

"Air Quality and Chemistry of airborne particulates"
(Determination of inorganic particulates in the atmosphere of Industrial,
Urban and Rural areas in Bahrain and their correlation with meteorological
conditions)



By

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for the degree of

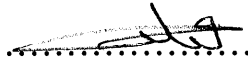
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DECLARATION

I declare that this work is the result of my own investigation and that it has not already been accepted in substance for any degree, nor is it being currently submitted for any degree.

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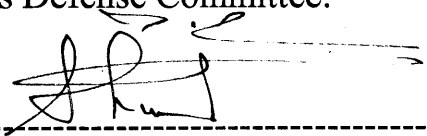
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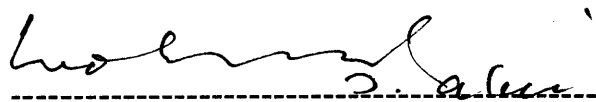
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Abstract

A comparative estimate of dry fall deposition of suspended particulate matter in heavy polluted industrial area (Ma'amir Village), in urban area (Manama City), and in rural area (Al-Hamalah Village) of Kingdom of Bahrain was conducted. Samples of the dry fall aerosol particles were collected weekly during the period of 10th Dec 04 to 16th June 05 using an open one litre beaker trap of deionized water placed on the roof of an 8 m high building above the ground level for the three areas of study. Ion chromatography method was used to analyze the chemical composition of anions and cations in the water soluble matter. Atomic absorption spectrophotometer (AAS) and ICPS techniques were used to analyze heavy metals and MS-GC device was used to analyze organic composition of tarry matter. The data obtained were correlated with meteorological and surface feature of Bahrain. SPSS analysis was used to analyze data and to find the correlations between the measured parameters.

The relation between total suspended solid (TSS) and conductivity indicates that the high levels of TSS are associated with high levels of conductivity and the total suspended solid shows relatively high mass, whilst the tarry matter airborne aerosol particulates solids make up on an average 3.6% of the total suspended solid. This indicates that most of the atmospheric particles were soil derived. The mean concentration of TSS and TM are highest in Ma'amir (96.53 mg/L, & 3.289 mg/L) compared to Hamalah (18.904 mg/L & 0.692 mg/L) and Manama (19.283 mg/L & 0.933 mg/L). In addition Ma'amir has the highest content of the measured "trace metals" compared to Hamalah and Manama.

The industrial (Ma'amir) and urban area (Manama) contain organic components on airborne inorganic particulate matter much more than the rural area (Hamalah).

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Nomenclature and Abbreviations

Abbreviations	Name
AAS	Atomic absorption spectrophotometer
nm	Nanometer
μm	Micrometer
PM	Particulate matter
PM ₁₀	Particulate matter of size 10 μm
PM _{2.5}	Particulate matter of size 2.5 μm
IC	Ion chromatography
μS	microsiemen
MS-GC	Mass spect and gas chromatography
ppm	Part per million
ppb	Part per billion
PAH	Polycyclic aromatic hydrocarbon
ICPS	Inductive Couple Plasma Spectrophotometer
WHO	World health organization
EPA	Environmental protection agency
VOC	Volatile organic compounds
UV/VIS	Ultra violet and visible
COHb	Carboxyhaemoglobin
DSS	Dry suspended solid
TSS	Total suspended solid
TM	Tarry matter
TSP	Total suspended particulate

1. Introduction

Air pollution is becoming an increasingly important issue in the past few decades due to its alarming impact on human health and environment. The degradation in air quality started to increase with the increase in industrial development that depends on fossil fuel as energy. Combustion of fossil fuels releases a great amount of SO₂, NO₂, and soot into atmosphere, assisting the formation of smog which is a major problem in urban areas and big cities such as photochemical smog in London and Los Angeles (WHO, 2000). In most urban areas, emissions from traffic are major source of harmful pollutants such as nitrogen oxides and particulate matter (Lim et al, 2005). Several controlled and epidemiological studies had been conducted to assess the impacts of air pollution on human health, animals, plants and environment. The World Health Organization and U.S. Environmental Protection Agency reported studies concerning the effect on human health, and environment (WHO, 2003).

