.5}$ was an added parameter to the Balad Air Sampling Program.[16]

[8] Air samples were taken from the following sites at Joint Base Balad: Mortar pit/Background site, H6 (Troop living areas), CASF (Contingency Aeromedical Staging Facility), guard tower and the transportation area.

During the Balad Air Sampling Program, incinerator facilities became operational and materials routed to the burn pit area began to decrease. Of Importance, the Balad Air Sampling Periods coincided with the four operational stages of incinerator facilities at Balad. During the January – April 2007 sampling period, no incinerator facilities were operational. The third and fourth sampling periods at Balad occurred from May – June 2009 and March – May 2010, respectively. Three incinerator facilities were operating prior to the third sampling period and four incinerators were operational by the end of 2009.

The Balad Air Sampling Program conducted during seasonal periods in 2007, 2009 and 2010 provided the foundation for a screening Health Risk Assessment (HRA) of military and contract personnel working at the JBB site.[15, 16, 19, 20] To date the data from the Balad Air Sampling Program has not been analyzed to determine whether a positive temporal association in ambient air quality among selected analytes from the VOC, PAH, PM, Dioxin and Furan chemical groups is observed during the transition of solid waste management on base from solely using the JBB burn pit to solely using incinerators.

Hypothesis

Balad Air Sampling data during the four stage transition from open burn pit to incineration facilities will show a positive temporal association with ambient air quality among selected VOCs, Metals, PAHs, Dioxin and Furan chemical groups.

Research Question

Can a positive temporal association with ambient air quality among selected chemical groups be observed during the four stage transition from open burn pit to incineration facilities using a linear fixed effect regression model?

Research Objectives

Objectives of this research were to: characterize the solid waste management phases and their transitional timelines (e.g. burn pit usage to incinerator facilities) as they occurred at Balad Air Base during the 2007-2010 period and determine whether a positive temporal or spatial association exists between the airborne chemical concentrations of the following analytes and sampling sites during the transition from open burn pits to incinerator use:

VOC Group	PAH Group	Dioxin - Furan Group	Metals
acetone	acenaphtylene	1,2,3,4,6,7,8 HeptaCDD	arsenic
benzene	anthracene	1,2,3,7,8 – PentaCDD	cadmium
chloromethane	chrysene	2,3,7,8 – TetraCDD	lead
hexane	naphthalene	1,2,3,4,7,8 – HexaCDF	
n-heptane	pyrene	2,3,4,7,8 – PentaCDF	
o-xylene	benzo(a) pyrene	2,3,7,8 – Tetra CDF	
toluene			

USACHPPM and AFIOH collected 173 specific analytes from the VOC, Metals, PAH, Dioxin and Furan chemical groups during the Balad Air Sampling Program in 2007, 2009 and 2010,[16, 19, 20] Twenty-two chemicals were selected for data analysis for this research design. The list of analytes was reduced to six in order to efficiently analyze each chemical group using a linear fixed effect regression model. The selection of analytes were based on the following criteria:

1) Analyte samples were collected during each of the four sampling periods in 2007, 2009 and 2010;

2) Each analyte's potential health risks;[16, 19-21]

3) Possible combustible by-products from waste materials being processed at the Balad burn pits;[16, 22]

4) Analytes listed as a "Priority Chemical" on the EPA's National Waste Minimization Program; [23]

5) Four of the analytes (arsenic, benzene, toluene and xylene) were chemicals of interest from the 332nd Air Expeditionary Wing Memo that initiated further air sampling assessments by USACHPPM and AFIOH.[15-17]

6) The six analytes selected as representative analytes for the chemical groups were based on the results from the multiple comparison tests (*Chapter Three – Methods*), historical significance and potential health effects from acute and chronic exposure.

Chapter Two: Literature Review

Military Burn Pit Operations

In deployed settings, the military has utilized burn pits as an expedient method to manage solid waste.[8] Incineration, solid waste materials segregated for recycling/reuse, landfills and off site transport of hazardous materials are the preferred methods of managing waste materials.[8, 24] Unlike incinerators, open air burn pits do not operate under engineering controlled settings and conditions that allow for the regulated dispersion of harmful and hazardous emissions from municipal waste.[9] Burn pits are characterized by their low temperature burning (170^{o} F) and smoldering, which attributes to the incomplete combustion of organic materials (plastics, paper, solvents).[25] The incomplete breakdown of these materials enable formation of VOCs, Metals, PAHs, Dioxins and Furans and their release through the smoke plume generated from the burn pit.[26] Chemical concentration levels released into the ambient air from the burn source is dependent on meteorological conditions, waste composition and background activities.[11, 27]

The Department of Defense (DoD) estimates that current military operations in Afghanistan and Iraq generates approximately 10 pounds of solid waste per soldier each day.[8] The exact number of active burn pits on U.S. bases in Afghanistan and Iraq to handle this enormous amount of waste generated has fluctuated over time; in November 2009, U.S. Central Command (USCENTCOM) reported 50 active burn pits in Afghanistan and 67 in Iraq. The number of active burn pits increased to 184 in Afghanistan due to increases in troop level concentrations, while operating bases in Iraq experienced a slight decrease (from 67 to 52) in the number of burn pits in Iraq from Nov 2009 to April 2010.[8] In August 2010, USCENTCOM estimated that U.S. forces within Afghanistan were operating 251 active burn pits; over the same time period, U.S. forces in Iraq had 22 active burn pits that were being utilized to manage the solid waste materials generated at military bases in their Areas of Responsibility (AOR).[8, 28]

Figure 2-1: Afghanistan burn pit area, 2009[6]

A 2010 burn pit study conducted by the Army Institute of Public Health (formerly USACHPPM), found that the waste stream routed to burn pit areas at large bases (bases consisting of >1,000 service members[13]) located in Iraq and Afghanistan were comprised of a composition of "5-6% plastics, 6-7% wood, 3-4% miscellaneous non-combustibles, 1-2% metals and 81-84% combustible materials."[13]

In 2009, USCENTCOM published Regulation 200-2 *CENTCOM Contingency Environmental Guidance*, which provided environmental guidance and best management practices (BMPs) for U.S. base camps being operated by USCENTCOM and involved in contingency operations within USCENTCOM's AOR.[8, 28] Regulation 200-2 (R200-2) applies to all U.S. service members, U.S. units, DoD civilian employees and DoD contractor personnel deployed with U.S. forces.[28] USCENTCOM defines burn pits as:

"A dug out area of the ground used for open burning. Waste is burned in an open pit or burn pit, when contingency conditions prevent other options from being considered, such as the hauling of waste away or incinerating. Burn pit operations can be harmful to human health and the environment and should only be used until more suitable disposal capabilities are established."[28]

Figure 2-2: Burn pit at Camp Warhorse, Iraq – February 2010[8]

Due to the potential health and environmental hazards associated with burn pit operations, USCENTCOM R200-2 outlined a segregated waste policy in 2009 prohibiting the following materials from being transported to a burn pit area and incinerator facility: "Petroleum, oil and lubricant (POL) products (other than waste fuel to start a fire), rubber, tar paper, asphalt shingles, tires, treated wood, batteries, unexploded ordnance (UXO), aerosol cans, compressed gas cylinders, plastics, paint, paint solvents, pesticides, asbestos, appliances and electrical equipment or other materials that create unreasonable smoke, fumes or hazardous air pollutants."[28] In addition, to further reduce the potential health risks from exposure to the smoke plume generated by the burn pit, USCENTCOM R200-2 stipulated that burn pits / burn boxes operate from three hours after sunrise to three hours before sunset with discontinued (additional materials prohibited) burning three hours before sunset.[28] Since the publication of Regulation 200-2, the Department of Defense has approved plans and installed 39 solid waste incinerators in Iraq and 20 in Afghanistan.[8] Typical U.S. bases with active burn pits operating within USCENTCOM area of responsibility are briefly listed and described within this section:

Contingency Operating Base Speicher, Iraq

Situated in Northern Iraq in the Tigris River Valley by the city of Tikrit, Contingency Operating Base (COB) Speicher contained an airfield that was utilized by the Iraqi military. A large oil and gas production facility as well as agricultural fields occupy the surrounding vicinity of COB Speicher.[11] The solid waste materials at COB Speicher were managed at a burn pit area comprised of seven open pits approximately 20 feet in depth; dominant winds are from the northwest toward the southeast direction. The burn pits are positioned along the southern portion of COB Speicher, away from the camp populace.[11] A local waste segregation program/policy at COB Speicher has been enforced since 2005 and hazardous materials and waste, tires, medical waste, plastics and metals were separated and prohibited from being burned. A 20-ton per day solid waste incinerator was installed and operational in July 2010.[11, 29] COB Speicher military activities included flight and convoy operations, power generation and fueling missions.[11]

Camp Taji, Iraq

Located at a former Iraqi military airfield in central Iraq (north of Baghdad), agriculture land and the Al Samud industrial complex surrounds Camp Taji. In addition, a brick factory which operates one day per month is located adjacent to the north side of the camp along with two 30-ton municipal waste incinerators positioned on the western edge of the U.S. base.[8, 11] Predominant wind direction is defined from northwest to the southeast; Camp Taji military activities included flight and convoy operations, base vehicle traffic, power generation and fueling missions which contribute to the analyte concentrations in the ambient air.

Figure 2-3: Contract workers segregating waste materials at Camp Taji, Iraq[8]

Along the northern perimeter of Camp Taji, a large burn pit area consisting of 20 individual burn pits operates 24 hours per day, seven days per week. However, during the week, only two of the pits are concurrently used at any given time. Each pit is designated to burn certain waste materials; one pit has been allocated to burn mattresses and electrical equipment. Similar to Camp Speicher, hazardous materials, hazardous waste, tires, medical waste, and batteries were segregated from the waste stream and not burned. The burn pit area was estimated to have a burn rate of 50 tons per day. A small percentage of the camp population was located within 1.5 km of the burn pit area, with the majority of the population residing 3-5 km from the burn pit area.[8, 11]

Figure 2-4: Camp Taji, Iraq burn pit area - January 2010[8]

Camp Arifjan, Kuwait

Established in December 2002 in southern Kuwait near the Persian Gulf Coast, Camp Arifjan is a U.S. base that is the home to military and DoD civilian support personnel and headquarters elements. Frequent summer sandstorms along with the on-site military flight and vehicle operations, as well as established petroleum and chemical industries (located approximately 15 km north, south and west to Camp Arifjan), are the primary sources of airborne emissions.[11, 30] Burn pits are not utilized at Camp Arifjan, instead solid waste materials are containerized and routinely removed by contractors to off-base municipal landfills.[8]

Joint Base Balad, Iraq

Joint Base Balad (JBB), also known as LSA Anaconda and Balad Air Base, was located in North Central Iraq, approximately 68 km north of Baghdad and 1.5 km from the Tigris River.[16] The site encompassed 25 square km and was one of the largest operational airbases in Iraq. It served as a major transient hub for personnel and supplies. During operations in 2007 and 2008, the Government Accountability Office reported that inspection of materials transported to the burn pit area were not properly segregated, items entering the burn pit included: “lubricant products, munitions, unexploded ordnance, wood waste with jet fuel (JP-8) being used as the accelerant.“[8, 15, 16] Since the withdrawal of U.S. forces in December 2011, the area in which JBB formerly operated is now controlled by the Iraqi government. In May 2008, JBB reportedly had a population of approximately 25,000 military, DoD civilian, contractor and coalition forces personnel.[15, 16] The base housing area for military personnel was located 1.5 km south and downwind of the burn pit area.[11, 15, 16] Aside from the burn pits, other sources of potential airborne emissions during the Balad Air Sampling Program included the military activities of flight and convoy operations as well as fueling and power generation operations. Predominant winds travel from the west and northwest direction (45 percent of the time); from the north-northwest and the north-northeast 15 percent of the time and an additional northerly direction about 6 percent of the time.[16]

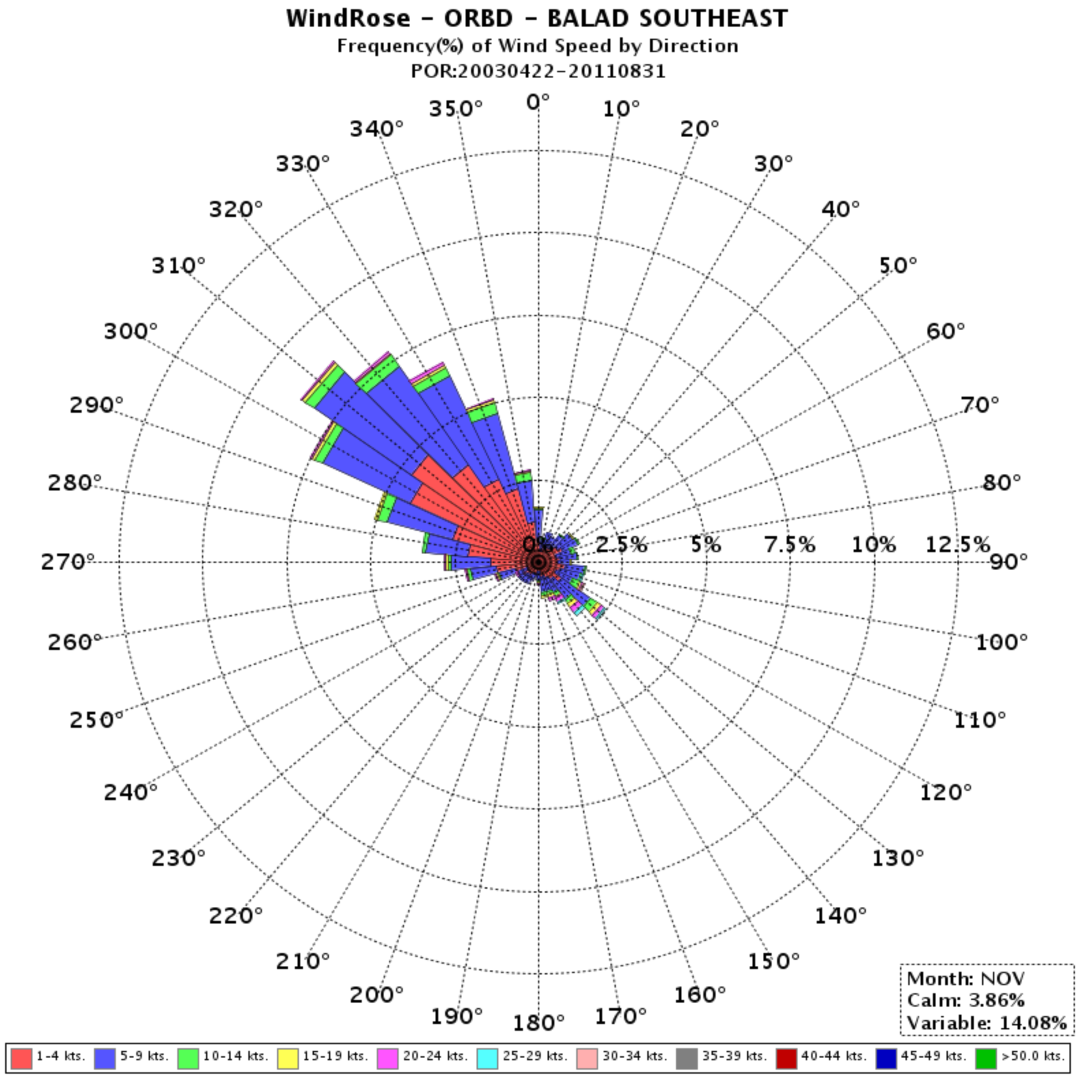


Figure 2-5: Joint Base Balad Wind Rose[16]

While in operation, the JBB burn pit was the largest operating burn pit located in the USCENTCOM area of responsibility. During an assessment in 2007 by USACHPPM, the JBB burn pit was observed to have a burn load rate of 200 tons per day.[8, 11, 15, 16] The burn pit was located at the northeast corner of the base and initially operated with limited segregation and removal of flammables, ammunition and bulk metal materials prior to being ignited at the burn pit area. [15, 16, 31]

Figure 2-6: Contractors segregating waste materials at JBB, Iraq[6]

The transition to reduce the use of the burn pit area at JBB began in July 2007 with the installation and operations of two incinerator facilities.[8, 11] Subsequently, a third incinerator facility was installed in April 2008 and by October 2009 a fourth incinerator facility became operational at JBB and all solid waste was managed either by the four incinerator facilities or by an off-site recycling facility.[8, 19, 20, 31] The Balad burn pit area was operating until the fourth incinerator became operational in 2010. Limited segregated hazardous waste material was removed from JBB under the contractual provisions of the Defense Reutilization and Marketing Service (DRMS).[8, 31]

Figure 2-7: Incinerator facilities at Joint Base Balad, Iraq – November 2009[6]

Table 2-1 provides a periodic overview of the JBB burn pit transition phases (TP) during the sampling periods. The Balad air samples collected and managed by USACHPPM (now the USAPHC) and AFIOH were the primary comprehensive airborne sampling for burn pit emissions in Iraq. Hence, the retrospective analysis of JBB air sampling data may elucidate relationships between variables and factors associated with observed airborne analyte concentrations.

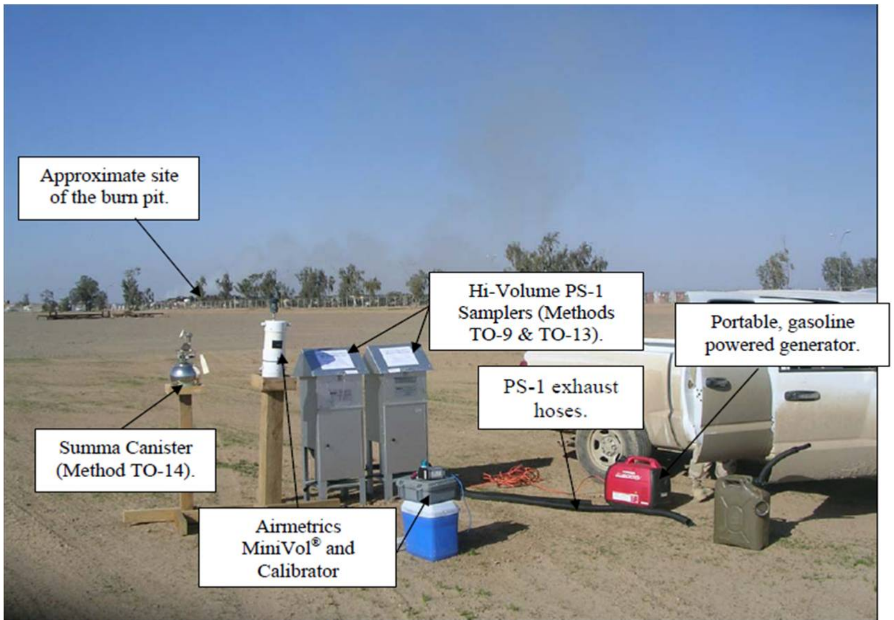
Transition Phase	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
Air Sample Period	Jan – Apr 2007	Oct – Nov 2007	May – Jun 2009	Mar – May 2010
Burn Pit Load rate (tons / day)	100-200	50 -100	10	0
Operational Incinerators	0	2	3	4

Table 2-1: Balad burn pit transition phases[8, 19, 20, 31]

Balad Air Sampling Protocol and Methods

As indicated in the thesis background section, air sampling data was collected in 2007 (Jan-Apr and Oct-Nov), 2009 (May-Jun) and 2010 (Mar-May) by U.S. Air Force Bioenvironmental Engineers and U.S. Army Preventive Medicine personnel under the guidance of the AFIOH and USACHPPM. Guidance documents utilized for the collection of pollutants in the ambient air included the U.S. EPA's Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, the USACHPPM Technical Guide 251 and the AFIOH Sampling and Analysis Plan for the Collection of Ambient Air Samples at Receptor Locations from Open Pit Burning Operations in the Deployed Environment.[15, 16] Sampling methods employed at JBB were based on the analytes of primary interest and the capabilities of the deployed environmental health science personnel. These methods and the sample analytes are detailed below:

- TO-9A: Dioxins and Furans
- TO-13A: Polycyclic aromatic hydrocarbons
- TO-14A / TO-15: Volatile organic compounds
- $PM_{2.5}$, PM_{10} plus 10 metals



Note: MiniVol® is a registered trademark of Airmetrics

Figure 2-9: Balad air sampling equipment[16]

To characterize exposures to individuals operating in the area of the burn pits, all sampling equipment inlets were placed within the personal breathing zone of the sampled personnel.[15, 16] The five sampling sites at JBB were: 1) mortar pit (Background), 2) CASF (Contingency Aeromedical Staging Facility), 3) transportation field (TMO), 4) guard tower and 5) housing (H6). These sites were selected based on the location of the population living areas and the prevalent winds with respect to the burn pit area.[15, 16] Table 2-2 provides distances from the burn pit to the Balad sample sites as well as distances between each sample site.