In U.S.A., 1970, the amendment of the clean air act gave authority to Environmental Protection Agency to establish and enforce air pollution standards to emissions from factories and in 1987, WHO published Air Quality Guidelines (AQG) for Europe where they treated sulfur dioxide and particulate matter jointly (WHO, 2000). This AQG was revised and updated several times and in 1996 a second edition of AQG that summarized the effect of several air pollutants was edited and published in 1997 to be globally applicable (WHO, 2003).

Air pollution can be defined as "The presence of one or more contaminants (i.e., dust, fumes, gas, mist, odor, smoke, or vapor) in the outdoor atmosphere in sufficient quantities, for such duration that can threaten to be injurious to human, plant, or animal life or to property, or which reasonably interferes with the comfortable enjoyment of

life or property" (Peavy H.S. and Rowe D.R., 1985). The substances or chemicals that are discharged into air and cause air contamination are known as air pollutants.

Generally, air pollution has significant adverse impacts on human health and environment. In Sweden, it has been found that there is an increase in lung cancer incidence in cities compared to rural areas and about 100 lung cancer cases annually may be attributed to air pollutants (Victorin, 1993).

Studies of the effect of air pollution on susceptible individual and children were also reported. Neidell, 2004, found the health effect of air pollution is greater on children of lower socio-economic status. While Bernstein et al, 2004, reported that patients with upper or lower respiratory symptoms should be aware that both gaseous and particulate outdoor air pollutants might affect the underlying pathophysiology of both lower and upper airways. Special concern of children exposure to air pollutant was expressed because their lungs and immune system are not fully developed as adults, plus they spend more time outside. Recent studies suggested that air pollution, especially from traffic, is associated with infant mortality and development of asthma and atopy (Schwartz, 2004).

In addition, more studies reported the effect of air pollutants on children's health (Gauderman WJ et al, 2000; Gilliland FD et al, 2001; and Gauderman WJ et al, 2002).

1.1. Types of air pollutants

Air pollutants can be classified into two types: Primary pollutants which are emitted directly from sources into atmosphere without undergoing chemical reactions such as smoke. Another example is the emissions of SO₂ (g) from combustion of sulfur-containing fossil fuels such as coal that is used for domestic heating and for power

generation in Europe. Secondary pollutants are formed in atmosphere as a result of chemical reaction such as tropospheric ozone.

Local, regional, or global is another type of pollutant classification.

1.2. Sources of air pollutants

Pollutants are introduced into the atmosphere from different types of sources. These sources can be classified by pollutant spatial distribution as point source, line source, or area source. Industrial chimneys, localized toxic waste dumps on land, and liquid waste discharge pipes are examples of point source pollutants. Highways, airlines routes and runoff from agricultural land are examples of line source pollutants. Area emissions that arise from industrial complex or extensive urban areas are examples of area source pollutants. They can be classified either as stationary such as factories or mobile source such as motor vehicle. Furthermore they can be classified on basis of the height of discharge such as: at street level, building level, stack level, or above atmospheric boundary layer level.

Other classification is Urban and Industrial (fossil fuel combustion, transportation and power generation plants), agricultural and rural (dust blowing, slash burning, soil emissions, pesticides, decaying wastes), or natural sources (wind erosion, volcanic eruptions, forest fires, sea spray and evaporation, and natural decay of organic matter, lightning). Therefore each type of pollutants comes from a unique combination of sources.

1.3. Emissions of pollutant

Distinction between different types of emissions is an important aspect and worth mentioning here. These are planned, fugitive and accidental emissions.

Planned emissions arise when it is economically or technically impossible to completely remove all discharge contaminants, and hence process operation allowed emissions of these pollutants under known and controlled rates. Emission of SO_2 (g) from combustion of sulfur-containing fossil fuels such as coal in power generation plants is an example of this type.

Fugitive emissions are emissions that arise through unanticipated or spurious leaks in the equipment of industrial process system. For example, leaking from valve, pump, or compressor of chemical and petrochemical industrial processes.