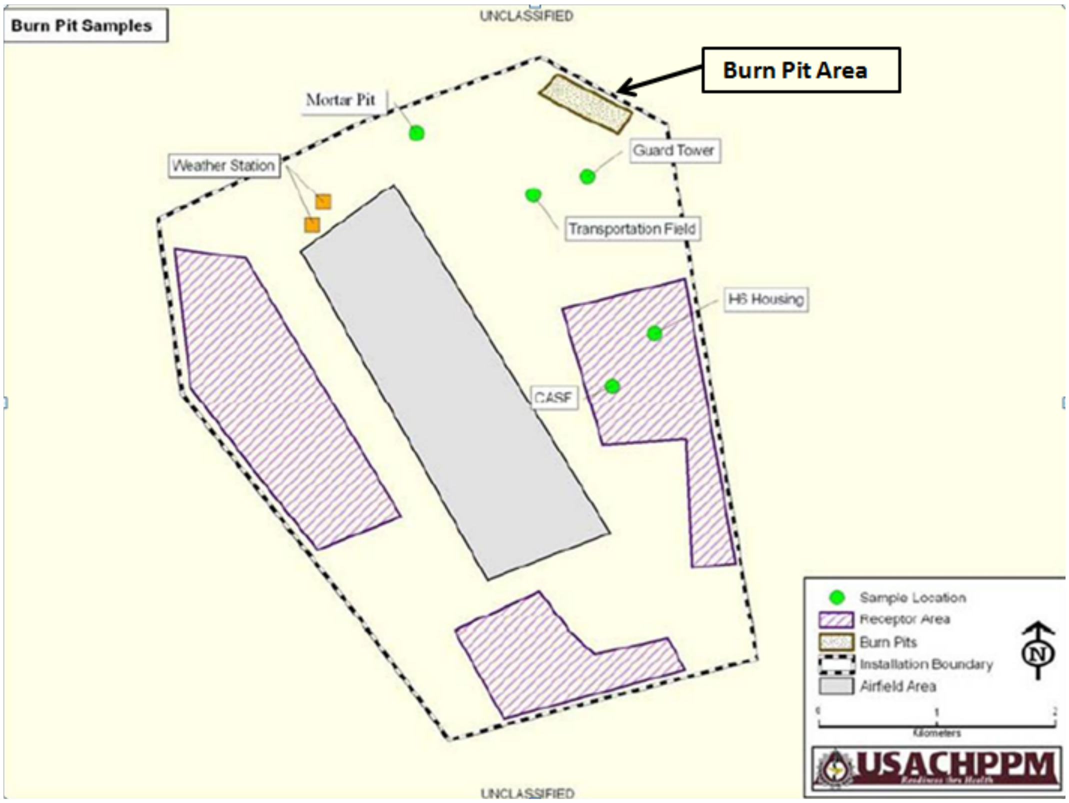


Figure 2-8: Joint Base Balad, Iraq air sampling sites[16]

Location[1,2]	Burn Pit	Background / Mortar Pit	H-6	Transportation	CASF	Guard Tower
Burn Pit	**0.00**	**2.42**	**1.50**	**0.83**	**1.61**	**1.21**
Background / Mortar Pit	2.42	0.00	2.85	1.81	2.79	1.74
H-6	1.50	2.85	0.00	1.25	0.58	1.93
Transportation	0.83	1.81	1.25	0.00	1.00	0.74
CASF	1.61	2.79	0.58	1.00	0.00	1.54
Guard Tower	1.21	1.74	1.93	0.74	1.54	0.00

Table 2-2: Balad air sampling site distances in kilometers[11, 16, 32, 33]

Notes:

1 Calculated distances are in kilometer units (km) and are approximate values.

2 Conversion and distance calculations from latitude / longitude coordinates between two points on earth assume that the earth is a perfect sphere with a radius of 6378 km.[33]

Dioxins and Furans

Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDDs/PCDFs) are comprised from a chemical group family of 75 different compounds (congeners). The PCDD group is divided into eight groups of chemicals based on the number of chlorine atoms and its structure is defined by two benzene rings joined by two oxygen bridges. The 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD) compound is a known carcinogen and has been associated as a contaminant in the chemical mixture code-named Agent Orange, a herbicide used during the Vietnam War.[24, 34-36] From their report, *Veterans and Agent Orange: Update* 2008, the Institute of Medicine (IOM) has continued to indicate an epidemiological association between exposure of Vietnam veterans to the TCDD-contaminated Agent Orange and adverse health outcomes including soft-tissue sarcoma, non-Hodgkin's lymphoma, Hodgkin's disease, and chronic lymphocytic leukemia.[13]

PCDDs are not intentionally manufactured by industry, except in small amounts for research purposes and may be formed during the chlorine bleaching process used by pulp and paper mill factories. The combustion of fossil fuels (coal, oil, and natural gas), materials containing plastics made from chlorine (polyvinylchloride – PVC), wood treated with pentachlorophenol (PCP), pesticide-treated wastes, other polychlorinated chemicals (polychlorinated biphenyls-PCBs), and bleached paper can produce PCDDs that are emitted to the environment.[24, 34] The *Screening Health Risk Assessment Burn Pit Exposures Balad Air Base, Iraq May 2008* joint report from AFIOH and USACHPPM stated that the most significant source of dioxins and furans in the ambient air at JBB was likely due to inefficient combustion of municipal waste containing halogenated compounds (such as, plastics, wood) in the burn pit.[16] PCDDs are typically found in the environment together with other structurally–related, toxic chlorinated chemicals, such as chlorinated dibenzofurans (CDFs) and polychlorinated biphenyls (PCBs).[35] PCDD and PCDF airborne exposures are usually reported in TEQs (Toxic Equivalent Quotients) and TEFs (Toxic Equivalency Factors), and have a reported urban air concentration level of 2.3 picograms per cubic meter (pg/m^3) in the United States.[34] However, the *Screening Health Risk Assessment Burn Pit May 2008* report, as well as subsequent health risk assessment reports in May – June 2009 and Mar-May 2010, indicated that the "cumulative carcinogenic risk levels of all receptors from inhalation exposures to burn pit emissions at Balad Air Base are within or below the U.S. EPA's target cancer risk range of $1x10^{-4}$ to $1x\ 10^{-6}$"[15, 16, 19, 20] The EPA's cancer risk range is a process that determines the "safe or acceptable" concentration contamination level from exposure to a particular chemical contaminant.[37] The following factors determine the target risk concentration:

- Individual lifetime risk of no greater than about 1 in 10,000 of contracting fatal cancer.
- Lifetime risk for the majority of people within a given area, of less than 1 in 1,000,000 of contracting fatal cancer.
- Small total estimated number of additional cases of death or disease as a result of exposure to a contaminant.

Information regarding acute respiratory effects of tetraCDD in humans is limited. However, acute symptoms from short term exposure may include the irritation of eyes, bronchitis and laryngitis.[34] Studies examining humans acutely exposed to high concentrations of 2,3,7,8-TCDD or other CDD congeners (as contrasted with long-term studies) reported acute instances of death.[67] Lymphocytic leukemia has been associated with chronic effects associated with tetraCDD exposure.[13]

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic Aromatic Hydrocarbons (PAHs) consist of a large group of fused 5-carbon and 6-carbon (benzene) aromatic rings that are formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances.[35] Several known PAHs are utilized to manufacture dyes (anthracene), plastics (acenaphtylene), pesticides and petroleum products (naphthalene). PAHs may be categorized as “alternant” (e.g. benzo[a]pyrene, chrysene) or “non-alternant” (e.g. fluoranthene, pyrene) based on the electron density associated with the molecule. Alternant PAHs have an equally distributed electron density whereas non-alternant PAHs exhibit characteristics of two different molecules due to their uneven distribution of electron density from one portion of the molecule to another.[38] The toxicological significance of this difference is that alternant and non-alternant PAHs appear to behave differently, with regards to how they are metabolized and their subsequent carcinogenicity. Several epidemiologic studies have shown increased mortality due to lung cancer in humans exposed to coke oven emissions, roofing-tar emissions, and cigarette smoke. Conversely, the ability of PAHs to induce acute respiratory effects in humans is not definitive; although toxicology studies have provided evidence that benzo[a]pyrene has a high acute toxicity from oral exposure among rats.[38] Each of these emission mixtures contained concentration levels of benzo[a]pyrene, chrysene, benz[a]anthracene, benzo[b]fluoranthene, and dibenz[a,h]anthracene, as well as other potentially carcinogenic PAHs.[38] In a separate dose-related study involving hamsters, a decrease in survival after 60 weeks of inhalation exposure to 46.5 mg/m^3 benzo[a]pyrene was recorded; the study attributed the reduced survival life-span in part to toxic and carcinogenic effects induced by benzo[a]pyrene (e.g., tumors in the pharynx and larynx that could have inhibited food intake).[39]

In general, PAHs occur as complex mixtures or adsorbed onto particulate matter (e.g. combustion products - soot) and not as single compounds. Ambient air concentration levels of PAH emissions vary with the combustion source; emissions from residential wood combustion contain more acenaphtylene than other PAHs, whereas; auto emissions contain more benzo[g,h,i]perylene and pyrene.[38] PAHs in diesel exhaust particulates are dominated by three- and four-ring compounds, primarily consisting of fluoranthene, phenanthrene, and pyrene.[40] The total average daily intake of PAHs by the general populace in the United States is estimated at 0.207 µg, with a total potential exposure to carcinogenic PAHs for adult males to be approximately 3 µg/day.[24, 38] The permissible exposure limit (PEL) based on a 8-hour time weighted average

(TWA) set by the Occupational Safety and Health Administration (OSHA) is 0.2 mg/m^3.[41]

Volatile Organic Compounds (VOCs)

As defined by the Environmental Protection Agency (EPA), volatile organic compounds (VOCs) are characterized by any compound of “carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions, except those designated by EPA as having negligible photochemical reactivity.”[27] VOCs are also characterized by high vapor pressures (vapor pressure of approximately 0.01 millimeters of Mercury or higher) at room temperature.[35] Major sources of VOCs are from the combustion of organic-based materials, exhaust from motor vehicles, industrial emissions, glues, paints (toluene), petroleum products (hexane) and detergents.[24]

In 2004, the EPA estimated the nationwide benzene atmospheric emissions from various sources were 34,000 metric tons/year.[42] Moreover, the general populace may be exposed to VOCs from inhalation of contaminated air, particularly in areas of heavy traffic and around gas stations. The EPA, International Agency for Research on Cancer (IARC), and the Department of Health and Human Services have concluded that benzene is a human carcinogen. This determination is based on sufficient inhalation data in humans supported by animal evidence, including the oral studies in animals. Based on human leukemia data, EPA derived a range of inhalation unit risk values of 2.2×10^{-6} to 7.8×10^{-6} $(\mu g/m^3)^{-1}$ for benzene.[42] Corresponding air concentrations for lifetime exposure range from 13.0–45.0 µg/m^3 (4–14 ppb) to 0.013–0.045 µg/m^3 (0.004–0.014 ppb), respectively.[43] Inhalation unit risk values are based on an average person (70 kg body weight) inhaling a daily average volume of 20 m^3 of air per day.[44] Respiratory effects have been reported in humans after acute exposure ($\leq$ 14 days) to benzene vapors. A study involving male shipyard workers exposed to residual fuel from shipyard tanks were evaluated for benzene exposure. Findings from the study noted mucous membrane irritation in 80% of the workers and dyspnea was evident in 67% of the workers with occupational exposures of >60 ppm for up to 3 weeks.[45] The EPA has derived an inhalation minimum risk level (MRL) of 0.009 for benzene.[42] The MRL serves as an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse effects (non-carcinogenic) for acute-duration inhalation exposure.[42] Ambient air concentration of benzene have been recorded at average levels ranging from 0.88 to 5.3 ppm in Manhattan, New York during the peak summer tour season.[42] The 8-hour time weighted average (TWA) set by the Occupational Safety and Health Administration (OSHA) is 1 ppm.[42]

During the active use of the Balad burn pit area, JP-8 was used as an accelerant in the burning of solid waste.[15, 16] The primary component in JP-8 is kerosene, along with a performance based mixture of other volatile chemicals such as benzene, toluene, xylene (single-ring aromatic compounds) and polycyclic aromatic hydrocarbons. Byproducts of these chemicals, along with particulates are produced during the JP-8 combustion process.[46] Jet fuel may also be released to the environment via in-flight jettisoning of fuel and from accidental spills or leaks to soil during use, storage, and transportation. VOC components of JP-8 can be introduced to the atmosphere from the soil through volatilization.[46] In addition, the reaction between JP-8 and atmospheric chemicals may form aerosols; however, the specific composition of the particulate material is not known.[46] Some components of JP-8 are soluble in water (e.g., the aromatics–benzene, toluene, and xylene) and under turbulent water conditions, the more soluble hydrocarbons remain dissolved longer increasing the possibility to partition into the soils and sediments and be biodegraded.[35] The rate and extent of biodegradation will depend on the ambient temperature, the presence of a sufficient number of microorganisms capable of metabolizing the component hydrocarbons, the amount of aromatic species in the jet fuel, and the concentration of jet fuel.[46]

The International Agency for Research on Cancer (IARC) has concluded there is not enough information available to determine whether jet fuels or distillate (light) jet fuels cause cancer (Group 3 classification). However, IARC has determined that occupational exposures during petroleum refining are probably carcinogenic to humans (Group 2A classification).[46, 47] *The Balad Health Risk Burn Pit Assessment Reports* from AFIOH and USAPHC did not specifically address any health risk associated with kerosene, JP-8's primary component. The EPA has assessed the MRL of JP-8 at 3 mg/m^3.[46]

Metals

Cadmium occurs in the earth's crust at a concentration of 0.1–0.5 ppm and is commonly associated with zinc, lead, and copper ores.[24] Natural emissions of cadmium to the environment can result from volcanic eruptions, forest fires or other natural phenomena.[35] Non-ferrous metal mining and refining, manufacture and application of phosphate fertilizers, fossil fuel combustion, waste incineration and disposal are the main anthropogenic sources of cadmium in the environment.[24, 35] Highest levels of occupational exposure occurs in operations involving heating cadmium-containing products by smelting, welding, soldering, or electroplating, and also in operations associated with producing cadmium powders. The primary route of occupational exposure is through inhalation of dust and fumes. Interestingly, for inhalation exposure, particle size and solubility in biological fluids (in contrast to solubility in water) appear to be the more important determinants of the toxicokinetics for cadmium.[48] Cadmium can undergo long-range atmospheric transport and deposition causing cadmium contamination in areas with no local cadmium sources.[35, 48]

Numerous studies of cadmium workers and populations living in areas exposed to low, moderate, or high cadmium pollution levels have been conducted. Results from these studies suggest that acute inhalation exposure to cadmium at concentrations above about 5 mg/m^3 may be associated with the destruction of lung epithelial cells, resulting in pulmonary edema, tracheobronchitis, and pneumonitis in both humans and animals.[48, 49] In the United States, cadmium levels in ambient air range from 0.1 to 5 nanograms per meter cubed (ng/m^3) in rural areas, 2–15 ng/m^3 in urban areas, and 15–150 ng/m^3 in industrialized areas.[48] EPA reports cadmium's acute inhalation exposure MRL at a concentration value of 3×10^{-5} mg/m^3.[48] Animal studies support the findings in humans that acute exposure (MRL) to cadmium results in lung damage. Single exposures to cadmium at approximately 1–10 mg/m^3 in the form of cadmium chloride or cadmium oxide resulted in interstitial pneumonitis, diffuse alveolitis with hemorrhage, focal interstitial thickening, and edema.[49, 50] OSHA has established a permissible exposure limit of 5 $\mu g/m^3$ for occupational exposure to airborne cadmium.[41]

Lead is a naturally occurring metal found in the Earth's crust at about 15–20 mg/kg.[24] Levels of lead in the environment (not contained in ore deposits) have increased over the past three centuries as a result of human activity.[24] The atmospheric concentration of lead varies greatly, with levels in ambient air observed at greater than 10 $\mu g/m^3$ near lead point sources.[43] Lead is primarily dispersed throughout the environment as the result of anthropogenic activities such as the mining and smelting of ore, manufacture of lead-containing products, leaded gasoline, lead-based paint, lead solder in food cans, lead-arsenate pesticides, combustion of coal and oil, and waste incineration.[24, 35, 51] Aviation fuel is not regulated for lead content and can contain significant quantities of lead.[51] Moreover, releases from lead-based paints are frequently confined to the area in the immediate vicinity of painted surfaces, and deterioration or removal of the paint by sanding or sandblasting can result in high localized concentrations of lead dust in both indoor and outdoor air.[51]

The most sensitive targets for lead toxicity are the developing nervous system, the hematological and cardiovascular systems, and the kidney.[36] Unlike cadmium, MRLs were not derived for lead because a clear threshold for some of the more sensitive effects in humans has not been identified.[51] Previous epidemiological studies and clinical observations have provided evidence for a progression of adverse health effects of lead in humans that occur in association with blood lead concentration ranging between10 to 60 micrograms per deciliters (μg/dL).[51] At the low end of the blood lead concentration range, adverse effects include delays and/or impaired development of the nervous system, delayed sexual maturation, neurobehavioral effects, increased blood pressure, depressed renal glomerular filtration rate, and inhibition of pathways in heme synthesis.[51] The EPA national ambient air quality standard for lead is 1.5 μg/m^3, with the OSHA PEL defined at 0.050 mg/m^3.[36, 51]

Table 2-3 provides an overview of the potential sources and possible health risks associated with the chemical compound groups analyzed in this research thesis.[13, 21, 36, 47]

Analyte Name[6]	Chemical Group	Material Source(s) from Combustion[5]	Potential Health Risks or Effects from Exposure[1]
Arsenic	Metals	Pesticides in treated wood products; semiconductor in electronic devices; strengthening alloy in lead for batteries	Ulceration of nasal septum; dermatitis; GI disturbances; peripheral neuropathy; respiratory irritation; hyperpigmentation of skin; lung and lymphatic cancer.
Lead[6]	Metals	Lead-acid batteries; paint; pipes; metal solder	Probable carcinogen, lung and kidney tumors, neurotoxicity, developmental delays, hypertension, impaired hearing acuity, impaired hemoglobin synthesis, and male reproductive impairment
Cadmium[6]	Metals	Nickel cadmium batteries; plastics (Cadmium acts as a stabilizer); corrosion resistant plating on steel; paint	Pulmonary edema, dyspnea, cough, tight chest, substernal pain, headache, chills, muscular aches, nausea, vomiting, diarrhea, emphysema, proteinuria, anosmia (loss of sense of smell), mild anemia, cancer.
1,2,3,4,6,7,8-HeptaCDD[6]	Dioxin	Medical waste; paper products, plastics, petroleum products, herbicides; chlorine products, smelter operations	IARC – Group 1: Carcinogenic to humans[2] EPA – Group B: Likely to be carcinogenic to humans[2]
1,2,3,7,8-PentaCDD[6]	Dioxin	Medical waste; paper products, plastics, petroleum products, herbicides; chlorine products, smelter operations	IARC – Group 1: Carcinogenic to humans[2] EPA – Group B: Likely to be carcinogenic to humans[2]
2,3,7,8-TetraCDD[6]	Dioxin	Medical waste; paper products, plastics, petroleum products, herbicides; chlorine products, smelter operations	Irritation eyes; allergic dermatitis; chloracne; porphyria; GI disturbances; possible reproductive, teratogenic effects; liver, kidney damage; hemorrhage; cancer.
1,2,3,4,7,8-HexaCDF[6]	Furan	Medical waste; paper products, plastics, petroleum products, vehicle exhaust; chlorine products; power plants; PCB filled transformers, capacitors	IARC – Group 1: Carcinogenic to humans[2] EPA – Group B: Likely to be carcinogenic to humans[2]
2,3,4,7,8-PentaCDF[6]	Furan	Medical waste; paper products, plastics, petroleum products, vehicle exhaust; chlorine products; power plants; PCB filled transformers, capacitors	IARC – Group 1: Carcinogenic to humans[2] EPA – Group B: Likely to be carcinogenic to humans[2]
2,3,7,8-TetraCDF[6]	Furan	Medical waste; paper products, plastics, petroleum products, vehicle exhaust; chlorine products; power plants; PCB filled transformers, capacitors	IARC – Group 1: Carcinogenic to humans[2] EPA – Group B: Likely to be carcinogenic to humans[2]

Analyte Name[6]	Chemical Group	Material Source(s) from Combustion[5]	Potential Health Risks or Effects from Exposure[1]
Acenaphtylene[3,6]	PAH	Dyes; plastics; pesticides; semiconductor	Not Determined[3]
Anthracene[6]	PAH	Dyes; plastics; pesticides; wood preservatives; semiconductor	Skin, nose, throat, and eye irritation, itching, burning, coughing, and wheezing, photosensitizer.
Chrysene	PAH	Vehicle exhaust; petroleum products; wood preservatives	Probable carcinogen, carcinomas and malignant lymphoma
Benzo[a]pyrene	PAH	Vehicle exhaust; petroleum products; cigarette smoke; combustion of organic products; charbroiled food	Probable carcinogen, stomach and respiratory tract tumors
Naphthalene[6]	PAH	Vehicle exhaust; petroleum products; cigarette smoke; combustion of organic products; charbroiled food	Possible carcinogen, respiratory tumors; decreased body weight
Pyrene[6]	SVOC	Vehicle exhaust; petroleum products; cigarette smoke; combustion of organic products	Nephropathy and decreased kidney weight
Acetone	VOC	Solvents; plastics; adhesives	Eye and respiratory tract irritation, neurobehavioral and neurological effects (e.g., reduced nerve conduction velocity, increased reaction time)
Benzene[6]	VOC	Vehicle exhaust; petroleum products	Known carcinogen, leukemia and hematologic neoplasms; progressive deterioration of hematopoietic function with chronic exposure, suppression of circulating B-lymphocytes, menstrual disorders, limited evidence of reproductive toxicity and neurotoxicity
Chloromethane	VOC	Refrigerants	Cerebellar lesions, central nervous system dysfunction
Hexane	VOC	Solvents; Vehicle exhaust; petroleum products; adhesives	Peripheral neuropathy
n-Heptane	VOC	Vehicle exhaust; petroleum products; adhesives	Skin, eye and respiratory irritant, and CNS depression at high exposures
Toluene	VOC	Solvents; paint thinner; petroleum products; adhesives; disinfectant	Increased liver and kidney weight, nephropathy, neurological effects
o-Xylene[4]	VOC	Solvents; paint thinner; petroleum products; adhesives; disinfectant	Irritation eyes, nose throat, CNS effects; GI distress; pulmonary inflammation[4]

Table 2-3: Material source(s) of combustion and potential health risks from exposure for the chemical compounds analyzed in this research.

Notes:

[1] Unless otherwise annotated, potential health risks or health effects from exposure were extracted from the EPA's Integrated Risk Information System (EPA IRIS) and/or USACHPPM Technical Guide 230: Chemical Exposure Guidelines for Deployed Military Personnel.[21, 43]

[2] Potential health risks or health effects from exposure were based on the IARC's (International Agency for Research on Cancer) and the EPA's IRIS cancer classification [52, 53]

[3] Potential health risks or health effects from exposure of Acenaphtylene could not be determined [53, 54]

[4] O-Xylene is a constitutional isomer of m-xylene and p-xylene; health effects and health risks were developed from dose-response reports and toxicology reports from animal studies [53, 54]

[5] Information on material source(s) from combustion was extracted from the EPA's IRIS and the CDC's Agency for Toxic Substances and Disease Registry [53, 55]

[6] Analytes listed on the EPA's Priority Chemicals – National Waste Minimization Program have been designated as chemicals to be eliminated or substantially reduced in their use in production [23]

Chapter Three: Methods

Research Data

Laboratory analytical results of the samples collected during the Balad Air Sampling Program in Balad, Iraq (2007, 2009, and 2010) and obtained from the U.S. Army Public Health Command (USAPHC) represent the primary data source for this analysis. This data set contained the following information:

- Sample site location
- Field sample identifier
- Defense Occupational Environmental and Health Readiness System (DOEHRS) sample identifier
- Time / Date that the sample was taken
- Analyte / Chemical Abstracts Service (CAS) identifier
- Chemical Group of the analyte
- Field notes (If applicable)
- Individual lab results for each sample, measured in concentration units of $\mu g/m^3$

The laboratory data set includes 173 specific analytes for over 8,000 individual laboratory analyte results.[15, 16, 19, 20, 56] Joint Base Balad (JBB) weather data during the sampling periods (Jan-Apr 2007, Oct-Nov 2007, May-Jun 2009 and Mar-May 2010) were obtained from the National Center for Medical Intelligence (NCMI) and the Air Force Combat Climatology Center (AFCCC) – 14th Weather

Squadron.[57, 58] Climatology report(s) included the following information for the sampling periods:

- 24-Hour temperature readings for each day (includes extreme high and extreme low temperature)
- Daily precipitation readings (includes minimum, maximum and average 24 hour readings)
- Monthly moisture dew point readings (includes monthly maximum and minimum readings)
- 24-Hour vapor pressure readings for each day
- 24-hour wind readings (includes wind speed and prevailing wind directions)

The discrete data for the Balad wind readings also include a graphical presentation on a wind rose for the average monthly wind speed and prevailing wind direction (Refer to Figure 2-5).