Accidental emissions occur as a result of plant failure, such as accident involving either equipment or operator error.

1.4. Examples of air pollutants

Many pollutants are released into atmosphere but some need more control measures than others due to their significant impact on human health, animal, vegetation, and environment. These chemical pollutants are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), toxic organics, volatile organic compounds, and particulate matter (Spiro and Stigliani, 2003).

1.4.1 Sulfur Dioxide

Anthropogenic activities such as coal combustions, smelting of ferrous and non ferrous metals, and paper production, are the main source of this colorless gas emissions into the atmosphere. In fossil fuel, the sulfur content of coal is high while the sulfur content of refined petroleum is quite low (Spiro and Stigliani, 2003). The combustion of coal and residual fuel oil is responsible for introducing approximately 100 million metric tons of sulfur mainly as sulfur dioxide into global atmosphere. In contrast, the natural

introduction of sulfur into the atmosphere is much lower than the anthropogenic one (about one million metric tonnes) and it is mainly from volcanoes and biological decay of organic matter such as H_2S which is rapidly converted to SO_2 (Manahan, 1994).

In India, sulfur dioxide emissions from fossil fuel combustion were estimated to be $4.03 \text{ Tg SO}_2 \text{ yr}^{-1}$ for 1996-97. Half of this amount came mainly from coal combustion and diesel combustion in transportation (Chandramouli, 1997)

Sulfur dioxide is classified as an air pollutant because of its impacts on human health and environment since it is considered as a major contributor to smog and acid rain. It has the ability to undergo photochemical and catalytical reactions with other components in air producing more harmful substance. For example, the exposure to SO_2 gas can cause health problem since SO_2 itself is lung irritant but due to its oxidation reactions in air and its high solubility in water, sulfuric acid aerosol is produced which has more damaging health effects. These aerosols cause swelling in the fine vessels of the pulmonary region and therefore blocks the vessel passage making breathing a very hard process especially to the elderly and susceptible people with pre existing respiratory problems (Spiro and Stigliani, 2003).

Several controlled studies have been conducted to assess the effect of exposure to SO_2 by normal people (Lawther P.J. et al,1975;Linn et al,1984) and by elderly and susceptible people with heavy exercise (Linn et al,1983; Linn et al 1984,Linn et al 1987). Studies of short term exposure (Derrienic F. et al,1989) to about ten minutes showed changes in pulmonary function and respiratory symptoms and based on these results WHO put guidelines of a value of $500 \mu\text{g}/\text{m}^3$ (0.175ppm) of ten minutes exposure to SO_2 not to be exceeded. On the other hand studies of daily and long-term exposure had led to guidelines of $125 \mu\text{g}/\text{m}^3$ for 24-hour period and $50 \mu\text{g}/\text{m}^3$ for annual exposure (WHO, 2000-a).

In addition to the health problems, ecological impacts were reported. Sulfuric acid that is main contributor to acid rain, can damage forests and crops plus acidifying the water system making it unsuitable for fish to grow. Furthermore, it corrodes human artifact by dissolving lime stones and damage outdoor monuments (EPA, 2006-d).

In U.S.A., the average SO₂ ambient concentrations have decreased 54 percent from 1983 to 2002 and 39 percent over the more recent 10-year period 1993 to 2002, that is mainly due to the implementation of the Acid Rain Program installing flue gas control equipment at coal-fired generating plants, reducing emissions from industrial processing facilities such as smelters and sulfuric acid manufacturing plants, reducing the average sulfur content of fuels burned, and using cleaner fuels in residential and commercial burners(EPA,2006-d).

1.4.2. Nitrogen Oxides (NO_x)

NO_x are considered indirect air pollutants. They are major contributor to photochemical smog and acid rain formation since their presence in air is serving as a catalyst for ozone production in the troposphere. The most important two oxides in air pollution are NO₂ and NO. Nitrogen dioxide is soluble in water vapor in air to produce nitric acid which will fall out as acid rain causing adverse impacts on vegetation. In addition NO₂ has impacts on human health. It is considered as irritant to the alveoli of the lungs and frequent exposure to higher concentrations of NO₂ can cause increase incidence of acute respiratory illness in children.