Descriptive Data Analysis

The following tasks were performed on the Balad air sampling data in order to determine whether data were normally distributed, as well as to provide a concise statistical characterization of the standard deviation, histogram plot, mean plot, standard error mean, range, maximum values, minimum values and variances. Calculations were performed using MS Excel 2007 and IBM SPSS Statistics V20 programs[59, 60]. If the data were not normally distributed, a log transformation was applied. Furthermore, analyte concentrations (µg/m^3) which are below the limits of detection (LOD) were categorized as non-detects and incorporated with the average monthly concentration value of each analyte by using one-half of the LOD value.[61]

Multiple Comparisons of Analyte Mean Concentrations

In order to effectively analyze the temporal association of analyte concentrations during the different sampling periods (transition phases from open pit burning to incinerator operations), analyte(s) from each chemical group (Metals, VOCs, PAHs, Dioxins-Furans) were selected as representative of the chemical groups if appropriate. One-way Analysis of Variance (ANOVA) multiple pairwise comparisons (Tukey Procedure) were performed to select representative analyte(s). Mean concentration values for the pairwise comparisons are calculated from the daily analyte concentration values for the Jan-Apr 2007 sampling period. The Jan-Apr 2007 period was chosen for the ANOVA multiple comparison procedure in order to capture the initial sampling burn pit conditions prior to the first operating incinerator at Balad. The following assumptions were made with the ANOVA multiple pairwise comparison:[62]

- Each of the analyte data points is normally distributed
- Each of the analyte data points have the same variance (σ^2)
- Analyte samples are random and independent of each other

As indicated in the *Descriptive Data Analysis* section of this chapter, where data points are not normally distributed, a log transformation was applied and a histogram generated to confirm normal distribution. Levene's homogeneity-of-variance test was applied to confirm the assumption of equal variances.[62] The p-value was compared to an α-value of 0.05. The null hypothesis (H_o) testing for Levene's homogeneity-of-variance test consists of the following conditions:[62]

- H_o = The variances are equal

- H_a = The variances are not equal
- If the p-value $\leq \alpha$, reject the null hypothesis (H_o) and accept that variances are not equal
- If the p-value $> \alpha$, fail to reject the null hypothesis (H_o) and accept that the variances are equal

Multiple pair-wise comparison was calculated with the Tukey Procedure when variances were equal and with the Dunnett's-C Procedure when variances were not equal.[59] Both the Tukey and Dunnett's -C procedures incorporate the Studentized range statistic to make all of the pair-wise comparisons between analytes (groups).[59] When zero falls within the lower bound and upper bound ranges of the 95% confidence intervals for the multiple pair-wise comparisons, then means (average) of the compared analytes correlate. Correlated analytes provided a representative analyte for each chemical group. Results from the Levene's homogeneity-of-variance test and the multiple pair-wise comparisons are included in the *Results* section.

Selection of Analytes

TetraCDD was selected as a representative analyte for the Dioxin-Furan group based on the following factors:

- Historical Agent Orange and tetraCDD association during the Vietnam War Era,
- TetraCDD has the highest Toxic Equivalency Quantity (TEQ) and Toxic Equivalency Factor (TEF) values assigned to the Dioxin-Furan group,

- And tetraCDD is a known human carcinogen.

Benzo[a]pyrene (BaP) was selected as a representative of the PAH chemical group based on the following criteria:

- Historical occupational exposure associated with England's chimney sweepers during the 18th century,[24, 36]
- And epidemiologic studies have shown that BaP may be a cancer tumor promoter or initiator.[13, 38]

The selection of benzene and n-heptane for the VOC chemical group was based on the following factors:

- Documented acute respiratory effects (skin, eye, respiratory irritant) associated with exposure (>60 ppm) from benzene and *n*-heptane,[13, 45]
- Benzene and *n*-heptane are emitted from vehicle exhaust and combustion of petroleum products; therefore, airborne concentration levels can be used as a means to monitor increases or decreases in their emission into the atmosphere from various sources,
- And potential long term health effects for benzene include progressive deterioration of hematopoietic function and leukemia.[13, 42]

The selection of cadmium and lead to represent the Metals chemical group was based on the following:

- OSHA Permissible Exposure Limit (PEL) for cadmium (0.005 mg/m^3) is more restrictive than arsenic (0.010 mg/m^3),

- Inhalation exposure to high levels of cadmium oxide fumes or dust is intensely irritating to respiratory tissue,[48]
- Based on research studies, lead is a probable carcinogen and has been known to alter the hematological system,[13, 51]
- And based on documentation, multiple combustion sources of lead and cadmium were introduced in the burn pit waste stream.[6, 8, 15, 19, 20]

Temporal Association of Analyte Concentration(s)

In order to determine temporal association of analyte concentration(s) across the sampling periods, a bivariate correlation analysis was performed. The input variables for the analysis consist of the sampling periods and the mean analyte concentration values calculated from the five sampling sites during the sample periods. Using the scatter plot option in the IBM SPSS® Statistics V20 program, with the analyte mean concentration as the y-axis, sample periods as the x-axis and the five sample sites as "Set Markers" provided an aggregate graph representing the temporal association of the analyte concentration during the sample periods. Results from this analysis were analyzed to determine what association, if any, exists between change in time (over the 4 sampling periods) and respective airborne analyte concentrations at the five sample sites, without accounting for the influence of weather variables (e.g. temperature, wind speed, wind direction, precipitation).

Determining Potential Confounding Weather Variables

Prior to analyzing the data with the IBM SPSS® Statistics V20 program, analyses were performed to determine if weather variables (wind speed, wind direction, precipitation and temperature) were associated with either the sampling periods or the analyte concentration. The weather variables are considered as a "random effect" in the "Linear Fixed Effect Regression Model". The steps for the analysis are outlined below:

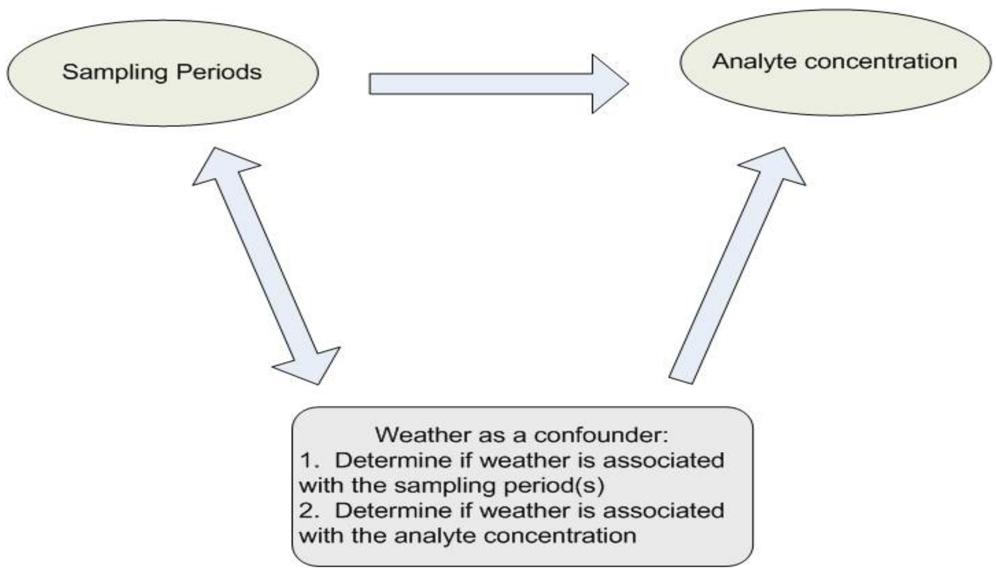


Figure 3-1: Determining if weather variables is a confounder

Analysis 1: Is weather associated with sampling period?

- One-way ANOVA – compare means
- Dependent variables were the weather factors (temperature, wind speed, wind direction, precipitation) during the four sampling periods

- Independent variables were the four sampling periods for the Balad Air Sampling Program (Jan – April 2007, Oct – Nov 2007, May – June 2009 and Mar – May 2010)

Analysis 2: Is weather associated with analyte concentration by site?

- Bivariate – correlation
- Input variables: Analyte concentration values during the four sampling periods and the weather factors (temperature, wind speed, wind direction, precipitation) during the four sampling periods
- Spearman correlation coefficient – Option is used in the IBM SPSS® Statistics V20 program when comparing two variables (weather – analyte concentration)

The p-value compared to $\alpha = 0.05$ to determine significance of the weather variables with respect to the sampling periods and analyte concentration(s). Weather factors determined to be significant were utilized and input in the linear fixed effect regression model.

Multiple Linear Fixed Effect Regression Model

Multiple linear fixed effect regression was utilized to determine independent factors (weather variables, troop level, sample sites, sample period) that best predict the analyte concentration (dependent variable) at each sample site for the different sampling periods. With the multiple linear fixed effect regression model, the sample sites and sample period were considered "fixed effects" since they do not change. The selected weather variables and troop level concentrations were defined as "random effects" and initially represented potential confounders to analyte concentration(s). Similar to the linear regression model, the general equation for the multiple linear fixed effect regression model is as follows:

$Y = \beta_o$ *(Sample Periods)* + β_1*(Sample Sites)* + β_2 *(Weather variables)* + β_3 *(Troop levels)*

The sample sites were entered as a categorical value assigned as either "1" or "0". This step allowed for the background sample site (Site 5) to be compared against the remaining sample sites (Site 6 to Site 9). Table 3-1 provides a presentation of how the sample sites were entered in SPSS.

Table 3-1: Categorical variable values for sample sites

SITES	Site 6	Site 7	Site 8	Site 9
Site 6	1	0	0	0
Site 7	0	1	0	0
Site 8	0	0	1	0
Site 9	0	0	0	1
Site 5	0	0	0	0

- Site 5: Background sample site
- Site 6: CASF sample site
- Site 7: H6 (Housing) sample site
- Site 8: Guard tower sample site
- Site 9: Transportation sample site

The defined independent and dependent variables and how each were incorporated in the linear fixed effect regression model are listed below:

- Analyte concentration ($\mu g/m^3$) is the dependent variable of the linear regression equation and was input as a continuous value based on the concentration reading from a specific sample day. The input data for the analyte concentration was based on the log transformation values, since the original data are not normally distributed.
- Temperature was input as a continuous independent variable based on the daily average temperature over a 24-hour period.
- Wind speed was input as a continuous independent variable based on the daily average wind speed over a 24-hour period.
- Wind direction data obtained from the AFCCC, was converted from a circular reference to a linear measurement. A linear scale of 1 to 16 was used to represent the wind direction, based on the 16 points of the wind rose compass: a wind direction of north will have a linear scale of 1, a wind direction of NNE was assigned a linear scale of 2 and an east wind direction was assigned a linear scale of 4. After converting the wind direction to a linear scale, a wind factor on a linear scale from 0 to 8 was assigned based on the influence of the wind direction relative to the site. For example, the background sample site is located west from the burn pit area. If the wind direction was generating from the background site in a west direction, the wind factor was "0", since emission from the burn pit area would not theoretically influence the analyte concentration.

- Precipitation was input as a numerical independent variable based on the maximum daily readings over a 24-hour period.
- Troop level was based on the average number of troops (U.S. forces and international coalition forces) stationed at military bases in Iraq for the specified sample month. Total troop numbers in the Iraq AOR was utilized since troop data for JBB was not available for all of the sampling periods. The value was input as a continuous independent variable based on a percentage of 100,000.

For example, it has been documented that the total troop concentration level in Iraq during April 2007 was estimated at 159,000.[8, 16, 63-65] Therefore, a numerical value of 1.59 was input into the linear regression model for the April 2007 sampling period. Although this estimate does not portray the exact number of troops stationed at JBB, justification of this method is based on the assumption that as troop concentration fluctuated from month to month, as well as the influx and outflow of troops from the base (e.g. casualties, visitors, and transient personnel) JBB troop levels and activity levels would be correlated. Troop level concentrations were obtained from the following sources: the Brookings Institution, Congressional Research Service, U.S. Government Accountability Office and the U.S. Department of State Weekly Iraq Status Reports.[8, 29, 63-65]

Burn pit distances to the sample sites were not utilized in the model since the distances remain constant during the sample periods. Also, burn pit rates (tons/day) were not utilized in the model since their values correspond to the four sampling periods and remain constant throughout each period.

The following assumptions were made and confirmed with the linear fixed effect regression model:[59, 62]

- Normality - For each value of the independent variable, the distribution of the dependent variable must be normal.
- Equal variance - The variance of the distribution of the dependent variable should be constant for all values of the independent variable.
- Linearity - The relationship between the dependent variable and each independent variable should be linear.
- Independence - All observations should be independent.

A “block” approach was used to input the “fixed effect” independent variables (sample period and sample sites) in a single step. The second “block’ of “random effects” (weather variables, troop levels) were input with a “stepwise” method in the IBM SPSS® Statistics V20 program. The least squares method was incorporated to estimate beta (β) values. Using the least squares method approach will minimize the difference between the observed dependent variable values (Y) and those predicted by the fitted multiple linear fixed effect regression model.[62] The “stepwise” method in SPSS allows the program to automatically simulate several models before determining which input variables contribute significantly to the dependent variable (analyte concentration).[66] A t-test will identify the significance of each independent variable in the multiple linear fixed effect regression equation.[62] The p-value was compared to the alpha (α) value of 0.05 for the overall F-test and each t-test. The following residual plots were generated using the IBM SPSS® Statistics V20 program in order to confirm assumptions of normality, linearity, equal variance and independence are valid: P-P plot of standardized regression, standardized residual scatter plots of each independent variable. Results from the linear regression analysis are included in the *Results* section.

Chapter Four: Results

Descriptive Data Results

Figures 4-1 thru 4-8 represent the analyte histogram plots from each of the chemical groups before and after applying a log transformation on the original air sample data. With the exception of cadmium (metals), the histograms of each analyte from the chemical groups were skewed to the right prior to log transformation (Figures 4-1 to 4-12), indicating that the data set is not normally distributed.

Table 4-1 lists the frequency and log concentration results for the four chemical groups. The mean value for each chemical group is derived from the log concentration data (after log transformation). The Dioxin – Furan group had the smallest mean log concentration (-6.754) and the largest variance (1.620) and standard deviation (1.273) values among the chemical groups.

Table 4-1: Chemical Group Descriptive Statistics Results

Chemical Group	N	Mean Value Log Conc. [ug/m^3]	Std. Error Mean	Std. Deviation	Variance
Metals PM_{10}	180	-1.346	0.013	0.168	0.028
PAH	192	-2.455	0.067	0.931	0.867
VOC	294	0.5170	0.025	0.427	0.183
Dioxin-Furan	264	-6.754	0.078	1.273	1.620

Figure 4-1: 2,3,7,8-TetraCDD (Dioxin – Furan) histogram before log transformation.

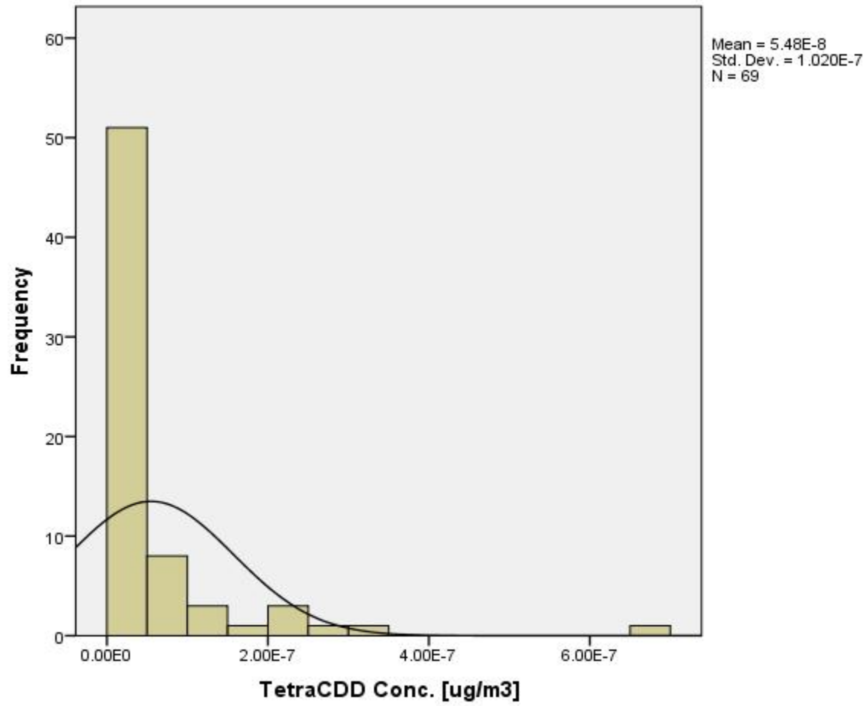


Figure 4-2: 2,3,7,8-TetraCDD (Dioxin – Furan) histogram after log transformation.

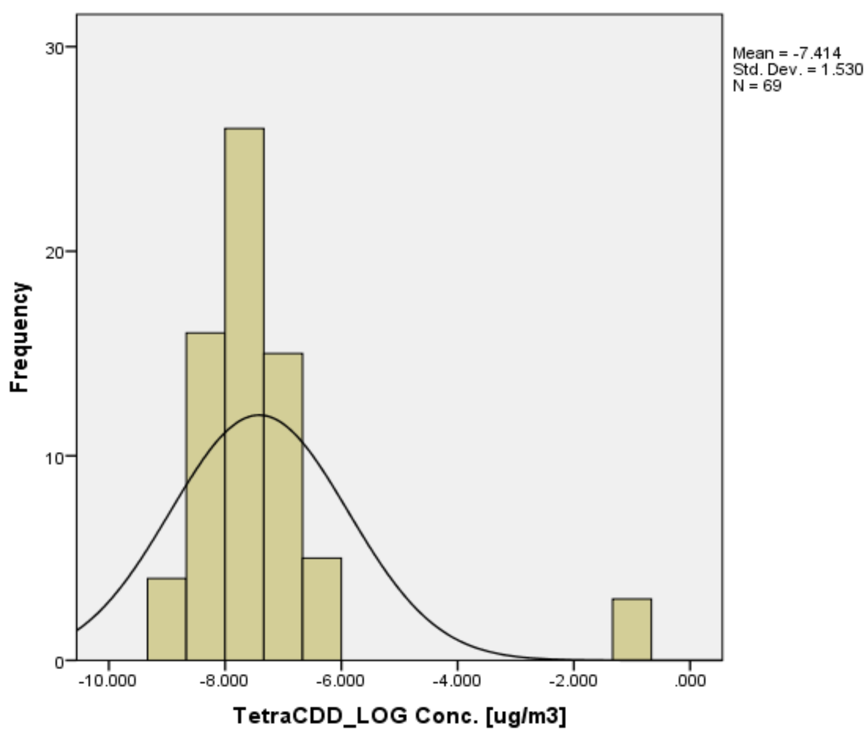


Figure 4-3: Benzo[a]pyrene (PAH) Histogram before log transformation.

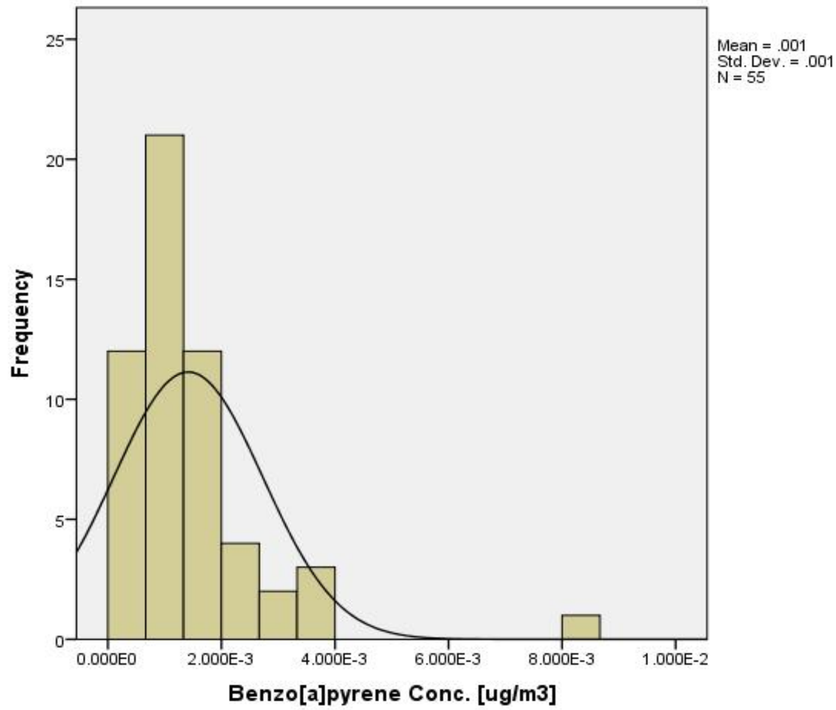


Figure 4-4: Benzo[a]pyrene (PAH) Histogram after log transformation.

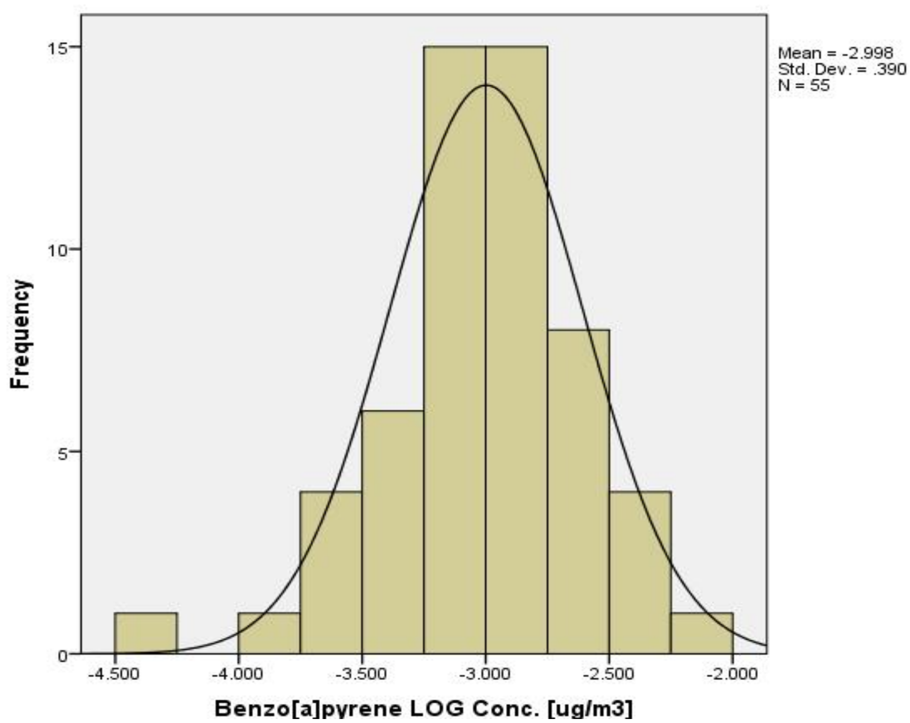


Figure 4-5: Benzene (VOC) histogram before log transformation.

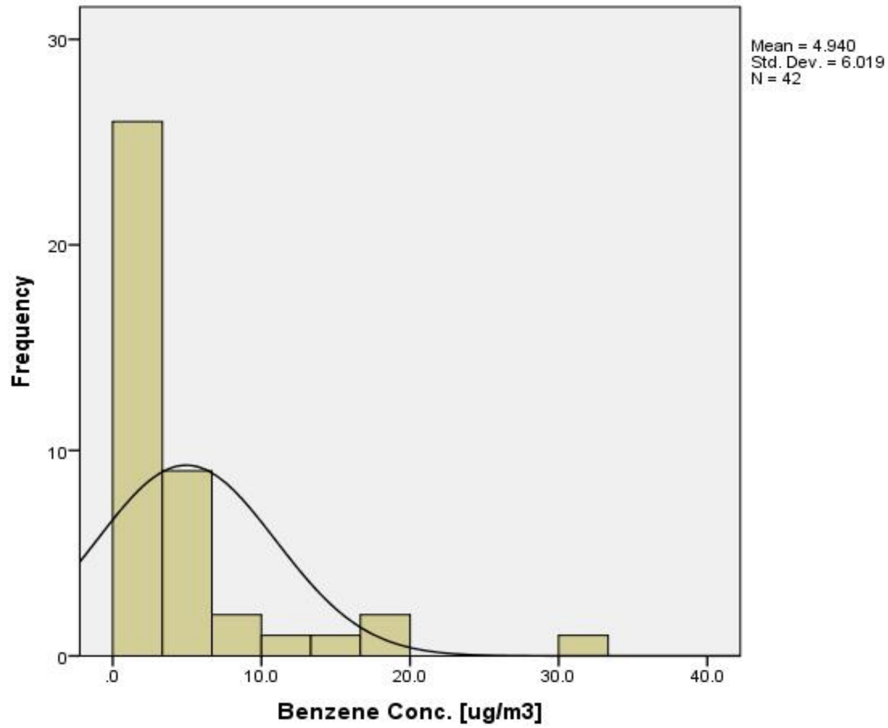


Figure 4-6: Benzene (VOC) histogram after log transformation.