Globally the natural occurrence of nitrogen oxides in air is ten times more than their anthropogenic emissions. Bacterial and volcanic action, lightning and intrusion of stratospheric nitrogen oxides are natural sources of nitrogen dioxide. Fossil fuel combustion in stationary sources such as heating and power generation and in

transportation (internal combustion engines) are major anthropogenic sources of nitrogen oxides in the atmosphere (WHO, 2000-b) (Manahan, 1994).

Controlled human clinical studies were conducted to see the effect of exposure to nitrogen dioxide on pulmonary function of healthy adults (EPA 1993, Berglund M. et al 1993, Wagner, H. M 1985). But the main concern was on the people with pre-existing lung disease. Numerous studies concerning these people showed different results, for example the study of Linn et al (1986) and Linn and Hackney (1984) found that the exposure to 1880-7520 $\mu\text{g}/\text{m}^3$ of NO_2 give no response of pulmonary function whereas Von Nieding and his colleagues (1970, 1971 and 1979) found that there is an increased airway resistance in people of chronic obstructive pulmonary disease when briefly exposed to levels of 3000 $\mu\text{g}/\text{m}^3$.

Epidemiological studies also conducted to observe the effect of nitrogen dioxide exposure to respiratory diseases of adults, elderly, and children has been conducted in different parts of the world like in U.K., USA, Germany, Japan, Switzerland, and Netherlands (EPA report 1993; EPA report 1995; AGMAAPE London, 1993). The most consistent general result was the one that showed increased respiratory illness in older children (5-15 years) at an increased level of exposure to NO_2 . The other epidemiological studies showed mixed results (WHO, 2000-b).

Some evidence provided by epidemiological studies indicated that long-term NO_2 exposure may decrease lung function and increase the risk of respiratory symptoms (WHO, 2003), But the NO_2 exposure and mortality is not associated in epidemiological studies since there are several other air pollutants in the ambient air.

The biochemical studies on experimental animals showed effects on both lipid metabolism and antioxidant metabolism is dependent on both concentration and duration of exposure (WHO, 2000-b).

1.4.3 Carbon Monoxide (CO)

Carbon Monoxide is colorless, odorless, tasteless, toxic gas. It can attack a person when he is unaware of its presence. Exposure to a high concentration of it could be fatal. Natural emission of this gas into atmosphere comes as a result of human metabolism and oxidation of methane gas by plants, but the main global emissions come from anthropogenic sources. It is released by incomplete combustion of fuel, especially from vehicle using petrol, as exhausts of internal combustion engines (WHO, 2000-c). Transportation and solid-waste disposal are other anthropogenic sources of CO. In U.S.A in the year 2002, 82 percent of the total emissions of CO were from transportation (EPA, 2006-c). In studies measuring the concentration of carbon monoxide inside motor vehicles and in ambient air of urban traffic environment (Rudolf W, 1994; Dor F et al, 1995; Fernandez-Bremauntz and Ashmore, 1995), found that the concentration of CO is generally higher in motor vehicles than in ambient air. The mean concentration of CO levels is 2-5 times higher in personal cars than those measured levels in street or inside subway trains (WHO, 2000-c).

Carbon Monoxide has an adverse effect on human health due to its high affinity for hemoglobin. It can displace the oxygen bonded to hemoglobin preventing it from reaching to human organs and tissues. Therefore it is the main cause of Hypoxia disease. Headaches, shortness of breath and unconsciousness are results of exposure to a very high concentration of carbon monoxide.

There are people who are continuously exposed to higher concentrations of CO than others because of their work (for examples policemen, traffic wardens, garage and tunnel workers, fire men, taxi and bus drivers) or because of habits like smokers. Extensive studies were conducted to observe the effect of exposure to different concentrations of carbon monoxide on health of those different population groups. For

example, study of driver's health who is exposed to volatile organic compounds, CO, ozone and NO₂ under different driving conditions by Chan et al, 1991. Atimtay A.T. et al, 2000 study of Urban CO exposure and its health effects on traffic policemen in Ankara.