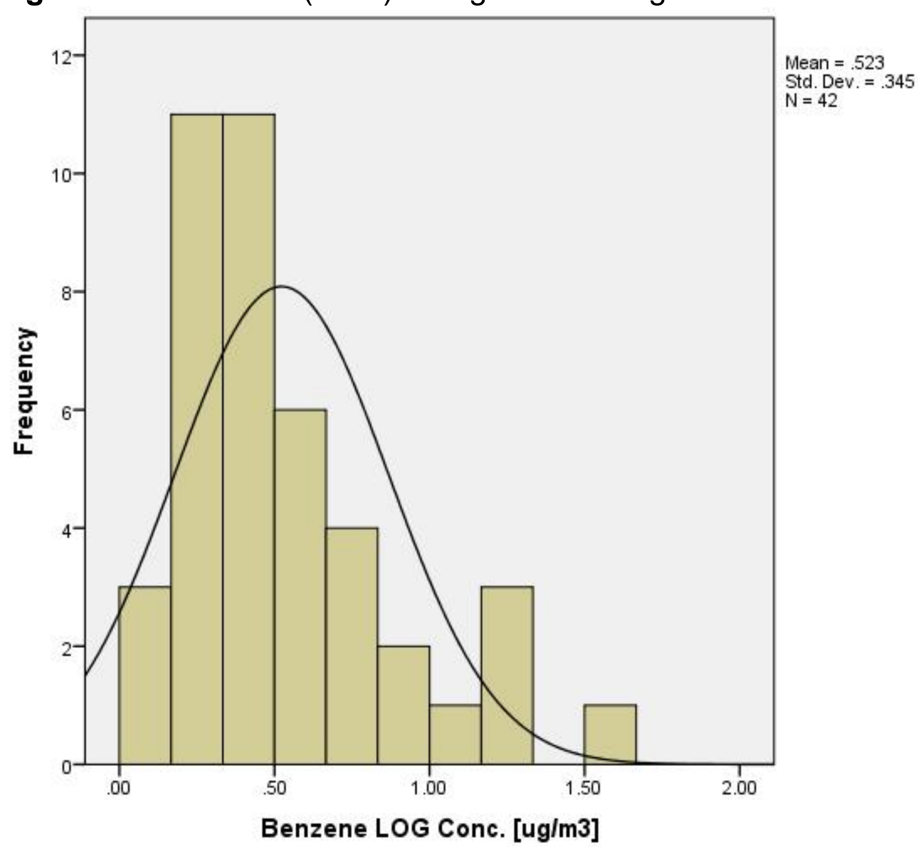


Figure 4-7: *n*-heptane (VOC) histogram before log transformation.

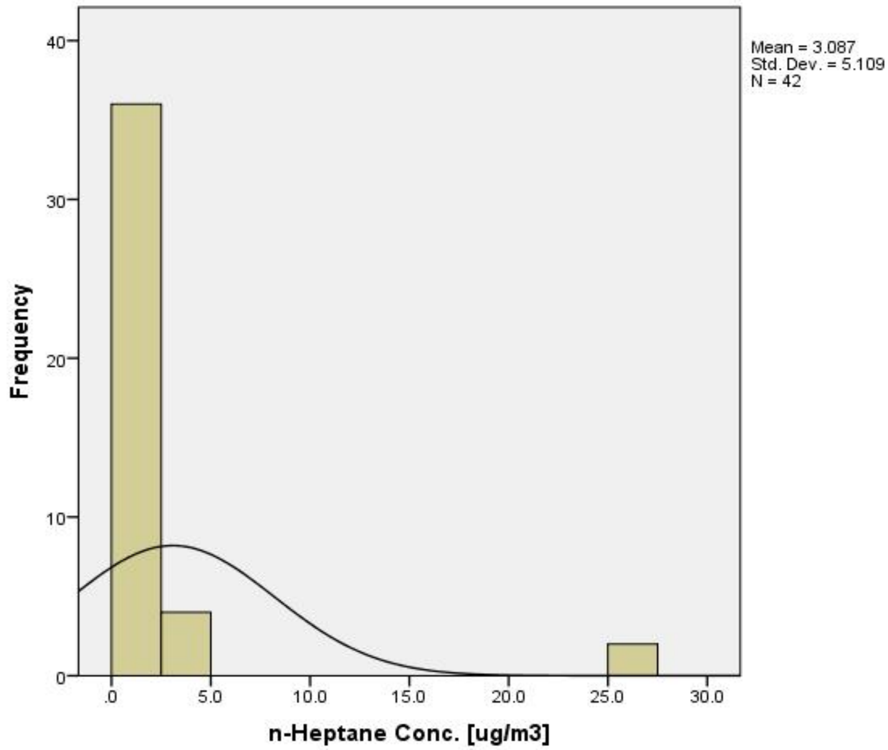


Figure 4-8: *n*-heptane (VOC) histogram after log transformation.

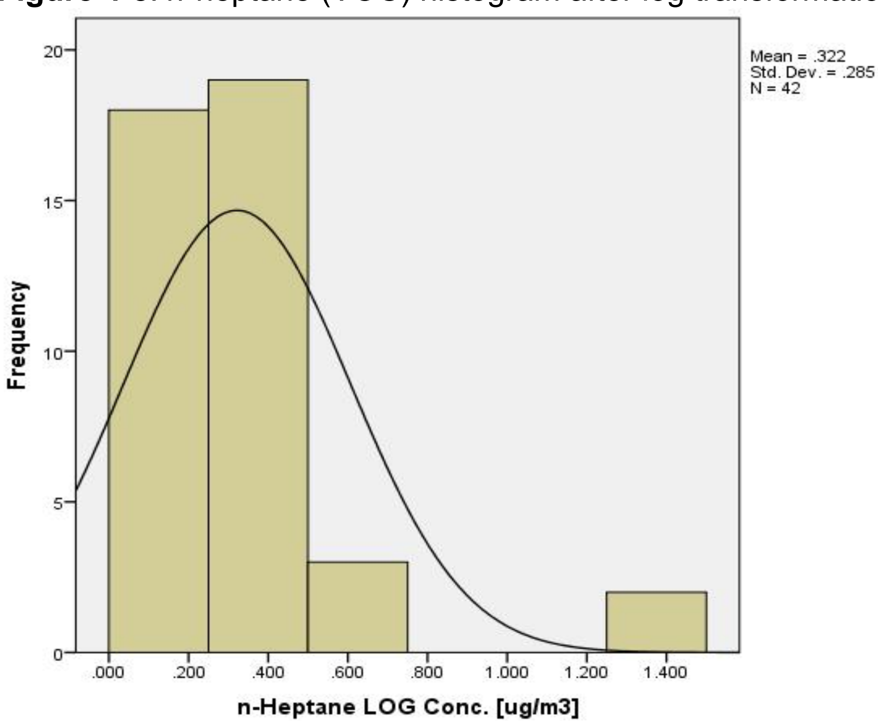


Figure 4-9: Cadmium (Metals) Histogram before log transformation.

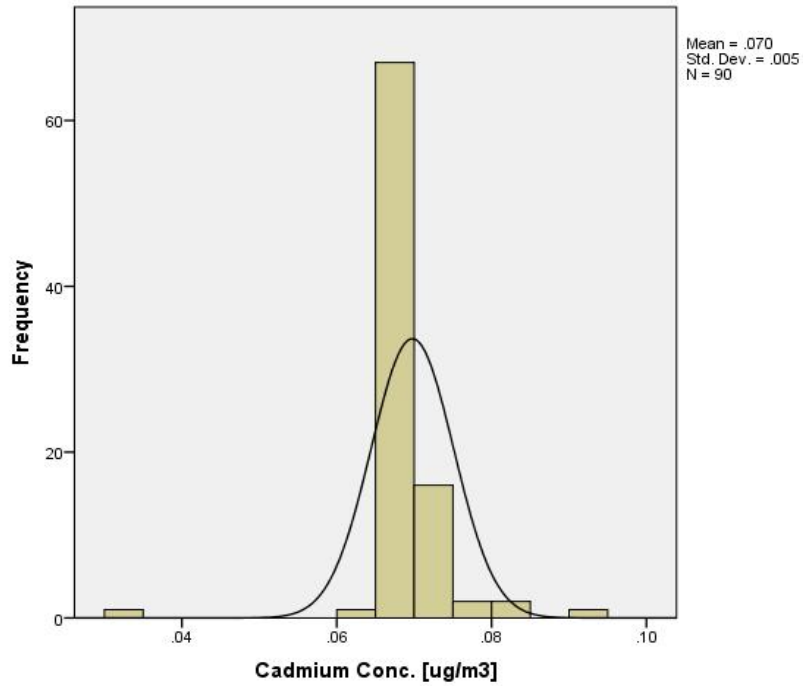


Figure 4-10: Cadmium (Metals) Histogram after log transformation.

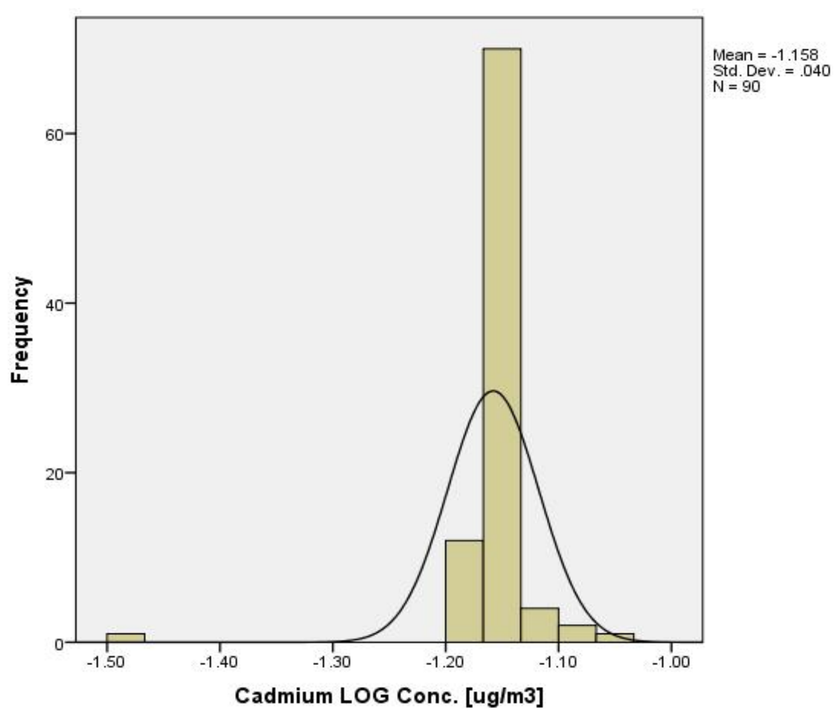


Figure 4-11: Lead (Metals) Histogram before log transformation.

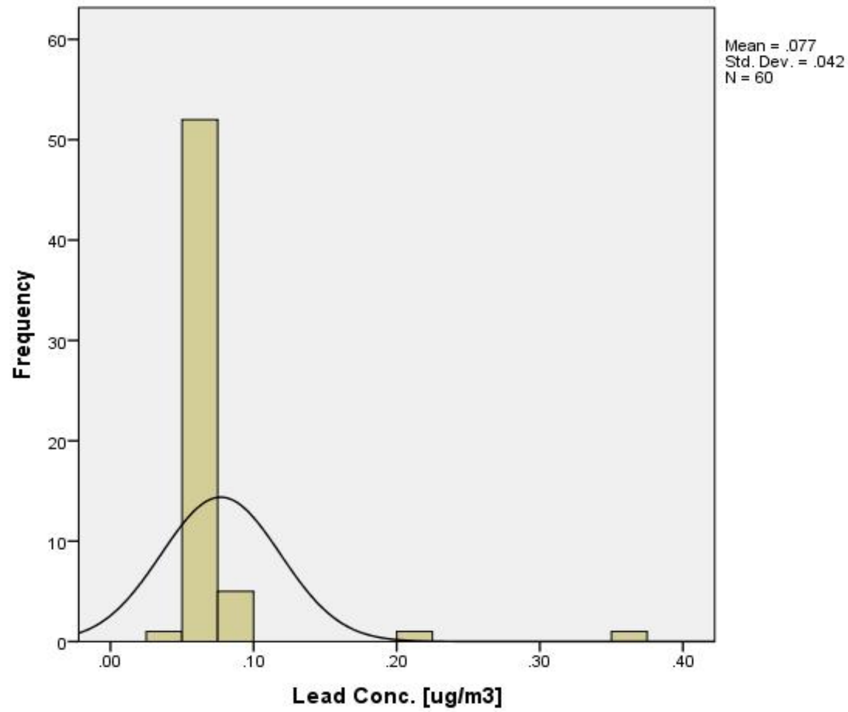
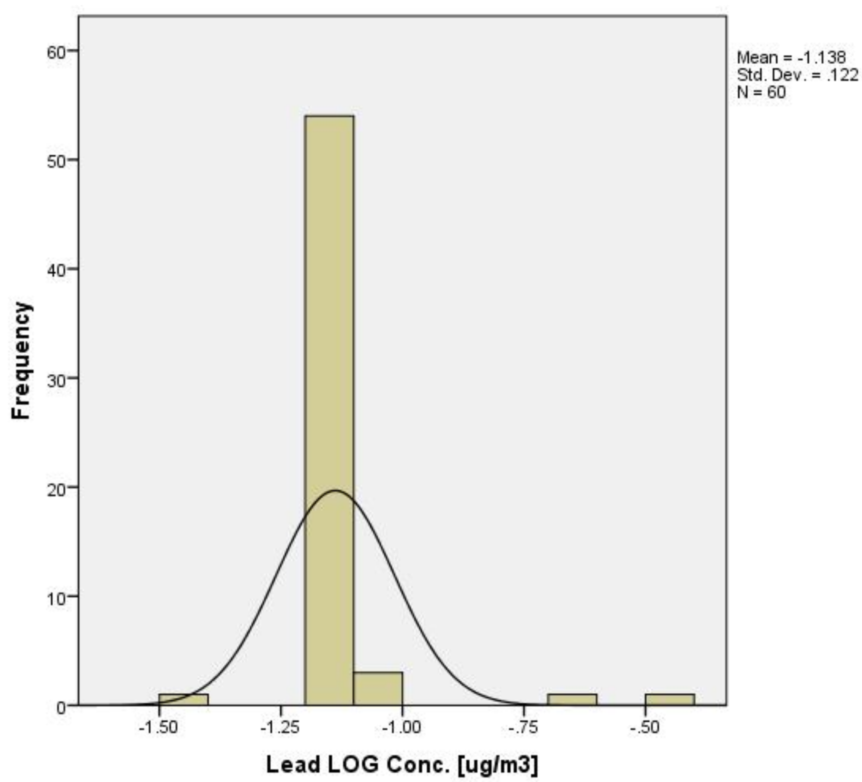


Figure 4-12: Lead (Metals) Histogram after log transformation.



Multiple Comparison Results of the Analyte Mean Concentrations

The selection of correlated analytes to represent each chemical group (Metals, PAH, VOC and Dioxin-Furan) were based on Levene's statistic (Test of Homogeneity of Variances) and the One-way Analysis of Variance (ANOVA) multiple pairwise comparisons. Comparing the p-value to the alpha value (α) of 0.05 determined whether or not to utilize Tukey's procedure or Dunnett's-C procedure to calculate the multiple pairwise comparison with the IBM SPSS® Statistics V20 program.[59] If the p-value is less than or equal to the alpha value of 0.05, the null hypothesis (H_o – the variances are equal) was rejected. Table 4-2 lists the results of Levene's statistics for the four chemical groups.

Table 4-2: Results of Levene's Statistics – Test of Homogeneity of Variances

Chemical Group	Levene Statistic	P-Value	α - Value	H_o – Null Hypothesis	Comparison Method
Metals	3.275	0.040	0.050	Reject	Dunnett's - C
PAH	0.993	0.423	0.050	Accept	Tukey
VOC	5.051	0.000	0.050	Reject	Dunnett's - C
Dioxin-Furan	3.007	0.012	0.050	Reject	Dunnett's - C

Figures 4-13 thru 4-16 represent the ANOVA pairwise comparison results for all analytes within each chemical group generated from the IBM SPSS® Statistics V20 program.[59]

Figure 4-13: Metals Group Multiple Comparisons Result

Multiple Comparisons

Dependent Variable: Concentration
Dunnett C

(I) Metals_PM10	(J) Metals_PM10	Mean Difference (I-J)	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Arsenic	Cadmium	.01746	.00911	-.0044	.0394
	Lead	-.30362*	.01701	-.3445	-.2627
Cadmium	Arsenic	-.01746	.00911	-.0394	.0044
	Lead	-.32108*	.01693	-.3618	-.2804
Lead	Arsenic	.30362*	.01701	.2627	.3445
	Cadmium	.32108*	.01693	.2804	.3618

*. The mean difference is significant at the 0.05 level.

Based on the ANOVA multiple comparison results, arsenic and cadmium are correlated; whereas, the analyte lead does not correlate with either arsenic or cadmium. This statement is based on the fact that zero falls within the lower and upper bound ranges of the 95% confidence interval. Figure 4-14 represents the ANOVA pairwise comparison results for the PAH chemical group. The ANOVA multiple comparison results indicate that benzo[a]pyrene, anthracene and chrysene are correlated. The ANOVA pairwise comparison results for the VOC chemical group (Figure 4-15) indicate that the analytes *n*-heptane, benzene, chloromethane, hexane and o-xylene are correlated and acetone did not correlate with any of the analytes within the VOC group.

Figure 4-14: PAH Chemical Group Multiple Comparisons Result

Multiple Comparisons

Dependent Variable: Concentration
Tukey HSD

(I) PAH	(J) PAH	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Acenaphthylene	Anthracene	.48568*	.13996	.008	.0826	.8887
	Benzo[a]pyrene	.81249*	.13996	.000	.4095	1.2155
	Chrysene	.50476*	.13996	.005	.1017	.9078
	Naphthalene	-1.49070*	.13996	.000	-1.8937	-1.0877
	Pyrene	.04812	.13996	.999	-.3549	.4512
Anthracene	Acenaphthylene	-.48568*	.13996	.008	-.8887	-.0826
	Benzo[a]pyrene	.32681	.13996	.185	-.0762	.7298
	Chrysene	.01908	.13996	1.000	-.3840	.4221
	Naphthalene	-1.97638*	.13996	.000	-2.3794	-1.5733
	Pyrene	-.43756*	.13996	.025	-.8406	-.0345
Benzo[a]pyrene	Acenaphthylene	-.81249*	.13996	.000	-1.2155	-.4095
	Anthracene	-.32681	.13996	.185	-.7298	.0762
	Chrysene	-.30773	.13996	.243	-.7108	.0953
	Naphthalene	-2.30319*	.13996	.000	-2.7062	-1.9001
	Pyrene	-.76437*	.13996	.000	-1.1674	-.3613
Chrysene	Acenaphthylene	-.50476*	.13996	.005	-.9078	-.1017
	Anthracene	-.01908	.13996	1.000	-.4221	.3840
	Benzo[a]pyrene	.30773	.13996	.243	-.0953	.7108
	Naphthalene	-1.99546*	.13996	.000	-2.3985	-1.5924
	Pyrene	-.45664*	.13996	.016	-.8597	-.0536
Naphthalene	Acenaphthylene	1.49070*	.13996	.000	1.0877	1.8937
	Anthracene	1.97638*	.13996	.000	1.5733	2.3794
	Benzo[a]pyrene	2.30319*	.13996	.000	1.9001	2.7062
	Chrysene	1.99546*	.13996	.000	1.5924	2.3985
	Pyrene	1.53882*	.13996	.000	1.1358	1.9419
Pyrene	Acenaphthylene	-.04812	.13996	.999	-.4512	.3549
	Anthracene	.43756*	.13996	.025	.0345	.8406
	Benzo[a]pyrene	.76437*	.13996	.000	.3613	1.1674
	Chrysene	.45664*	.13996	.016	.0536	.8597
	Naphthalene	-1.53882*	.13996	.000	-1.9419	-1.1358

*. The mean difference is significant at the 0.05 level.

Figure 4-15: VOC Chemical Group Multiple Comparisons Result

Multiple Comparisons

Dependent Variable: Concentration
Dunnett C

(I) VOC	(J) VOC	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Acetone	Benzene	.63886*	.07528	.4055	.8722
	Chloromethane	.95278*	.05992	.7671	1.1385
	Hexane	.78835*	.06868	.5755	1.0012
	n-Heptane	.83997*	.06906	.6259	1.0540
	o-Xylene	.84956*	.06346	.6529	1.0462
	Toluene	.44191*	.08084	.1914	.6924
Benzene	Acetone	-.63886*	.07528	-.8722	-.4055
	Chloromethane	.31392*	.06001	.1279	.4999
	Hexane	.14949	.06875	-.0636	.3626
	n-Heptane	.20111	.06913	-.0131	.4154
	o-Xylene	.21070*	.06354	.0138	.4076
	Toluene	-.19695	.08090	-.4477	.0538
Chloromethane	Acetone	-.95278*	.05992	-1.1385	-.7671
	Benzene	-.31392*	.06001	-.4999	-.1279
	Hexane	-.16443*	.05148	-.3240	-.0049
	n-Heptane	-.11281	.05198	-.2739	.0483
	o-Xylene	-.10322	.04428	-.2405	.0340
	Toluene	-.51087*	.06684	-.7180	-.3037
Hexane	Acetone	-.78835*	.06868	-1.0012	-.5755
	Benzene	-.14949	.06875	-.3626	.0636
	Chloromethane	.16443*	.05148	.0049	.3240
	n-Heptane	.05162	.06187	-.1401	.2434
	o-Xylene	.06121	.05556	-.1110	.2334
	Toluene	-.34644*	.07480	-.5782	-.1146
n-Heptane	Acetone	-.83997*	.06906	-1.0540	-.6259
	Benzene	-.20111	.06913	-.4154	.0131
	Chloromethane	.11281	.05198	-.0483	.2739
	Hexane	-.05162	.06187	-.2434	.1401
	o-Xylene	.00959	.05603	-.1641	.1832
	Toluene	-.39806*	.07514	-.6309	-.1652
o-Xylene	Acetone	-.84956*	.06346	-1.0462	-.6529
	Benzene	-.21070*	.06354	-.4076	-.0138
	Chloromethane	.10322	.04428	-.0340	.2405
	Hexane	-.06121	.05556	-.2334	.1110
	n-Heptane	-.00959	.05603	-.1832	.1641
	Toluene	-.40765*	.07004	-.6247	-.1906
Toluene	Acetone	-.44191*	.08084	-.6924	-.1914
	Benzene	.19695	.08090	-.0538	.4477
	Chloromethane	.51087*	.06684	.3037	.7180
	Hexane	.34644*	.07480	.1146	.5782
	n-Heptane	.39806*	.07514	.1652	.6309
	o-Xylene	.40765*	.07004	.1906	.6247

*. The mean difference is significant at the 0.05 level.

Figure 4-16: Dioxin-Furan Chemical Group Multiple Comparisons Result

Multiple Comparisons

Dependent Variable: Concentration
Dunnett C

(I) PCDD_PCDF	(J) PCDD_PCDF	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
HeptaCDD	HexaCDF	.16501	.21039	-.4624	.7924
	PentaCDD	.94056*	.27143	.1312	1.7500
	PentaCDF	.51247	.20825	-.1085	1.1335
	TetraCDD	1.04609	.36691	-.0480	2.1402
	TetraCDF	.76642*	.20247	.1626	1.3702
HexaCDF	HeptaCDD	-.16501	.21039	-.7924	.4624
	PentaCDD	.77554*	.22727	.0978	1.4533
	PentaCDF	.34746	.14611	-.0882	.7831
	TetraCDD	.88108	.33556	-.1196	1.8817
	TetraCDF	.60140*	.13775	.1906	1.0122
PentaCDD	HeptaCDD	-.94056*	.27143	-1.7500	-.1312
	HexaCDF	-.77554*	.22727	-1.4533	-.0978
	PentaCDF	-.42809	.22529	-1.0999	.2437
	TetraCDD	.10553	.37684	-1.0182	1.2293
	TetraCDF	-.17414	.21997	-.8301	.4818
PentaCDF	HeptaCDD	-.51247	.20825	-1.1335	.1085
	HexaCDF	-.34746	.14611	-.7831	.0882
	PentaCDD	.42809	.22529	-.2437	1.0999
	TetraCDD	.53362	.33422	-.4630	1.5303
	TetraCDF	.25395	.13446	-.1470	.6549
TetraCDD	HeptaCDD	-1.04609	.36691	-2.1402	.0480
	HexaCDF	-.88108	.33556	-1.8817	.1196
	PentaCDD	-.10553	.37684	-1.2293	1.0182
	PentaCDF	-.53362	.33422	-1.5303	.4630
	TetraCDF	-.27967	.33066	-1.2657	.7063
TetraCDF	HeptaCDD	-.76642*	.20247	-1.3702	-.1626
	HexaCDF	-.60140*	.13775	-1.0122	-.1906
	PentaCDD	.17414	.21997	-.4818	.8301
	PentaCDF	-.25395	.13446	-.6549	.1470
	TetraCDD	.27967	.33066	-.7063	1.2657

*. The mean difference is significant at the 0.05 level.

From Figure 4-16 (Dioxin-Furan Chemical Group Multiple Comparisons Result) analytes PentaCDF and TetraCDD correlate with all analytes within the Dioxin-

Furan Group. Based on the ANOVA multiple comparison analysis results, the following analytes could be selected as representatives of each chemical group:

- Cadmium: Metals chemical group
- Lead: Metals chemical group
- Benzo[a]pyrene: PAH chemical group
- Benzene: VOC chemical group
- n-Heptane: VOC chemical group
- 2,3,7,8 TetraCDD: Dioxin-Furan chemical group

Aggregate Data Results

Results from the analyte log concentration versus sampling period aggregate graph indicate that a temporal association between analyte log concentration and the sampling periods exists for the 2,3,7,8 TetraCDD, cadmium, lead, benzene and *n*-heptane analytes. The aggregate graphs for these analytes indicate that the mean log concentration values decrease during the four sample – transition stages at JBB. However, the benzo[a]pyrene analyte recorded a negative correlation (mean log concentration increases during the sample-transition stages) to ambient air quality (Refer to Figure 4-17). Despite cadmium's positive correlation (mean log concentration decreases) to Balad's ambient air quality during the four sampling periods, a p-value >0.05 for the Spearman test results indicate that the correlation was not statistically significant (Refer to Table 4-4).

Table 4-3: Spearman Results for Benzo[a]pyrene

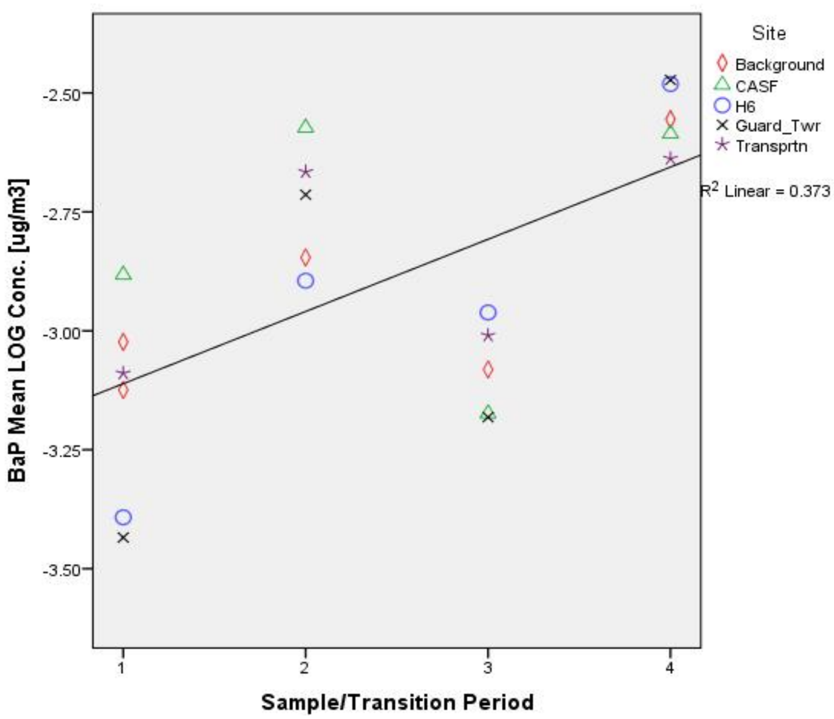
Correlations

			Period	Benzo_a_pyrene_mean_1
Spearman's rho	Period	Correlation Coefficient	1.000	.598**
		Sig. (2-tailed)	.	.004
		N	21	21
	Benzo_a_pyrene_mean_1	Correlation Coefficient	.598**	1.000
		Sig. (2-tailed)	.004	.
		N	21	21

**. Correlation is significant at the 0.01 level (2-tailed).

The positive Spearman correlation coefficient value (0.598) indicates analyte concentration for benzo[a]pyrene increased during the four sampling - transition periods at JBB.

Figure 4-17: Benzo[a]pyrene Aggregate Graph



The benzo[a]pyrene aggregate graph in Figure 4-17 indicates an increase in analyte concentration during the first two sampling periods, a decrease in concentration during the third sampling period and mean log concentration values greater in the fourth sample period when compared to values in the first sample period.

Table 4-4: Spearman Results for Cadmium

Correlations

			Period	Cadmium_mean
Spearman's rho	Period	Correlation Coefficient	1.000	-.318
		Sig. (2-tailed)	.	.172
		N	20	20
	Cadmium_mean	Correlation Coefficient	-.318	1.000
		Sig. (2-tailed)	.172	.
		N	20	20

The negative Spearman correlation coefficient value (-0.318) indicates that the analyte concentration of cadmium decreased over the four sampling periods. With the exception of the housing sample site (H6), all sample sites experienced a decrease in mean log concentration values over the sample periods.

Figure 4-18: Cadmium Aggregate Graph

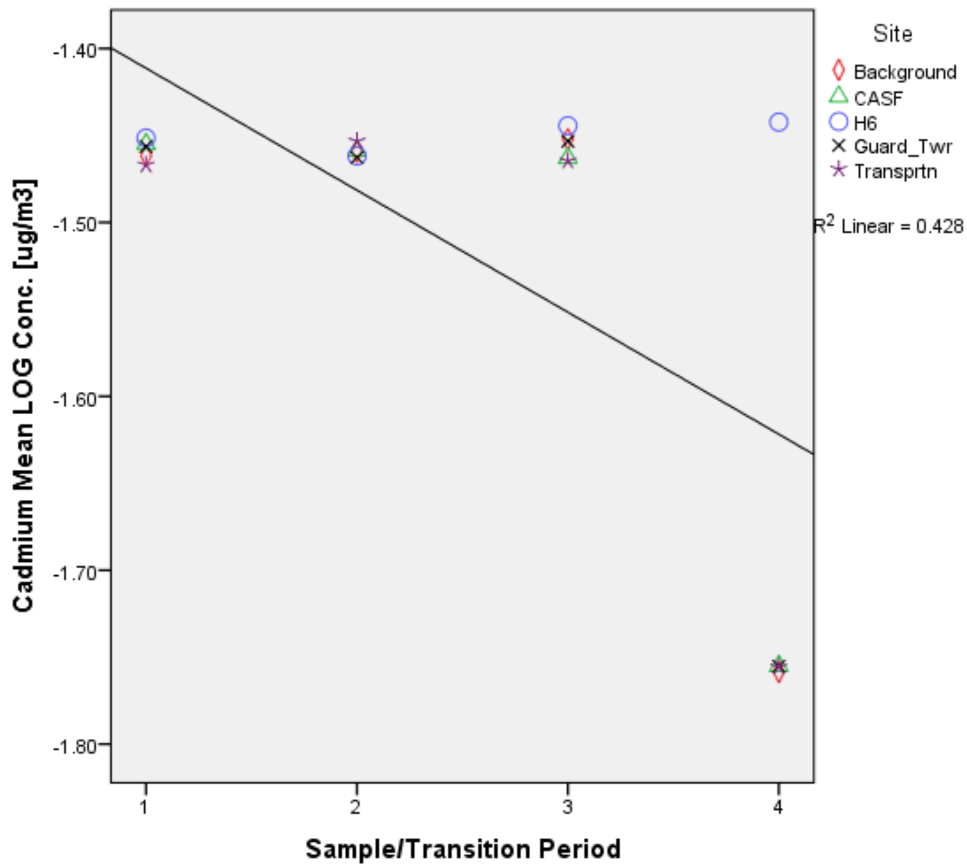


Table 4-5: Spearman Results for Lead

Correlations

			Period	Lead_mean
Spearman's rho	Period	Correlation Coefficient	1.000	-.349
		Sig. (2-tailed)	.	.132
		N	20	20
	Lead_mean	Correlation Coefficient	-.349	1.000
		Sig. (2-tailed)	.132	.
		N	20	20

The negative Spearman correlation coefficient value (-0.349) indicates that the analyte concentration of lead decreased over the four sampling periods.

Similar to cadmium, the H6 (housing sample site) observed the highest mean log concentration value at the last sampling period.

Figure 4-19: Lead Aggregate Graph

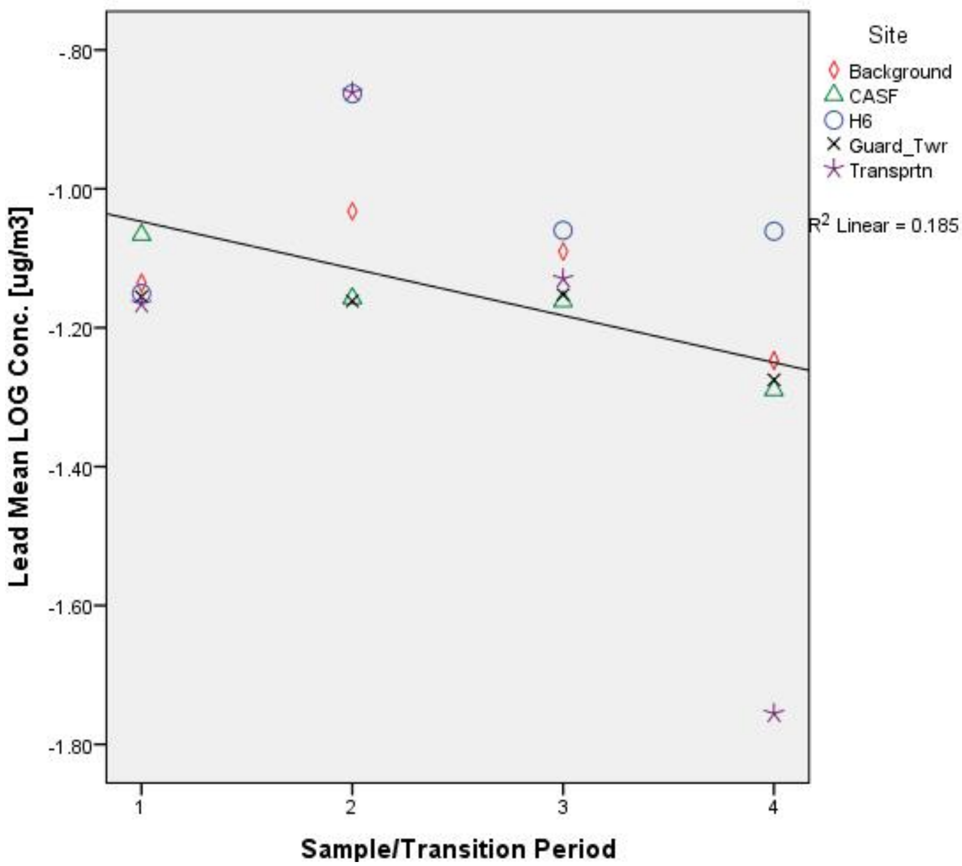
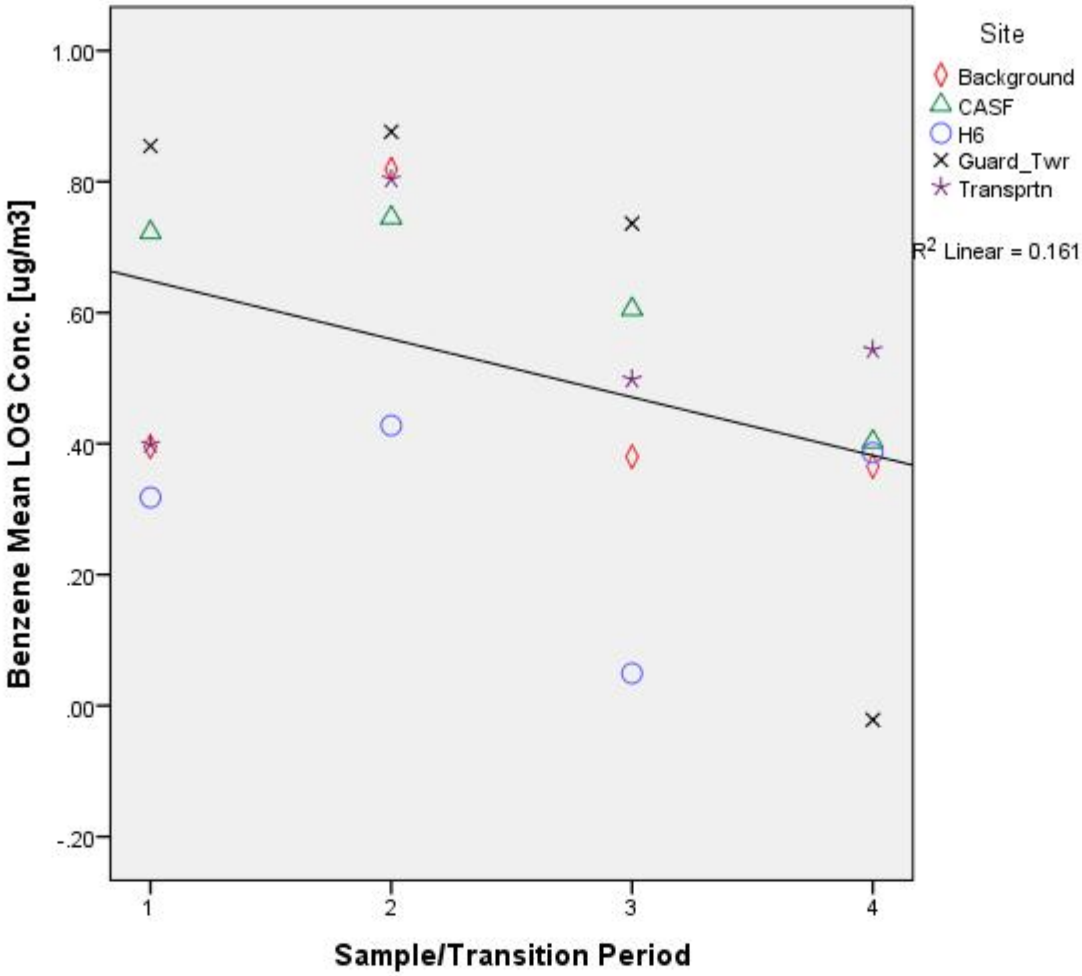


Table 4-6: Spearman Results for Benzene

Correlations

			Period	Benzene_mean
Spearman's rho	Period	Correlation Coefficient	1.000	-.357
		Sig. (2-tailed)	.	.123
		N	20	20
	Benzene_mean	Correlation Coefficient	-.357	1.000
		Sig. (2-tailed)	.123	.
		N	20	20

Figure 4-20: Benzene Aggregate Graph



The negative Spearman correlation coefficient value (-0.357) in Table 4-6, indicates that the analyte concentration of benzene decreased over the four sampling periods. Based on Figure 4-20, the transportation and housing (H6) sample sites recorded increases of benzene concentration in comparing sample period 1 versus sample period 4. Table 4-7 indicates that *n*-heptane's mean concentration value decreased over the four sampling period (Spearman correlation coefficient value of -0.496). Unlike benzene, an analyte from the same VOC chemical group, both the background and transportation sites recorded increases of *n*-heptane concentration in comparing sample period 1 versus sample period 4 (Figure 4-21).

Table 4-7: Spearman Results for *n*-heptane

Correlations

			Period	n_Heptane_mean
Spearman's rho	Period	Correlation Coefficient	1.000	-.496*
		Sig. (2-tailed)	.	.026
		N	20	20
	n_Heptane_mean	Correlation Coefficient	-.496*	1.000
		Sig. (2-tailed)	.026	.
		N	20	20

*. Correlation is significant at the 0.05 level (2-tailed).

Figure 4-21: *n*-heptane Aggregate Graph

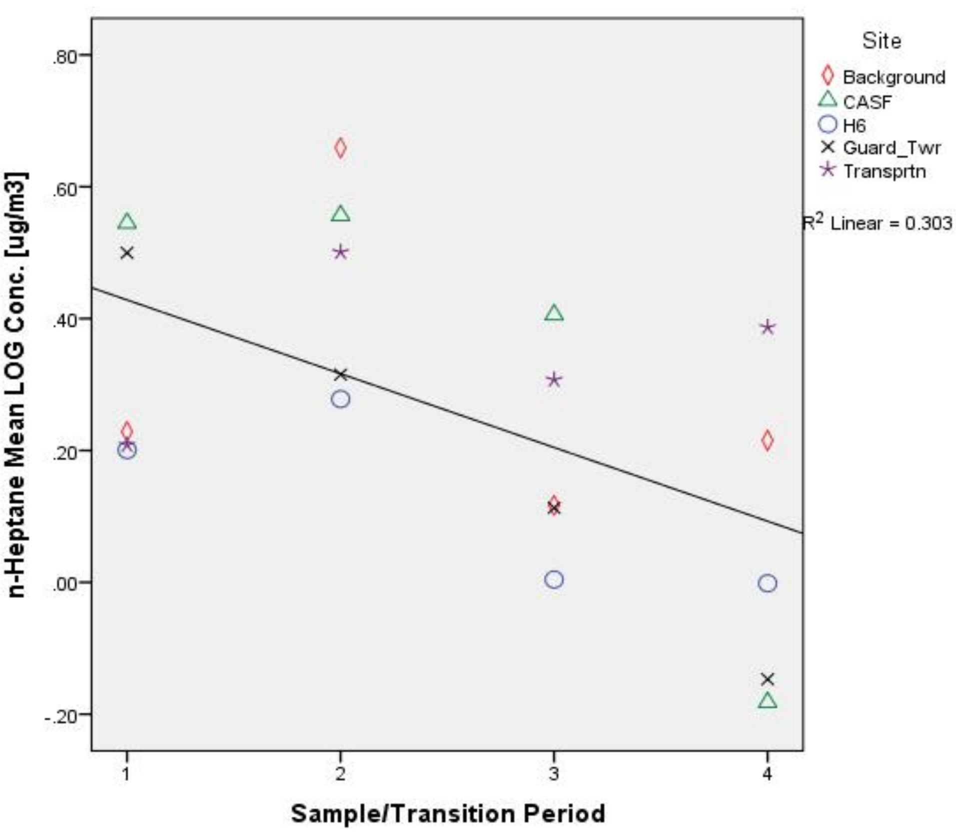


Table 4-8 indicates that the TetraCDD mean log concentration value decreased over the four sampling period (Spearman correlation coefficient value of -0.760). Unlike the analytes from the three chemical groups (Metals, VOC, PAH), all five sample sites for tetraCDD recorded a decrease in analyte concentration in comparing sample period 1 versus sample period 4 (Figure 4-18).

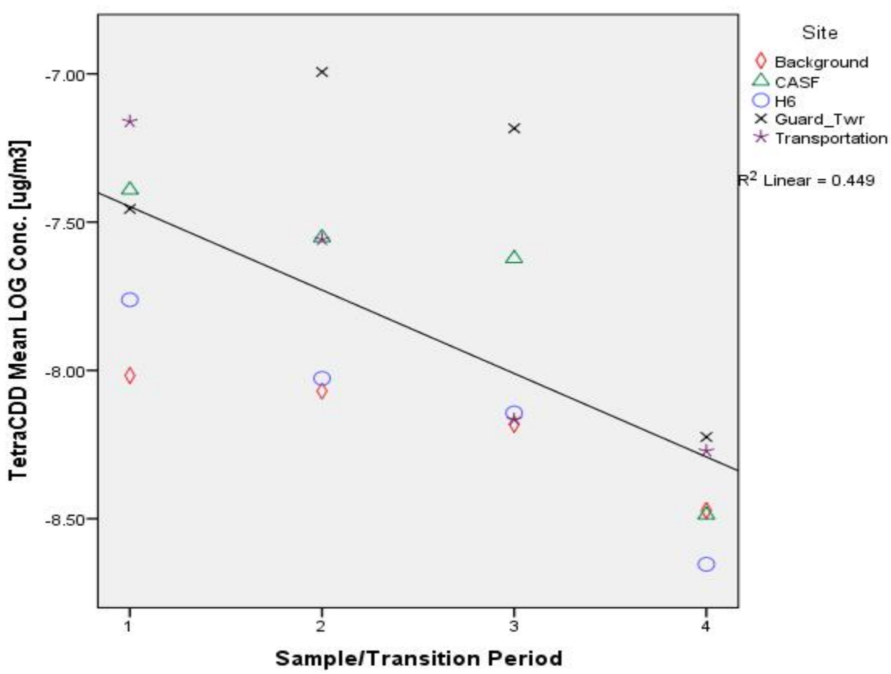
Table 4-8: Spearman Results for TetraCDD

Correlations

			Period	TetraCDD_mean
Spearman's rho	Period	Correlation Coefficient	1.000	-.760**
		Sig. (2-tailed)	.	.000
		N	20	20
	TetraCDD_mean	Correlation Coefficient	-.760**	1.000
		Sig. (2-tailed)	.000	.
		N	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4-22: TetraCDD Aggregate Graph



Multiple Linear Fixed Effect Regression Model Results

Coefficient results for the benzo[a]pyrene linear fixed effect regression model are shown on Figure 4-19. The beta (B-coefficients) values for the independent variables of wind speed and temperature are -0.008 and -0.023, respectively. The p-values for temperature (<0.001) and wind speed (0.045) are below the alpha value ($\alpha = 0.05$) indicating that each of these factors contribute significantly to the benzo[a]pyrene (BaP) concentration. The beta value of -0.023 for the wind speed variable indicated that as the wind speed increased over the sample periods, the analyte concentration decreased by 0.023 units. The temperature beta value of – 0.008 also indicated that as temperature increased during the sample periods, the analyte concentration decreased by 0.008 units. All sample sites recorded a p-value >0.05 resulting in no significant differences of the sites when compared to the background sample site (Site 5). The Period variable results demonstrated a p-value $\leq$ 0.05 indicating that the sample - transition periods have a significant effect on BaP's concentration. The pattern of the data points on the P-P plot of the benzo[a]pyrene linear fixed effect regression model (Figure 4-21), correlated with the histogram frequency bar(s) exceeding the normal distribution curve line (Figure 4-20). Each of the P-P plots for the chemical groups had similar characteristics with the histogram frequency bar(s) and normal distribution curve line(s).