Other studies concerning the exposure to CO by susceptible people also were addressed. Raub, 1999 study the health effects of exposure to ambient carbon monoxide. He focused on susceptible individuals to CO. Neidell, 2004 study the air pollution, health and socioeconomic status: the effect of outdoor air quality on childhood asthma. Carbon monoxide was found to have a significant effect on asthma for children ages 1-18.

In addition to health problems, carbon monoxide has impacts on environment especially global effects. Carbon monoxide contributes indirectly to global warming and ozone depletion (Badr and Probert,1995)(Wikipedia ,2006).

1.4.4. Toxic organics

Toxic organics such as formaldehyde and acetonitrile, benzene, and polycyclic aromatic hydrocarbons PAHs, are considered to be direct air pollutants. Formaldehyde is flammable and colorless gas with irritant odor. It is the simplest form of aldehyde and it is readily polymerized at normal room temperature and pressure (WHO, 2001). Naturally it is formed by oxidation of hydrocarbons. The most important anthropogenic source of formaldehyde is from exhaust of engines without catalytic convertor. Industries of production and use of formaldehyde emit this gas directly into air. But the indoor levels of formaldehyde are often higher than in the outdoor air, where it is released from various consumer products such as building materials and home furnishings especially in new homes and new furniture (EPA,2006-e).

The inhalation of this gas causes irritation of the eyes, nose, and throat. In addition, it can cause discomfort, sneezing, dyspnoea and death. It is also considered as a genotoxic (WHO, air quality guide lines, 2001). Maibach H, 1983 studied the effect of formaldehyde on animal and human skin. He found out that formaldehyde can cause allergic contact dermatitis and it is a skin irritant.

Benzene (C_6H_6) is flammable, colorless, and volatile aromatic hydrocarbon. It is derived from crude oil and used in petroleum, chemical and manufacturing industries. It is classified as carcinogenic and a causative agent in human leukemia. If four or more benzene rings are attached, they produce what is known as polycyclic aromatic hydrocarbons which are also considered as carcinogenic. PAHs are released as a byproduct of carbon fuel combustion. When large quantities of soot particles are produced from diesel exhaust or from coal or wood fire smoke, their concentration in air is high.

1.4.5. Volatile organic compounds (VOCs)

Volatile organic compounds are also important air pollutants. Like the nitrogen oxides, they are not direct air pollutants but are important ingredients in formation of chemical smog. Their emissions mostly come from the industrial processing, solvent utilization, and vehicles. Household products including: paints, paint strippers, aerosol sprays, dry-cleaned clothing and others are indoor sources of VOCs (EPA, 2006-a)

The ability for this group to cause health effect varies from causing eye, nose, and throat irritation, headaches to causing cancer to animal and some to human.

spray, soil erosion, yeast, pollen, viruses, bacteria, and volcanic eruptions as well as a result of human activities such as in power plants, vehicles, wood stoves and industrial processes (WHO, 2003).

Particles can be classified as primary or secondary depending on formation mechanism. Primary particles get emitted into air through natural and anthropogenic processes, whereas secondary particles are formed in atmosphere as a result of chemical reactions of gaseous pollutants. (WHO, 2005)

Hildemann et al, 1993 showed that diesel trucks, cars with and without catalytic converters, industrial-scale boilers, fireplaces and meat cooking operations emit particles primary in the range 0.1-0.2 μ m, and petrol fuelled cars with converters emit much lower particle mass than the one without converter. By comparing the emission of particles from diesel trucks with emissions from car, it was found that in comparison diesel trucks emit 100 times of particle mass per one kilometer than cars with catalytic converters, for the same distance.

Particulate matter also is known by different terms according to the type of classification they are derived from. For example, "suspended particulate matter", "Total suspended particulate matter", "Black smoke" are derived from the sampling and analytical methods, whereas "inhalable particles " and "thoracic particles" are derived from the site of deposition in the respiratory tract, and "PM₁₀" related to both sampling and physiological connection (WHO,2000-d).

1.4.7.2. Size

The size of suspended particulates is actually broad. It varies from few nanometers to tens of micrometers. The largest particulates, that have a size greater than 2.5 μ m, are

known as the "Coarse Fraction". These coarse particles are mainly derived from natural sources such as the breakdown of larger solid particles which includes uncovered soil, wind-blown dust, unpaved roads operations, sea sprays, pollen grains and mould spores. The large particles can be broken into smaller sizes but the energy needed to do so increases as the size of the particle decreases. The releasing of non-combustible materials such as fly ash out of combustion of fossil fuels (petrol, oil, and coal) can produce coarse particles.

The smaller particles are known as "Fine fraction" or "fine mode" that are usually formed from gases (WHO, 2000-d). They have a size of $2.5\mu\text{m}$ and less. However, the smallest particles could have a size of less than $0.1\mu\text{m}$. Because of their significant effect on human health and environment, the U.S. Environmental Protection Agency imposed regulatory limits on fine particles $\text{PM}_{2.5}$ in the new ambient quality standard in 1997(Pope et al,2002). The smallest particles, which are less than 100nm , are formed by nucleation. The nuclei (particle) are formed by chemical reaction or condensation of low vapor pressure substance formed by high temperature vaporization in atmosphere. There are four major sources with equilibrium where low pressure can form nuclei: heavy metals that vaporized during combustion, elemental carbon generated from combustion, organic carbon, and sulfates and nitrates. Later these particles can grow either by coagulation or by condensation (WHO, 2003).

Xiu et al, 2004, studied the characterization of major water-soluble inorganic ion in size-fractionated particulate matters in Shanghai campus ambient air, found that emission of stationary source was still the important contributor to fine particulates. Because of fine particle size, they have low settling velocities and therefore they are transported from their source to 1000 km or more, whereas the larger particles tend to settle under the force of gravity.

1.4.7.3. Composition

Although the physical and chemical composition of airborne particulate matter varies in time and space, it is important to know their composition in order to determine the effect of exposure to these particles. The atmospheric particles are composed of variety of compounds depending on their source, processing and reactions they undergo in atmosphere between emission and analysis. Atmospheric particulates matter may compose of "heavy metals" (such as lead, chromium, arsenic, vanadium, and selenium), crustal material (such as silicon dioxide and calcium salt), carbonaceous compounds (such as elemental carbon and organic compounds), water, and inorganic electrolytes (Johnston and Wexler, 1995).

Atmospheric particles may contain diversity of water-soluble and insoluble components. 60-70% of total aerosol mass is water soluble ionic component, the major nine are Na^+ , Mg^{2+} , Cl^- (from marine source), K^+ , Ca^{2+} (from soil source), and NH_4^+ , SO_4^{2-} , NO_3^- , and H^+ (from atmospheric oxidations). The water-insoluble components are about 30-40% of total aerosol mass, and they include organic and elemental carbon and corrosive derived iron oxides (man-made materials), and quartz, calcite and clay minerals (natural processes) (Harrison, 2001; Ali-Mohamed, 1991).

Hitzenberger et al, 1999, stated that all atmospheric aerosols contain some black carbon that originates from incomplete combustion of carbonaceous fuels.

A study of the inorganic composition of aerosols dust haze storm settling in Hamad Town, Bahrain showed that the settling particles were rich in calcium, potassium, sulfates and chloride ions. (Ali-Mohamed, 2004)

According to Chow et al. (1993) study in California, USA, of the particulate matter of size 2.5 and PM10, fine particles are mainly composed of sulfate, nitrates, ammonium ions together with elemental and organic carbon made up 70-80% of the total PM2.5 mass. In contrast those are only 10-20% of the component of coarse particle mass, and 40-50% of coarse particle mass is composed of aluminum, silicon, sulfur, potassium, calcium and iron (WHO, 2000-d). Fine particles pollution contains mixture of soot, acid condensates, sulfate and nitrate particles (Dockery et al, 1993), and small particles may contain biological active elements and compounds (Morgan et al, 1970; Ali - Mohamed and Jaffar, 2000).