Figure 4-19: Benzo[a]pyrene B-coefficient Results

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
3	(Constant)	-2.828	.128		-22.019	.000
	CASF	-.021	.079	-.019	-.268	.789
	H6	-.025	.070	-.025	-.353	.725
	Guard Tower	-.054	.071	-.054	-.762	.447
	Transportation	.053	.070	.053	.749	.455
	Period	.235	.024	.672	10.003	.000
	Temp	-.008	.002	-.302	-4.194	.000
	WindSpd	-.023	.011	-.140	-2.018	.045

Coefficients[a]

a. Dependent Variable: Benzo_a_pyrene

Figure 4-20: Benzo[a]pyrene Linear Fixed Effect Regression Histogram

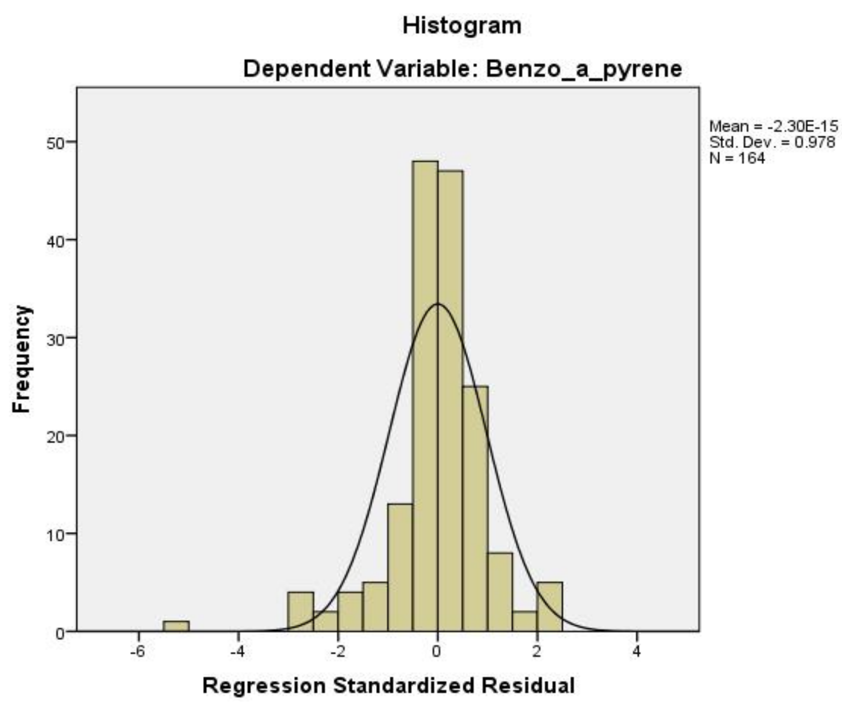
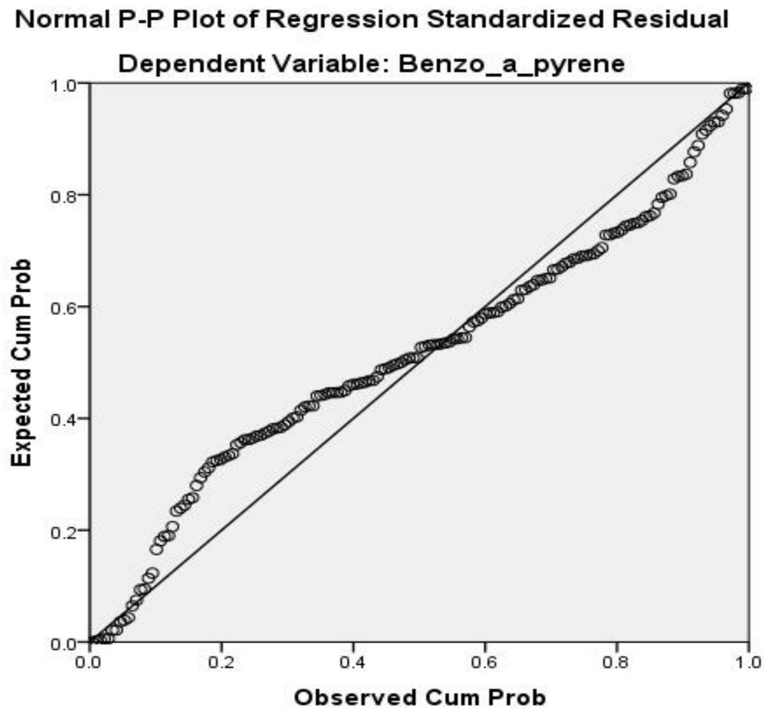


Figure 4-21: Benzo[a]pyrene Linear Fixed Effect Regression P-P Plot



The metals chemical group (cadmium and lead) coefficient results, histogram and P-P plots of the linear fixed effect model are shown in Figures 4-22 to 4-27. The cadmium B-coefficient values for troop level and temperature indicate a positive correlation. The troop level coefficient of 0.465 indicated cadmium log concentration increased as troop levels increased; a p-value $\leq$ 0.05 indicate that both temperature and troop level have a significant effect on the log concentration value for cadmium. The CASF, H6 and transportation sample sites observed a p-value >0.05 signifying no significant differences in comparison to Site 5 (Background sample site). However, Site 7 (Transportation) recorded a p-value $\leq$0.05 which indicates a statistical difference between the remaining sample sites (CASF, H6, transportation) and the background sample site. A p-value >0.05 for Period, reflects that the sample-transition periods do not affect the analyte log concentration value.

Unlike cadmium, the variable that had the most significant effect on the analyte lead concentration is the troop level. A beta-coefficient value 0.673 (troop level) represents a positive correlation with the analyte log concentration. CASF and guard tower sites recorded a p-value >0.05 reflecting no significant differences between these sites and the background sample site. Site 9 (Transportation) observed a p-value ≤ 0.05 indicating a statistical difference in comparison to Site 5 (background sample site). The Period variable had a p-value ≤ 0.05, which suggests that the sample-transition periods have an effect on the log concentration value for lead.

Figure 4-22: Cadmium B-coefficient Results

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
3	(Constant)	-2.313	.077		-30.018	.000
	CASF	-.010	.014	-.029	-.716	.475
	H6	.090	.014	.268	6.574	.000
	Guard Tower	-.010	.014	-.030	-.735	.463
	Transportation	.006	.013	.018	.440	.660
	Period	.005	.011	.043	.436	.663
	Troop_Lvl	.465	.046	.893	10.019	.000
	Temp	.002	.000	.248	5.300	.000

a. Dependent Variable: Cadmium

Figure 4-23: Cadmium Linear Fixed Effect Regression Histogram

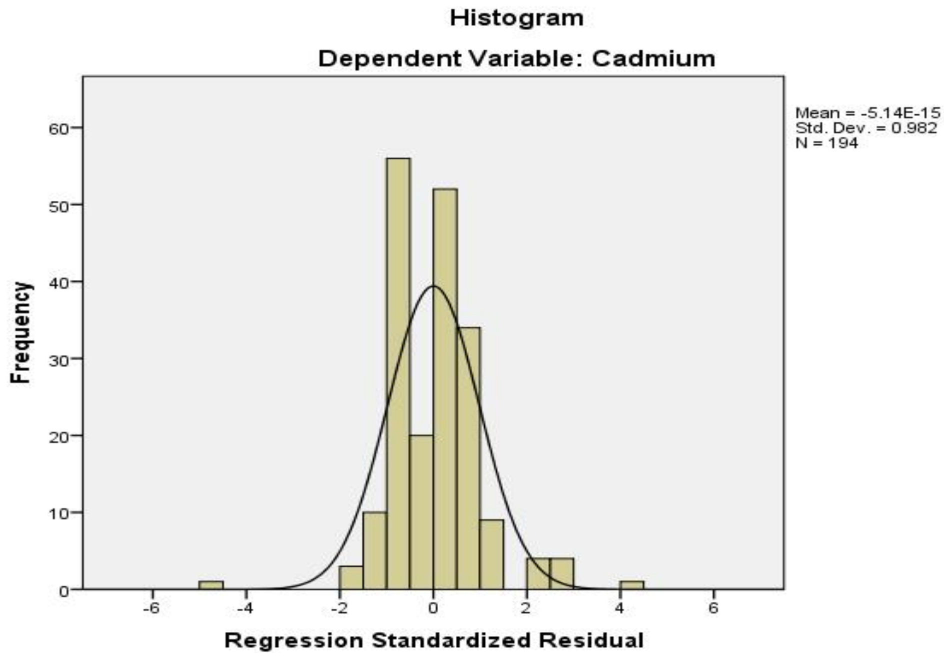


Figure 4-24: Cadmium Linear Fixed Effect Regression P-P Plot

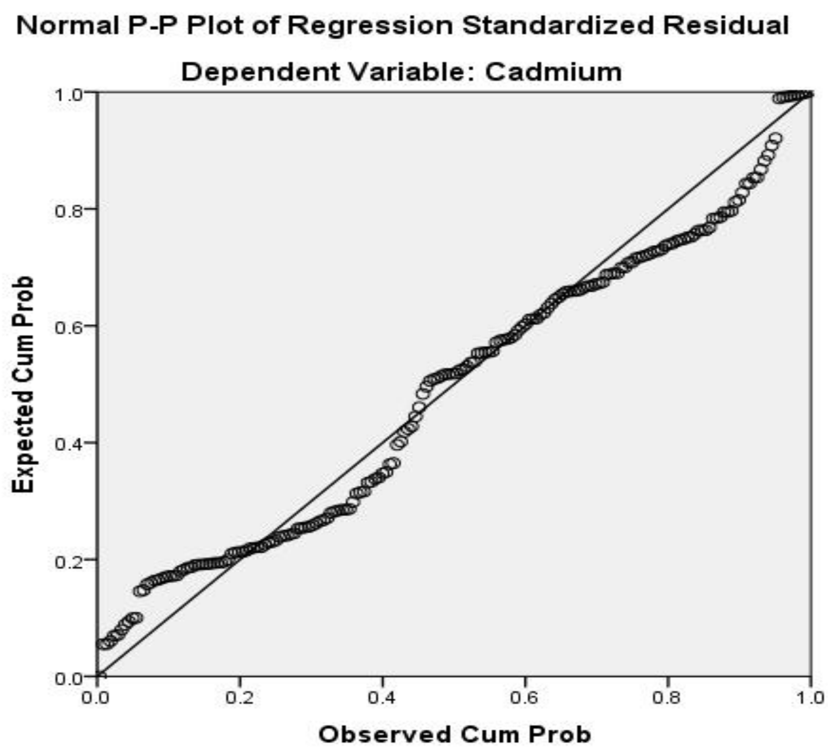


Figure 4-25: Lead (Metals) B-coefficient Results

Coefficients[a]						
Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
2	(Constant)	-2.211	.270		-8.175	.000
	CASF	-.042	.051	-.059	-.812	.418
	H6	.078	.049	.116	1.583	.115
	Guard Tower	-.065	.050	-.095	-1.291	.198
	Transportation	-.110	.048	-.171	-2.300	.023
	Period	.070	.031	.324	2.260	.025
	Troop_Lvl	.673	.148	.648	4.539	.000

a. Dependent Variable: Lead

Figure 4-26: Lead (Metals) Linear Fixed Effect Regression Histogram

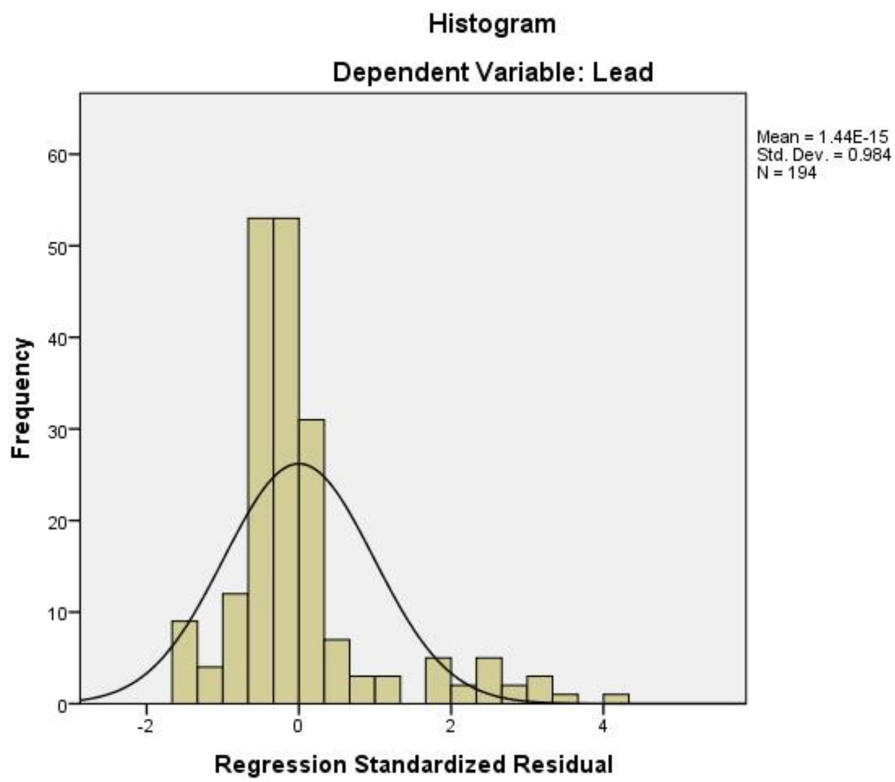
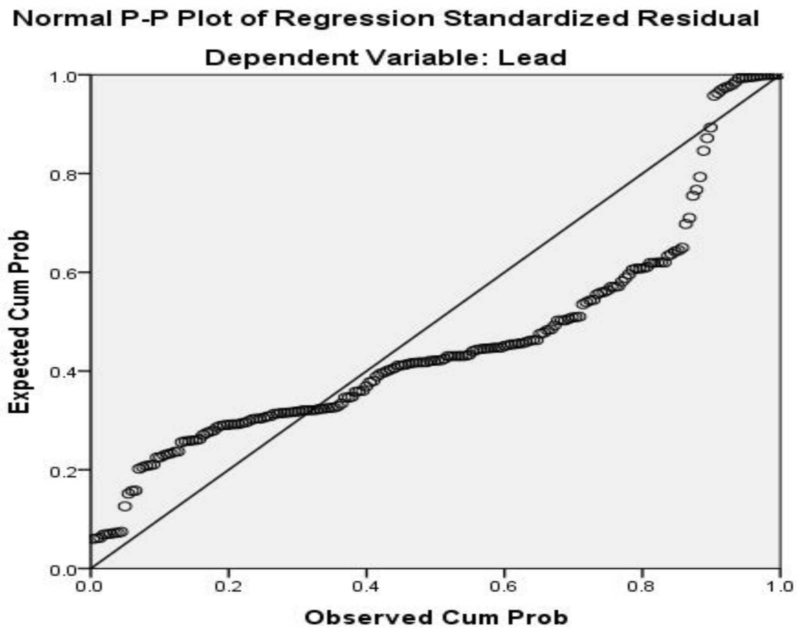


Figure 4-27: Lead (Metals) Linear Fixed Effect Regression P-P Plot



The benzene linear fixed effect regression model suggested that troop level, wind speed and wind direction have an effect on the analyte log concentration, since the p-values for all variables were less than 0.05 ($p \leq 0.05$). Negative B-coefficients for wind speed (-0.032) and wind direction (-0.138) indicate that as both factors increased, benzene log concentration decreased. Conversely, troop levels (B-coefficient of 0.638) will have a positive correlation on the benzene log concentration (Figure 4-28). CASF and transportation sample sites had a p-value ≤ 0.05 indicating a statistical difference with the background sample site. Whereas, Sites 7(H6) and 8 (guard tower) observed p-values >0.05 signifying no statistical difference with the background sample site. A p-value >0.05 for the Period indicates the sample-transition periods will not affect the log concentration value for benzene.

The *n*-heptane linear fixed effect regression model indicates that troop level (B-coefficient of 0.632) has a positive correlation with the analyte log concentration (Figure 4-31) over the sample periods. Site 6 (CASF) to Site 9 (Transportation) recorded p-values >0.05 signifying no significant differences in comparison to Site 5 (Background sample site). The Period variable observed a p-value >0.05 which indicates that the sample-transition period does not effect the analyte log concentration.

Figure 4-28: Benzene (VOC) B-coefficient Results

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
4	(Constant)	-.321	.313		-1.024	.307
	CASF	.162	.077	.165	2.115	.036
	H6	-.070	.080	-.068	-.881	.380
	Guard Tower	.129	.080	.129	1.615	.108
	Transportation	.189	.082	.194	2.292	.023
	Period	.061	.037	.190	1.651	.101
	Troop_Lvl	.638	.168	.423	3.791	.000
	WindSpd	-.032	.011	-.212	-2.987	.003
	Wind_Direction	-.138	.063	-.162	-2.178	.031

a. Dependent Variable: Benzene

Figure 4-29: Benzene (VOC) Linear Fixed Effect Regression Histogram

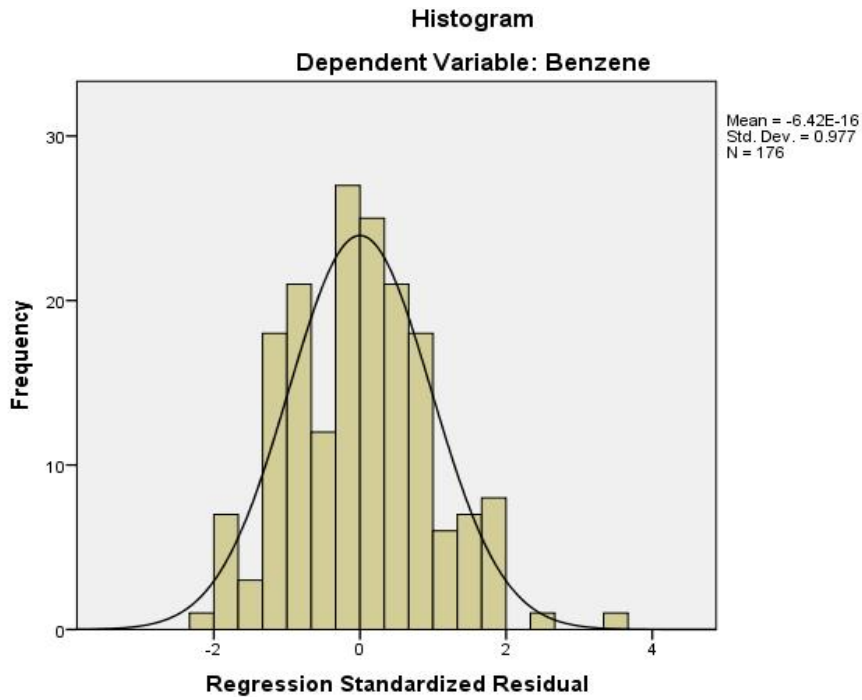


Figure 4-30: Benzene (VOC) Linear Fixed Effect Regression P-P Plot

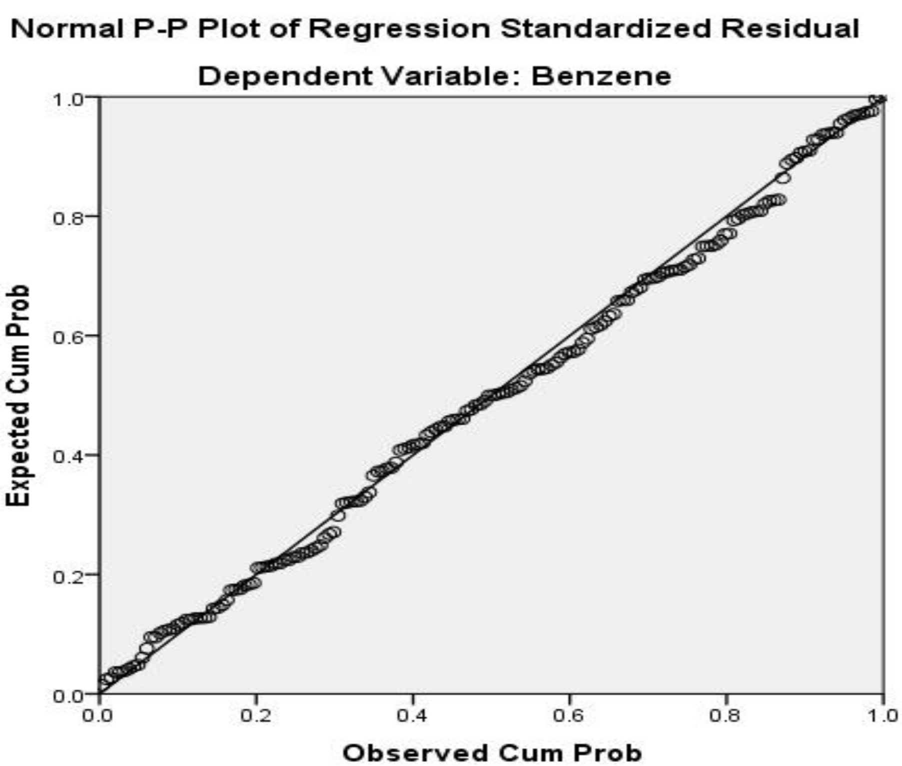


Figure 4-31: *n*-Heptane (VOC) B-coefficient Results

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
2	(Constant)	-.624	.334		-1.866	.064
	CASF	.039	.083	.037	.472	.637
	H6	-.133	.087	-.121	-1.524	.129
	Guard Tower	-.095	.084	-.089	-1.122	.263
	Transportation	.093	.084	.090	1.103	.272
	Period	.010	.040	.030	.262	.793
	Troop_Lvl	.632	.184	.392	3.441	.001

a. Dependent Variable: n_Heptane

Figure 4-32: *n*-heptane (VOC) Linear Fixed Effect Regression Histogram

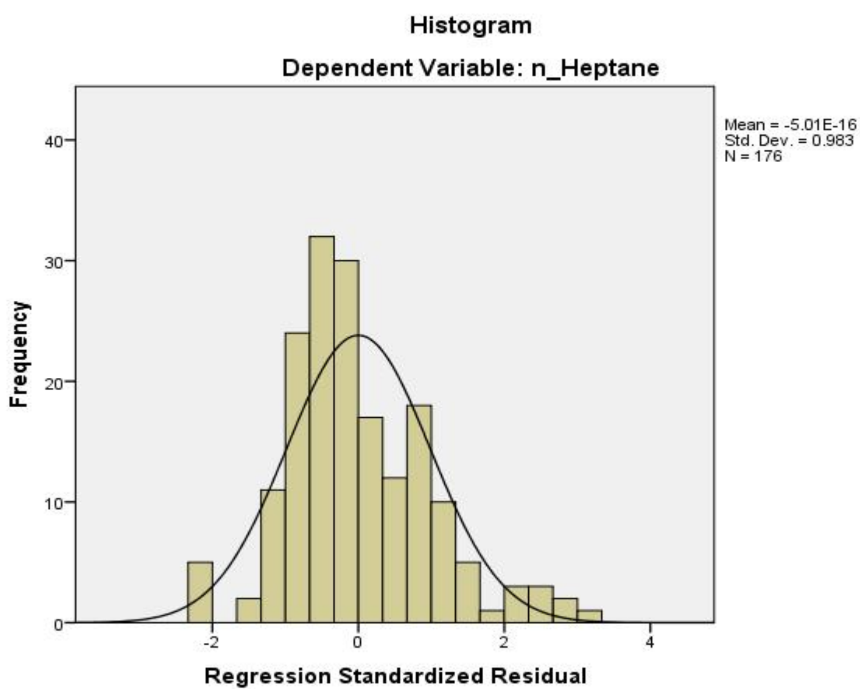


Figure 4-33: *n*-heptane (VOC) Linear Fixed Effect Regression P-P Plot

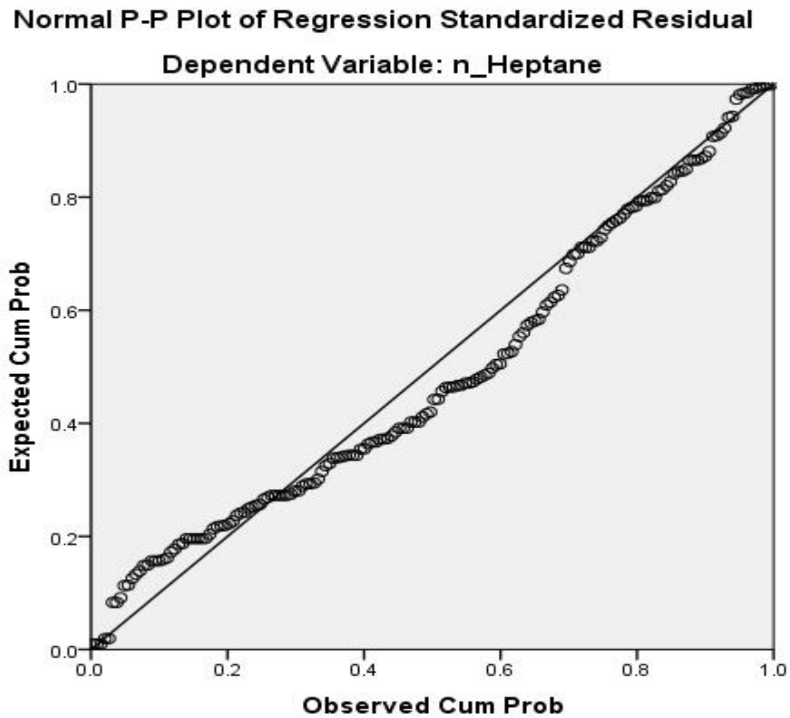


Figure 4-34: TetraCDD (Dioxin-Furan) B-coefficient Results

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
2	(Constant)	-9.678	.716		-13.517	.000
	CASF	.400	.133	.209	3.008	.003
	H6	.036	.134	.018	.264	.792
	Guard Tower	.670	.129	.365	5.205	.000
	Transportation	.350	.136	.177	2.566	.011
	Period	-.021	.085	-.034	-.253	.801
	Troop_Lvl	1.158	.385	.411	3.011	.003

a. Dependent Variable: TetraCDD

The troop level B-coefficient value for TetraCDD indicates a positive correlation for the analyte log concentration (Figure 4-34). A p-value of 0.003 relates a highly significant factor for troop level concentration. Sample site H6 recorded a p-value >0.05 indicating no significant differences with the background site. However, the CASF, guard tower and transportation sites observed p-values $\leq$ 0.05 indicating a statistical difference in comparison to Site 5 (Background). A p-value > 0.05 for the Period variable indicates that the sample – transition period does not affect the analyte log concentration.