The composition of fine particles showed seasonal variations. For example, in winter the organic and inorganic secondary production in outdoor atmosphere contributes about 75% of PM2.5 mass while in summer it is only 40% of PM2.5 mass (Giugliano et al, 2005).

Trace metals or "heavy metals" are one of the components of particulates matter. They are introduced naturally into atmosphere by volcanoes, wind-borne soil particles, sea salt spray and wild forest fires (Nriagu, 1989) and emitted into atmosphere as a result of human activities mainly from coal and fuel power generation plants, metal processing and smelting, waste incineration and transportation combustion (Fifield and Haines, 1995).

1.4.7.4. The Impacts of Particulates Matter On:

1.4.7.4.1. Human Health

PM10 is referring to particulates of a size 10 μm and less. These were considered to be of great importance in terms of human health effect. Since inhalation is the only route

of human exposure to particulate matter, therefore it has a direct effect on human health. The most adverse effects come from the inhalable particles which are less than 10 μm in diameter because of their ability to penetrate lower regions of respiratory tracts. But the greatest threat comes from those of less than 2.5 μm in diameter "respirable" because of their composition of gases and secondary pollutants, ability to absorb more toxic and carcinogenic compounds, and because of their tiny size they can go deeper into lungs to the alveoli where exchange of gases take place.

Airborne particles can adversely affect human health (Gard et al, 1998; EPA, 1996; Ali-Mohamed and Ali 2001). An association between fine particulates pollution levels and human health in epidemiological studies had been reported (Pope et al, 1995; Fraser et al, 1999). According to the epidemiological studies published between 1989 and 1996, low concentration of particulate air pollution reported to have health effects (Pope C.A and Dockery D.W, 1999; Pope C.A. et al., 2002) and Dockery D.W. et al 1993, suggested that fine particles air pollutions or particulate matter complex pollution mixture, contribute to excess mortality in U.S. cities.

In urban atmosphere, aerosols have been connected to the increased morbidity and mortality and the increase in particulates concentration lead to increase in incidence of health effect (Dockery D. W. et al, 1993; Jonston and Wexler, 1995). It has been found that black carbon concentrations in urban areas might cause deleterious health effects (Hitzenberger, 1999).

Several studies (Brunekreef 1997, Woodruff and Schoendroff 1997, Bobak and Leon 1999, Clarke et al 1999, Abbey et al 1999, McDonnell et al 2000 and others) have been conducted to assess the effect of short and long term exposure to atmospheric particulates on human health. These studies showed that long term exposure to PM can reduce a few years of life expectancy and that is mainly due to the increase of lung

cancer and cardio-pulmonary mortality. In addition, it causes a reduction in lung function and increases symptoms in lower respiratory tract in children, and causes pulmonary diseases and reduce lung function in adults (WHO, 2003).

Long term exposure to fine particles air pollution released from combustion is an important environmental risk factor for cardio-pulmonary and lung cancer mortality (Pope III C.A. et al, 2002)

Short term exposure to ambient PM also has an effect on human health especially on those people who have pre-existing pulmonary and cardio problems. There is no threshold under which it is safe to expose to ambient PM. These results have been shown in several studies conducted by two large multi centers (National Morbidity, Mortality, and Air Pollution Study, NMMAPS) in USA and (air Pollution and Health a European Approach, APHEA) in Europe (WHO, 2003). The risk for hospital admission of cardiovascular and respiratory diseases increases by short-term exposure to PM_{2.5} (Dominici et al, 2006). It is also reported that there is consistent evidence of association between the risk of death from all causes and from cardiovascular and respiratory illnesses and the levels of fine particulate matter in the air (Samet et al, 2000), and a suggestion of detrimental effect of relatively low levels of ambient particulate matter and gaseous pollutants on hospitalization for respiratory infections in children have been indicated (Lin et al, 2005).