Figure 4-35: TetraCDD Linear Fixed Effect Regression Histogram

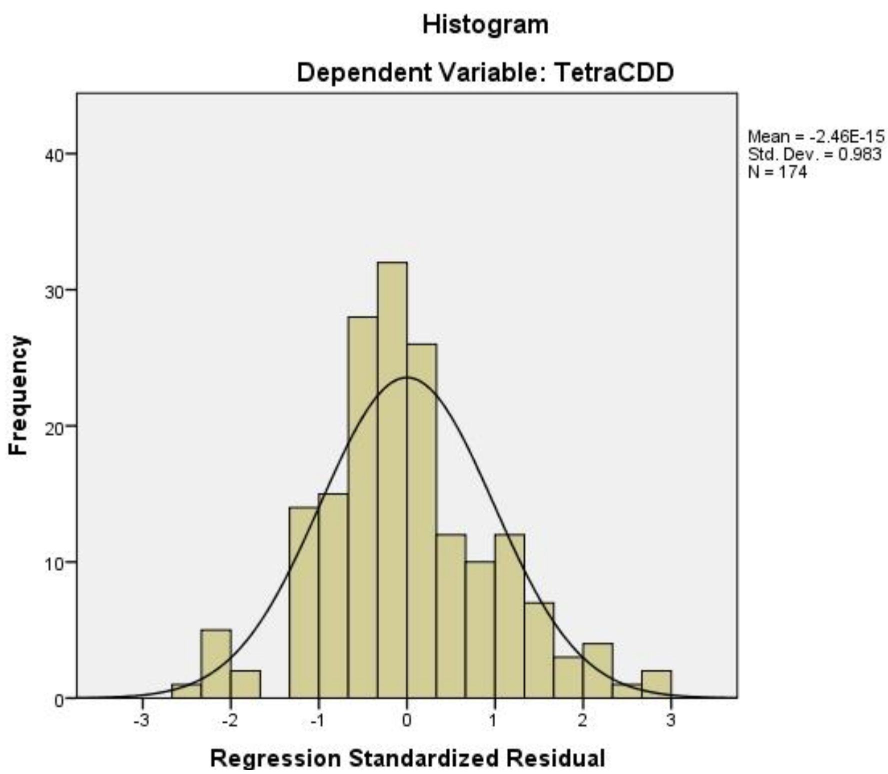
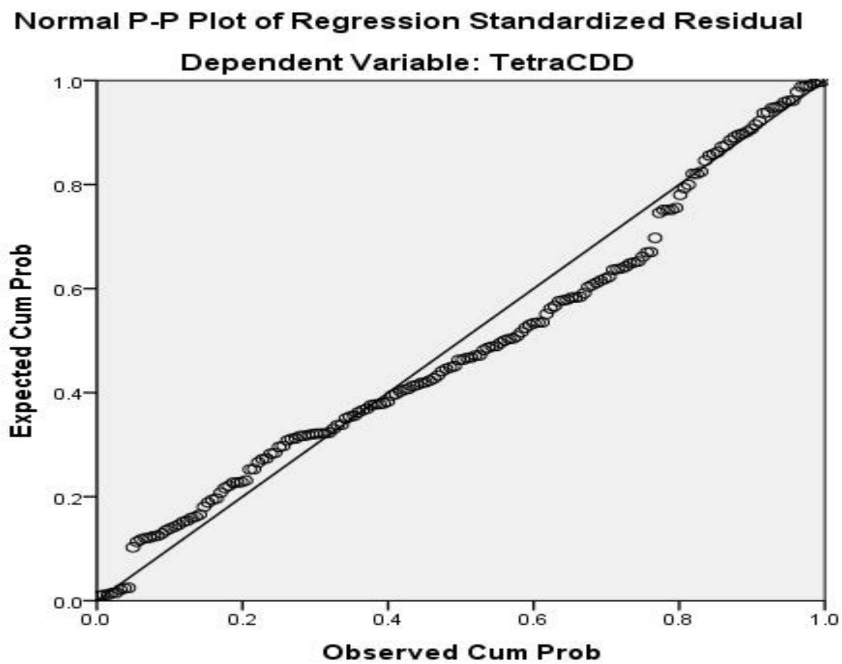


Figure 4-36: TetraCDD Linear Fixed Effect Regression P-P Plot



Summary – Results

With the exception of benzo[a]pyrene (BaP), all analytes observed a negative correlation between analyte log concentration and the sampling periods. This indicated that the analyte log concentrations for tetraCDD, benzene, *n*-heptane, cadmium and lead decreased over the four sample-transition periods. This suggests that the overall ambient air quality at JBB improved with respect to these analytes during the sampling periods. Conversely, BaP observed a positive correlation between analyte log concentration and the sampling periods, suggesting that the overall ambient air quality at JBB decreased with Benzo[a]pyrene's increased log concentration value over time.

The troop level variable was statistical significant (p-value ≤ 0.05) in the fixed effect regression model for the tetraCDD, benzene, n-heptane, cadmium and lead analytes. However, this variable was excluded in the SPSS stepwise simulation for benzo[a]pyrene. Weather variables were statistically significant (p-value $\leq$ 0.05) in the fixed effect regression model for the benzene and BaP analytes. Wind speed and wind direction, along with troop level, were significant factors for the analyte log concentration of benzene. Temperature and wind speed were significant factors for the log concentration of benzo[a]pyrene. In comparing all sample sites (CASF, H6, guard tower and transportation) versus the background site (Site 5), benzo[a]pyrene was observed to have no statistical significant differences during the sample periods. All sample sites (CASF, H6, guard tower and transportation) for benzo[a]pyrene recorded p-values >0.05 indicating no significant differences versus the background sample site. The remaining analytes observed varying results when comparing the sample sites (CASF, H6, guard tower and transportation) versus the background site during the sample periods.

Chapter Five: Discussion

Dioxin-Furan: 2,3,7,8-TetraCDD

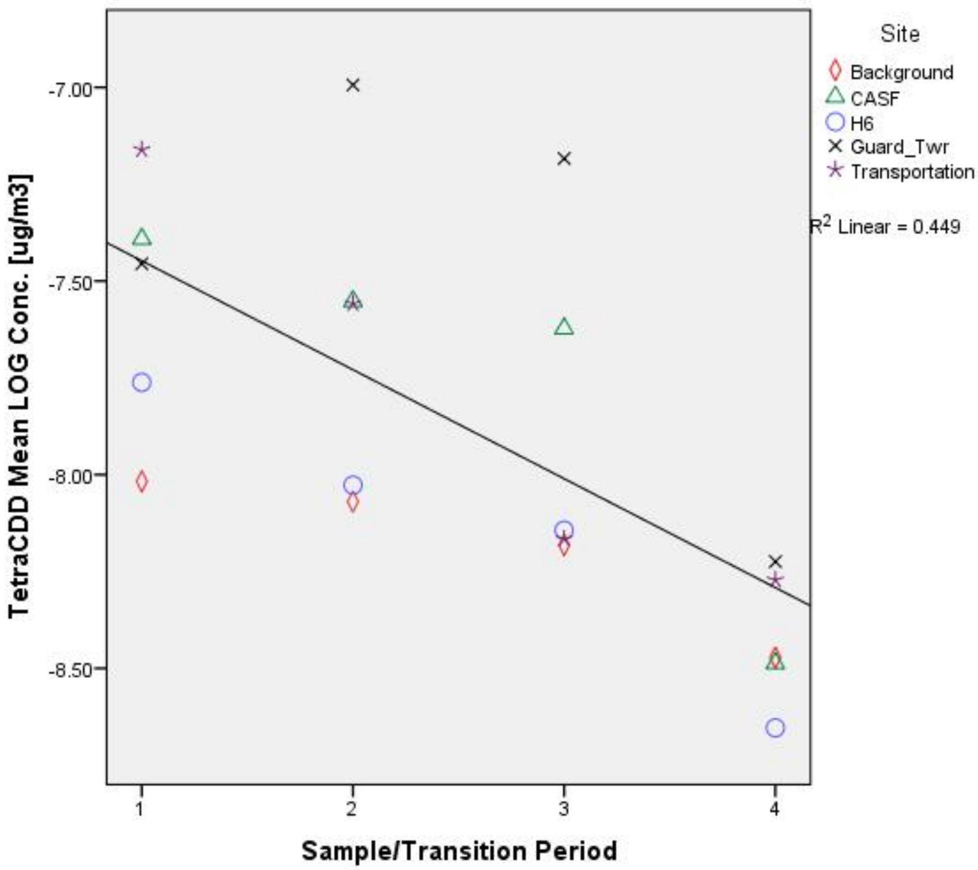
Results from the linear fixed effect regression model for tetraCDD indicate that Site 6 (CASF), Site 8 (Guard tower) and Site 9 (Transportation) recorded p-values $\leq$0.05 (Table 4-34), indicating a statistical difference with the background sample site(Site 5). The SPSS result suggests that the tetraCDD log concentration was influenced by the emissions from the burn pit during the sampling periods. Potential combustion sources of tetraCDD include paper products, medical waste, plastics and petroleum products.[1, 34] A comprehensive study conducted by the Institute of Medicine indicated that the burn pit at JBB was "likely the major source" of Dioxins – Furans.[13] In addition, Congressional reports as well as Congressional hearings support the fact that combustion sources of tetraCDD were introduced in the burn pit waste stream prior to being regulated in 2009 by CENTCOM Regulation 200-2.[8, 28] Site 7(H6-housing) observed a p-value >0.05 indicating no statistical difference with the background site. Troop level (B-coefficient 1.158, p-value $\leq$ 0.05) was observed to have a positive correlation with analyte concentration (e.g. as troop level increases, concentration level increases). The troop surge during Operation Enduring Freedom – Operation Iraqi Freedom (OEF-OIF) began in February 2007 and terminated in July 2008.[29, 63-65, 68] The first two air sampling periods at JBB coincided with the OEF-OIF troop surge, Figure 5-1 reflects that analyte log concentration levels increased for periods 1-2 and decreased in period 3 to period 4. The period variable recorded a p-value >0.05, which suggests that the sample periods do not have an effect on the analyte log concentration levels. It has been established that the four sampling periods corresponded with the increased use of incinerator facilities (Table 5-1) and decreased burn pit load rate (tons/day). Figure 5-1 supports that as the waste stream load to the Balad burn pit area decreased over the sample periods, analyte concentration levels for tetraCDD decreased at all five sample sites. Table 5-2 provides the mean concentration levels (ug/m^3) for tetraCDD at the five sample sites during the four sample periods. Results of the mean concentration values for tetraCDD indicate levels well below the OSHA PEL, NIOSH REL and 1-yr Long Term Military Exposure Guidelines criteria.[69]

Table 5-1: Balad burn pit transition phases[8, 11, 19, 20]

Transition Phase	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
Air Sample Period	Jan – Apr 2007	Oct – Nov 2007	May – Jun 2009	Mar – May 2010
Burn Pit Load rate (tons / day)	100-200	50 -100	10	0
Operational Incinerators	0	2 (July 2007)	3 (April 2008)	4 (October 2009)

According to analysis by AFIOH and USAPHC, results from the *Balad Health Risk Assessment Reports* indicate that exposure to inhaled burn pit emissions do not pose unacceptable non-carcinogenic or carcinogenic health threats to personnel located anywhere at the site.[15, 16, 19, 20]

Figure 5-1: TetraCDD Aggregate Graph



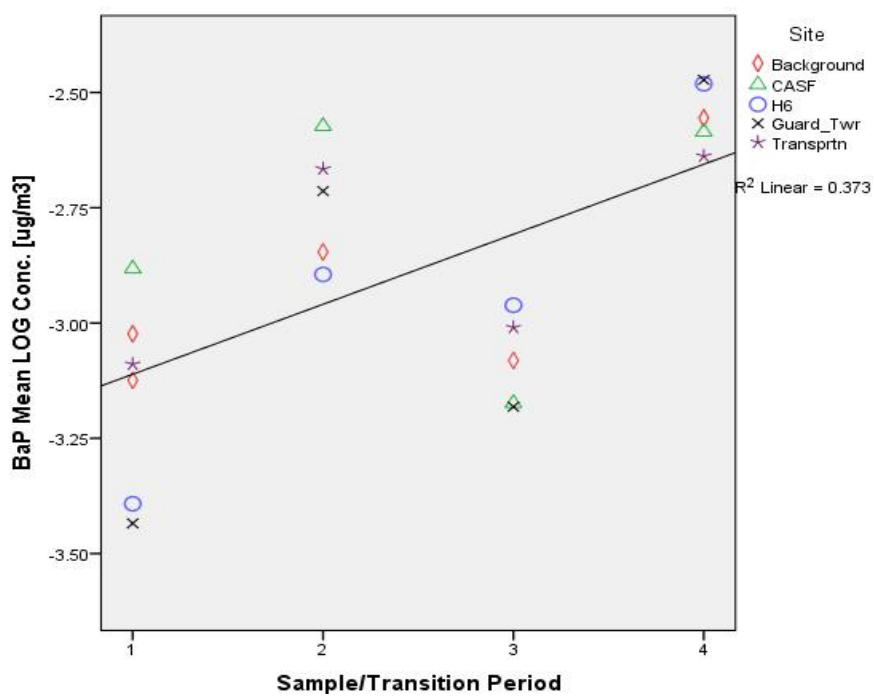
Sample Period / Site	Jan-Apr 2007 Mean Conc. [ug/m^3]	Oct-Nov 2007 Mean Conc. [ug/m^3]	May-June 2009 Mean Conc. [ug/m^3]	Mar-May 2010 Mean Conc. [ug/m^3]
Background	7.73×10^{-8}	1.50×10^{-8}	1.50×10^{-9}	8.46×10^{-9}
CASF	5.66×10^{-8}	5.95×10^{-8}	6.17×10^{-8}	4.96×10^{-9}
H6	4.62×10^{-8}	1.08×10^{-8}	8.27×10^{-9}	6.05×10^{-9}
Guard Tower	1.03×10^{-7}	2.11×10^{-7}	2.15×10^{-7}	1.88×10^{-8}
Transportation	8.58×10^{-8}	4.09×10^{-8}	8.34×10^{-9}	1.00×10^{-8}
8-hr Air MEG	None	None	None	None
1-yr Air MEG	0.00011	0.00011	0.00011	0.00011
OSHA PEL	None	None	None	None
NIOSH REL	None	None	None	None

Table 5-2: TetraCDD mean concentration values

PAH: Benzo[a]pyrene

Compared to the linear fixed effect regression model of the other analytes, benzo[a]pyrene was the only analyte with an increase in airborne concentration during the four sample periods (Figure 5-2). The p-values for all sample sites were greater than 0.05, indicating no statistical differences exist in comparison to the background sample site. The results for the BaP sample sites suggest that emissions from the burn pit do not have a statistical significant effect on the log concentration levels during the sample periods. Potential combustion sources from BaP include aircraft exhaust, vehicle exhaust, petroleum products and combustion of organic products. The fact that burn pit emissions did not have a statistical effect on the log concentration value further suggests that the increased trend may be attributed to other sources. The Institute of Medicine (IOM) reported that the major sources of PAHs at JBB can be attributed to regional background, ground transportation, generator sources and flight line related activities.[13] Figure 5-2 shows that all sites were observed to have increased log concentration levels from period 1 to period 2 and from period 3 to period 4. A log concentration decreasing trend was observed from period 2 to period 3. The increased log concentration in the first two sample periods coincided with the OIF troop surge period. Increased activities associated with the troop surge (e.g. increased aircraft sorties, increased convoy operations and increased power generator demand) may have contributed to the log concentration values. However, in order to provide a stronger association that statistically correlates troop level with increased activity, aircraft sorties and the number of vehicles transitioning through JBB during the sample periods would need to be incorporated into the linear fixed-effect regression model. The period variable recorded a p-value ≤ 0.05 which was statistical significant and indicates that the sample period has a significant influence on the log concentration levels. This correlates with the assumption that increased troop activity due to the drawdown redeployment of equipment and personnel from Iraq in the last sample period increased BaP's concentration levels. Based on the B-coefficient values, temperature and wind speed are weather variables that have a negative correlation with concentration (as temperature and wind speed increased, log concentration decreased). Table 5-3 provides the mean concentration levels (ug/m^3) for benzo[a]pyrene at the five sample sites during the four sample periods.

Figure 5-2: Benzo[a]pyrene Aggregate Graph



Sample Period / Site	Jan-Apr 2007 Mean Conc. [ug/m^3]	Oct-Nov 2007 Mean Conc. [ug/m^3]	May-June 2009 Mean Conc. [ug/m^3]	Mar-May 2010 Mean Conc. [ug/m^3]
Background	9.50×10^{-4}	1.64×10^{-3}	1.02×10^{-3}	2.85×10^{-3}
CASF	1.41×10^{-3}	2.70×10^{-3}	8.10×10^{-4}	2.60×10^{-3}
H6	6.80×10^{-4}	1.30×10^{-3}	1.13×10^{-3}	3.38×10^{-3}
Guard Tower	8.60×10^{-4}	2.28×10^{-3}	8.60×10^{-4}	3.44×10^{-3}
Transportation	8.60×10^{-4}	3.09×10^{-3}	1.05×10^{-3}	2.30×10^{-3}
8-hr Air MEG	None	None	None	None
1-yr Air MEG	5.4	5.4	5.4	5.4
OSHA PEL	200	200	200	200
NIOSH REL	100	100	100	100

Table 5-3: Benzo[a]pyrene mean concentration values

Despite the increase of analyte concentration of BaP, the mean concentration levels (μg/m^3) are well below established federal and military exposure guidelines. As stated in *Chapter 2 – Literature Review*, the health risk assessment reports on the Balad burn pit completed by USACHPPM and AFIOH indicate that the "total cancer risk from inhalation exposures originating from burn pit emissions at Balad Air Base to personnel present for 12 months, 4 months, and 1 month at all exposure point concentration (EPCs) are within or below the U.S. EPA acceptable cancer risk range of 1×10^{-4} to 1×10^{-6}.[11, 15, 18-20] In a human study involving the respiratory effects of 667 workers from benzo[a]pyrene exposure was investigated in a rubber factory. The respiratory health of the employees was evaluated and examined for correlations to length of employment at the factory. Results of the study indicated that workers exposed to a BaP concentration of 0.100 mg/m^3 for a duration range of 6 months to less than 6 years exhibited symptoms of reduced lung function, abnormalities in chest xrays, bloody vomit, chest irritation, throat irritation and cough.[70] The mean concentration levels at JBB during the Balad Air Sample Program were below the concentration of 0.100 μg/m^3 mentioned previously; however, a more detailed and in depth cohort epidemiology study would need to be conducted in order determine the chronic long term health effects of service members exposed to the BaP mean concentration levels during the sample periods.

VOCs: Benzene and *n*-Heptane

The linear fixed effect regression model (Table 4-28) for benzene shows that troop level, wind speed and wind direction have a statistically significant (p-value $\leq$0.05) effect on the benzene log concentration. A positive beta value (0.638) for the troop level variable indicates as troop level increased, the log concentration value increased. Negative beta values for wind speed (-0.032) and wind direction (-0.138) indicate a negative correlation with benzene's log concentration level; as the wind speed and wind direction increased, the log concentration value would decrease. Site 6 (CASF) and Site 9 (Transportation) observed p-values $\leq$0.05, indicate a statistical difference versus Site 5 (Background). This signifies that burn pit emissions have a statistically significant effect on the log concentration for the CASF and transportation sites. Conversely, Site 7 (H6) and Site 8 (Guard Tower) recorded p-values >0.05, indicating no statistical difference exists with the background sample site. This indicates that burn pit emission are not associated with benzene's log concentration level at Sites 7 (H6) and 8 (Guard Tower). Ideally, the background sample site (baseline concentration) would be far removed from the contaminant source (e.g. burn pit) that it would be considered unaffected by the burn pit emissions. Thus, the analyte concentration levels at the sample sites (CASF, H6, Guard Tower and Transportation) would have significantly different results in comparison with the background site. Due to security concerns, the background sample site was located inside the perimeter of JBB. The aggregate graph of benzene (Figure 5-3) reflects that Site 8 (Guard Tower) observed the highest log concentration levels from periods 1 to 3; however, in the last sample period Site 8 was observed to record the lowest log concentration level. This correlates with the increase use of incinerators and the significantly decreased use of the JBB burn pit for processing waste materials during the same period (refer to Table 2-1 and Table 5-1). While significantly different from background levels, the SPSS model results for Site 6 (CASF) and Site 9 (Transportation) suggests that log concentration levels at these sample locations may be influenced by other sources. This assumption is based on the positive beta coefficients for the CASF and transportation sites for benzene and *n*-heptane. Potential combustion sources of benzene at JBB include vehicle exhaust, combustion from flight line operations, regional background sources and stationary power generators. The burn pit study conducted by the IOM reports that VOC concentrations at JBB are likely from "major sources that include regional background, ground transportation and the JBB airport."[13]

Similar to benzo[a]pyrene, troop level has a positive correlation with benzene's log concentration level. As benzene is present in vehicle exhaust and petroleum products, the analyte concentration associated with the CASF and transportation sites may be attributed to increases/decreases in motor vehicle/combustion engine activities associated with increases/decreases in troop levels. However, in order to provide an association that statistically correlates troop level with increased activity, aircraft sorties and the number of ground vehicles transitioning through JBB over the duration of the four sample periods would need to be incorporated in the linear fixed-effect regression model.

The results from the SPSS model (Table 4-31) for *n*-heptane indicate that troop level has a positive correlation (B-coefficient of 0.632) for the analyte's log concentration. However, no statistically significant differences (p-values >0.05) between the background location and four sample sites (CASF, H6, Guard Tower and Transportation) for *n*-heptane were observed. This result implies that burn pit emissions do not have a statistically effect on *n*-heptane's log concentration, which suggests that the log concentration may be attributed to other sources. The aggregate graph for *n*-heptane (Figure 5-4) shows that the transportation site recorded a higher mean log concentration in the fourth sample period versus the first sample period. The increase in *n*-heptane concentration levels at the transportation site may be due to an increase in activities supporting movement of troops out of theater due to the drawdown timeline in Iraq (such as convoy operations, vehicle refueling, and vehicle maintenance). However, additional data and information regarding ground transportation as well as the number of flight sorties flown during the sample periods would need to be incorporated in the fixed-effect regression model. Results from the SPSS iterations would determine if these factors were statistical significant to the log concentration of *n*-

heptane. Table 5-4 and Table 5-5 provide the mean concentration levels (μg/m^3) for benzene and *n*-heptane at the five sample sites during the four sample periods.

Table 5-4: Benzene mean concentration values.

Sample Period / Site	Jan-Apr 2007 Mean Conc. [μg/m^3]	Oct-Nov 2007 Mean Conc. [μg/m^3]	May-June 2009 Mean Conc. [μg/m^3]	Mar-May 2010 Mean Conc. [μg/m^3]
Background	3.25	8.26	2.68	2.95
CASF	7.08	6.46	4.53	2.64
H6	2.12	3.18	3.03	2.86
Guard Tower	11.25	10.61	5.98	1.56
Transportation	2.84	8.24	3.82	6.32
8-hr Air MEG	1600	1600	1600	1600
1-yr Air MEG	39	39	39	39
OSHA PEL	1000	1000	1000	1000
NIOSH REL	100	100	100	100

Several published studies have recorded the acute and chronic effects of benzene exposure. As referenced previously in *Chapter Two – Literature Review*, a study on shipyard workers conducted by Midzenski, *et al.* observed leukopenia, anemia, and thrombocytopenia following two days of occupational exposure of more than 60 ppm (1.91x10^5 μg/m^3) of benzene.[45] However, the CDC reports that inhalation exposure exceeding the OSHA PEL for several months to several years can result in deficiencies in the circulating blood cells, which may cause pancytopenia.[42] Mean concentration levels for benzene did not exceed federal or military exposure limits at JBB and 8000 times lower than published acute and chronic effects from exposure. This suggests that respiratory effects reported by service members at JBB may not have been attributed to benzene.

Table 5-5: *n*-heptane mean concentration values

Sample Period / Site	Jan-Apr 2007 Mean Conc. [μg/m^3]	Oct-Nov 2007 Mean Conc. [μg/m^3]	May-June 2009 Mean Conc. [μg/m^3]	Mar-May 2010 Mean Conc. [μg/m^3]
Background	1.76	6.47	9.77	2.03
CASF	5.59	4.27	4.53	2.64
H6	1.64	2.47	3.03	2.86
Guard Tower	5.71	2.27	5.98	1.56
Transportation	1.70	3.25	11.71	3.72
8-hr Air MEG	None	None	None	None
1-yr Air MEG	None	None	None	None
OSHA PEL	$2x10^6$	$2x10^6$	$2x10^6$	$2x10^6$
NIOSH REL	$3.5x10^5$	$3.5x10^5$	$3.5x10^5$	$3.5x10^5$

The levels of *n*-heptane mean concentration are well below the regulatory time weighted average occupational exposure limits and published limits for short term health effects. Respiratory effects (irritation of eyes, nose, throat) reported by service members during the sample period may be attributed to other pollutants due to the recorded mean concentration levels of *n*-heptane at JBB.

Figure 5-3: Benzene Aggregate Graph

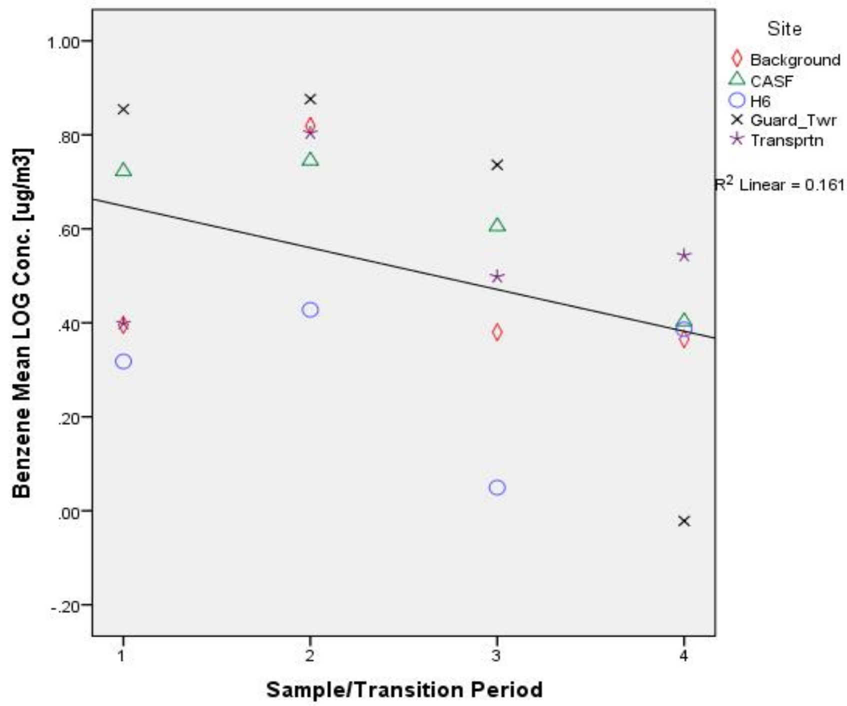
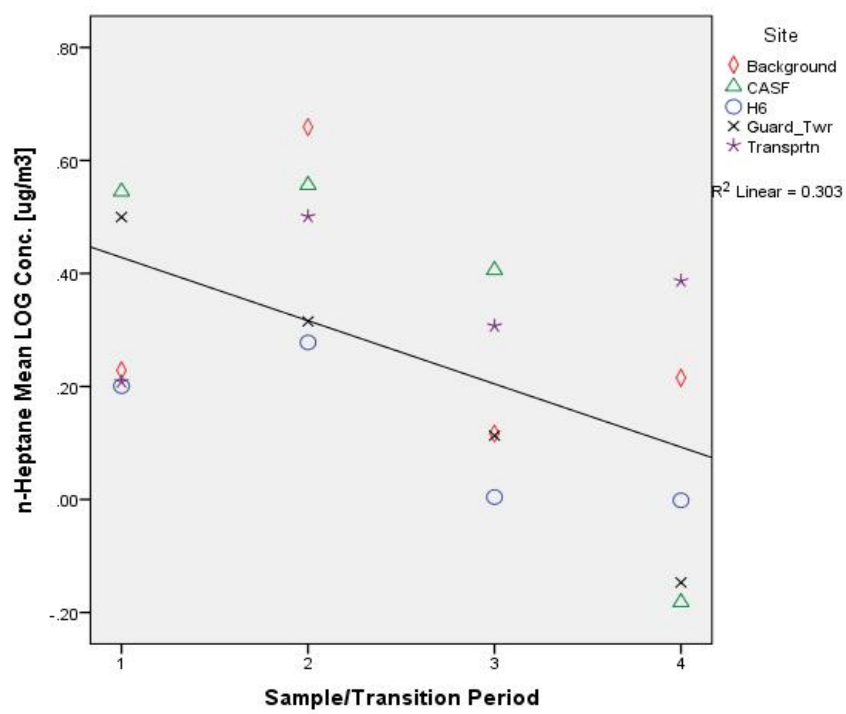


Figure 5-4: *n*-heptane Aggregate Graph



Metals: Cadmium and Lead

Results from the linear fixed effect model indicate that troop levels (B-coefficient:0.465) and temperature (B-coefficient: 0.002) had a positive correlation on cadmium's log concentration value and their p-values $\leq$0.05 show that the correlation was statistically significant. The SPSS results indicate that as temperature and troop level increased the cadmium log concentration increased. The site location(s) p-values from the fixed effect model indicate that Site 7(H6) was the only sample site that had a statistical difference (p-value $\leq$0.05) versus the background sample site. The result suggests that burn pit emission will have an affect the log concentration level at Site 7 (H6). The high log concentration levels observed at Site 7 (H6) in comparison to the remaining sample sites after the burn pit was not operational suggests that cadmium's log concentration may have other pollutant sources. An ambient air study conducted by Engelbrecht *et al*. reported that potential sources of lead and cadmium in the Balad region may be attributed to emissions from "secondary lead smelters and battery-manufacturing facilities."[43] In the same study, it was observed that trace concentrations of lead and cadmium were found in the soil and certain weather events (dust storms) may increase concentration levels of these analytes.[43] The remaining sample sites (CASF, Guard Tower and Transportation) observed p-values >0.05, reflecting no significant differences from the background site. The result infers that burn pit emission has an influence on log concentration for these locations. Figure 5-5 shows that all sample locations observe little variance in the mean log concentration levels during the first three sample periods.

However, in the fourth sample period, all locations excluding Site 7 recorded decreased log concentrations. This trend correlates with the decreased utilization of the JBB burn pit area and increased incineration facilities over the same timeframe. Table 2-3 lists potential sources of cadmium from combustion as nickel cadmium batteries, paint and plastics. Based on the *Iraq Index* report from the Brookings Institution, troop levels increased approximately 24.5 percent from January 2007 (146,650 troop strength) to October 2007(182,668 troop strength), before gradually decreasing to approximately 37.2 percent of its peak strength at the end of May 2010 (92,000 troop strength).[63] The gradual increase of cadmium concentration during the first two sampling periods (Jan - April 2007, Oct – Nov 2007) coincides with troop level increases during the same timeframe. Possible explanations include analyte concentration increase may be attributed to the increase in the amount of cadmium-containing materials being introduced into the burn pit waste stream. As stated previously, USCENTCOM did not mandate the segregation of hazardous materials until 2009 and the Balad burn pit area was operational until October 2009.[8, 11, 19, 20, 28]

Similar to cadmium, the linear fixed effect model for lead indicate that troop level B-coefficient (0.673) has a positive correlation on the analyte concentration. The statistical significance (p-value ≤ 0.05) between the background sample site and the transportation sample site is shown on Figure 4-25. This difference (p-value ≤ 0.05) indicates that the lead concentration may be attributed to the burn pit area during the first three sampling periods when the burn pit was operational. However, during the fourth sampling period, the JBB burn pit was no longer in use. A plausible source attributing to the lead concentration other than the burn pit during sample period four may be from other anthropogenic sources of lead, most notably leaded gasoline. Although the use of lead additives in motor fuels was banned in the U.S. after December 31, 1995, Iraq relies heavily on leaded fuel sources.[63, 71] Engelbrecht's published ambient air study in the middle east further supports this explanation of other sources contributing to the log concentration levels of lead: "As Iraq uses leaded gasoline…vehicle emissions previously deposited on dirt roads are continually being re-suspended and may for many years thereafter be a source of aerosol lead."[30, 72] Table 5-6 and Table 5-7 provide the mean concentration levels (μg/m^3) for cadmium and lead at the five sample sites during the four sample periods.

Table 5-6: Cadmium mean concentration values

Sample Period / Site	Jan-Apr 2007 Mean Conc. [μg/m^3]	Oct-Nov 2007 Mean Conc. [μg/m^3]	May-June 2009 Mean Conc. [μg/m^3]	Mar-May 2010 Mean Conc. [μg/m^3]
Background	3.45×10^{-2}	3.47×10^{-2}	3.53×10^{-2}	1.74×10^{-2}
CASF	3.51×10^{-2}	3.48×10^{-2}	3.45×10^{-2}	1.76×10^{-2}
H6	3.54×10^{-2}	3.45×10^{-2}	3.61×10^{-2}	3.63×10^{-2}
Guard Tower	3.50×10^{-2}	3.45×10^{-2}	3.52×10^{-2}	1.76×10^{-2}
Transportation	3.49×10^{-2}	3.52×10^{-2}	3.43×10^{-2}	1.75×10^{-2}
8-hr Air MEG	None	None	None	None
1-yr Air MEG	0.24	0.24	0.24	0.24
OSHA PEL	5.0	5.0	5.0	5.0
NIOSH REL	None	None	None	None

Table 5-7: Lead mean concentration values

Sample Period / Site	Jan-Apr 2007 Mean Conc. [µg/m^3]	Oct-Nov 2007 Mean Conc. [µg/m^3]	May-June 2009 Mean Conc. [µg/m^3]	Mar-May 2010 Mean Conc. [µg/m^3]
Background	7.68×10^{-2}	1.15×10^{-1}	9.03×10^{-2}	7.74×10^{-2}
CASF	1.05×10^{-1}	6.96×10^{-2}	6.90×10^{-2}	6.75×10^{-2}
H6	7.08×10^{-2}	0.22	0.11	0.11
Guard Tower	7.00×10^{-2}	6.89×10^{-2}	7.04×10^{-2}	6.88×10^{-2}
Transportation	6.98×10^{-2}	0.22	7.72×10^{-2}	6.75×10^{-2}
8-hr Air MEG	None	None	None	None
1-yr Air MEG	1.5	1.5	1.5	1.5
OSHA PEL	50	50	50	50
NIOSH REL	50	50	50	50

The mean concentration levels for cadmium did not exceed current regulatory or military exposure guidelines.

Limited information exists for respiratory effects in humans from lead exposure, and according to the CDC “animal data on lead toxicity are generally considered less suitable as the basis for health effects assessments than are the human data. There is no absolutely equivalent animal model for the effects of lead on humans.”[51] The mean concentration levels for lead did not exceed current regulatory or military exposure guidelines.

Figure 5-5: Cadmium Aggregate Graph

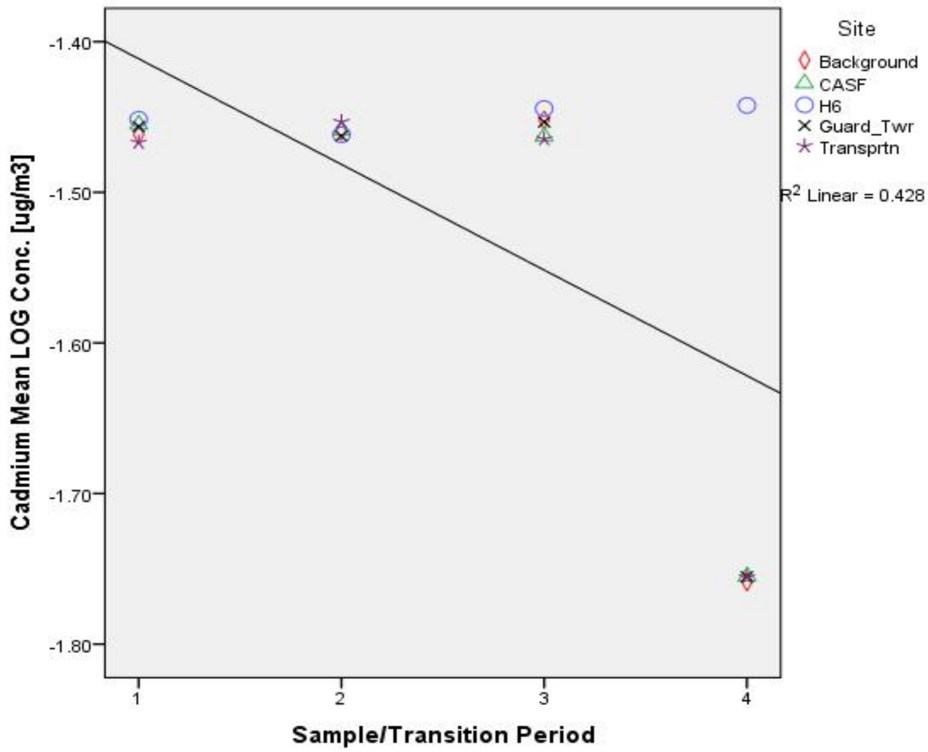
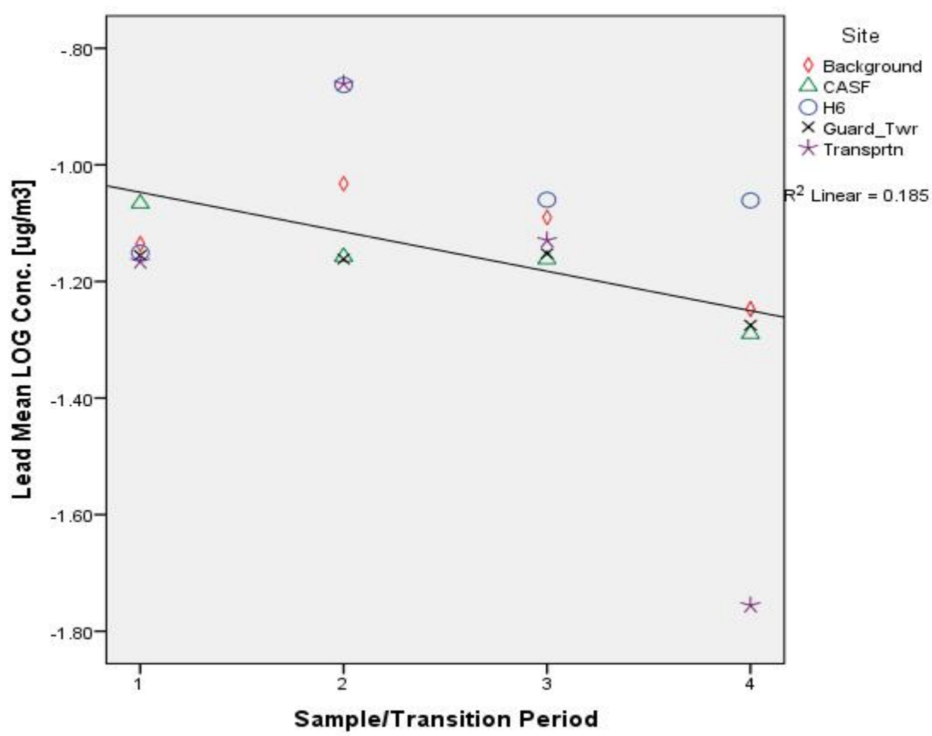


Figure 5-6: Lead Aggregate Graph



Chapter Six: Conclusion

A temporal association in ambient air quality among selected VOCs, Metals, PAHs, Dioxin and Furan chemical groups exists across the four burn pit operations transition periods at Joint Base Balad (JBB) was tested. Results from the SPSS fixed effect model suggest that selected analyte concentrations from the Metals (cadmium, lead), VOC (benzene, *n*-heptane) and Dioxin-Furan (tetraCDD) chemical groups decreased over the four sampling periods. With the exception of benzo[a]pyrene (PAH), ambient air quality improved through reductions on analyte concentrations. As stated previously in *Chapter Four – Results*, benzo[a]pyrene's concentration levels may be attributed to other potential combustion sources other than emissions from the burn pit.

Documentation to characterize the solid waste management phases and their transitional timelines (e.g. burn pit usage to incinerator facilities) as they occurred at Balad Air Base during the 2007-2010 period was researched and incorporated to create the database for analysis in this thesis. A positive temporal and spatial association between the airborne chemical concentrations of three classes (Dioxin-Furans, VOCs, Metals) of specified analytes during the transition from open burn pits to incinerator only use at Balad Air Base from 2007 to 2010 was observed. The mean concentration levels of the specified analytes were compared to regulatory and military exposure guidelines as well as published studies in order to determine whether any exposure limits were exceeded at Joint Base Balad. The mean concentration levels for all of the specified analytes were orders of magnitude below the established exposure limits. The low concentration levels for the specified analytes detected at the sample sites during the active burn pit periods at JBB suggests exposure sources other than the burn pit or to other chemical compounds which were not sampled for during the air sampling periods. A detailed and comprehensive epidemiology and environmental study analyzing exposure versus health effects/outcome would need to be conducted in order to determine any associations between exposure effects and airborne concentrations of various compounds from burn pit emissions.

The linear fixed effect regression model for the analytes did not include variables (burn pit rate, distance from burn pit) due to their correlation with sampling periods (e.g. burn pit distances for the sample sites did not change over time, number of incinerators did not vary within each sampling period). In addition, weather variables such as temperature, precipitation, wind direction and wind speed were not statistically significant in influencing the concentration levels for any of the analytes. It has been noted in the Middle East ambient air study by Engelbrecht *et al*. that dust events have a larger influence on air concentration than weather factors such as temperature and precipitation.[30, 72] The troop level variable was statistically significant factor in all the linear fixed effect analyte models, as it acted as a surrogate for waste volume and burn pit usage, as well as vehicle and aircraft traffic. It should be noted that the fixed effect model assumes that the variables (weather factors, troop level) has a linear correlation with the analyte concentration levels at the sample sites, this may or may not be true in all instances for all analytes.

The sampling protocol established by USACHPPM and AFIOH called for a 24-hour sample period at the five sample sites. One limitation of the sampling protocol is that the samples were not collected simultaneously at the sites for each sampling event.[13, 16, 19, 20] Sampling equipment to detect analytes from the different chemical groups (VOCs, PAHs, Dioxin-Furan, Metals) did not always occur during the same sampling dates. Overlapping sampling start times and the length of the sampling time(s) varied for each analyte. The variation of the sample time as well as varying weather conditions and Balad military operations may limit the comparability between samples and the various sample sites.[13, 16, 19, 20] In addition, the Balad Air Sampling period of 2007, 2009 and 2010 did not occur during the same seasonal period(s). The sampling period in 2007, 2009 and 2010 had a one-month overlap and no sampling occurred during the Fall season of 2009 and 2010.

Future fixed effect models should incorporate the following weather variables: Dust hours per day and Smoke hours per day. These weather factors may have a greater impact on concentration levels based on ambient air sampling than temperature and precipitation as indicated in the Middle East ambient air study by Engelbrecht.[72] In addition, data on the classification and weight of the waste materials being introduced to the burn pit area would provide variables associated with the burn pit rate. Information on the number of aircraft sorties ((fixed wing and rotary landings and takeoffs) as well as vehicle ground transportation activity (e.g. number of convoy operations, logistic missions and number of vehicles involved) may provide a more accurate surrogate of troop level numbers.

The fixed effect model provided a statistical method to determine whether a temporal association between the selected analytes and burn pit emission was observed during the transition phases to incinerator operations. Results from the SPSS model indicated the sample sites were associated with the specified analyte concentration levels in this study. Fixed effect models incorporating additional data on weather events (Dust hours/day, Smoke hours/day), waste stream materials and transportation activity could be utilized to approximate expected analyte exposure levels and determine if these levels approach regulatory or military exposure limits.

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