1.4.7.4.2. Visibility

The increase in airborne particles in the atmosphere has an effect not only on health but also on visibility. Particulates are responsible for much of visibility reduction occurrences in urban areas (National research council, 1993; Gard et al, 1998; Ali-Mohamed and Ali, 2001). Both primary and secondary aerosols are responsible for visibility impairment especially the fine particles which are considered as a major

contributor to haze (Shaw, 1987). Reduction in visibility happens when particles absorb and/or scatter light from sun. Elemental carbon (soot) and NO₂ are examples of most effective absorbing light particles. This phenomena increases by increase in humidity (Gourdeau and Ferrand, 2004). Some particles such as particles of sulfates and nitrates grow in size in humid air causing more impairment in visibility. A study in Hong Kong shows that sulfate and ammonium ions are the only ions that are important in visibility degradation (Lee and Sequeira, 2002). In the eastern part of the United States it is found that the sulfates particles are responsible of 50-70% in visibility reduction; while in the western part both the sulfates and nitrates particles are affecting visibility (EPA, 2005).

The U.S. Environmental Protection Agency proposed, on July 31, 1997, a new regulatory program to improve visibility' in the U.S national parks and Wilderness areas by reducing regional haze. Regional haze formed as a result of the presence of small particles, generally ranging in size from 0.1 to 1.0 micrometers in diameter, in the air that absorb and scatter sunlight, with the effect of reducing contrasts, and making distant objects indistinct or invisible (McCarthy et al, 1998).

1.4.7.4.3. Climate

Atmospheric particulates have an important effect on earth's radiation balance that lead to climate forcing (Charlson et al,1992;Ali-Mohamed and Ali,2001) Aerosols have direct and indirect effect on climate. They have direct cooling of the Earth surface right below them due to their ability to absorb and reflect sunlight back into space. This cooling depends on the size and composition of the aerosol particles. Reducing the amount of solar energy reaching the earth's surface may lead to a global cooling. They affect the climate indirectly by changing properties of clouds. First the increased number of cloud condensation nuclei lead to increase in number of smaller cloud

droplets that enhance scattering of light within clouds and an increase in cloud albedo. Secondly, because of small droplets, there is less rain, and the cloud lifetimes are longer and that leads to greater cover of cloud over the Earth. (Gourdeau and Ferrand, 2004) The atmospheric aerosols are major contributor to atmospheric light absorption in the visible, near ultra violet and near infra red and black carbon (in soot particles) is almost exclusively responsible for light absorption of particles (Horvath, 1993).

Sulfate particulates are known to have influence on the global heat balance due to their direct scattering of sun's rays and indirect effect as a major source of cloud condensation nuclei (Spiro and Stigliani, 2003). Coarse particles such as dust and sea spray are blown by wind but they settle out rapidly. While the fine particles are the ones that stays longer in air and carried away from their original source to other places by wind. These particles have a life time of days and weeks affecting the climate and visibility.

1.4.7.4.4. Other Ecological and Aesthetic Effects

In addition to the previously mentioned effects, atmospheric particles have other ecological and aesthetic effects. Soiling, reducing growth and productivity of plants by interfering with photosynthesis, and affecting the aquatic life through adsorption and ingestion of the settleable particulates are ecological impacts of particulate matter. The aesthetic effect can be realized by increasing of corrosion, erosion, and discoloration of building and materials. Studies of atmospheric effect on vegetation, aquatic life, and materials was conducted by the U.S. Environmental Protection Agency in late 1970's.

A recent study conducted by Grantz et al, 2003 of the ecological impacts of particulates matter has shown that deposition of particulate matter on vegetated surfaces depend on the chemistry and size distribution of particles. Abrasion and radiative heating is

caused by dust coating which as a result prevent photosynthetic photon to reach the photosynthetic tissues. Furthermore acidic and alkaline composition of PM can injure the leaf surface. The direct deposition of PM on soil can affect the nutrient cycling.

1.5. Ion Chromatography

Chromatography is a general term used to describe a wide range of physico-chemical separation techniques which have the same operating principle where the components to be separated are distributed between a mobile and stationary phase. Chromatography techniques are divided up according to the physical states of these two phases. Ion chromatography technique is a subdivision of high performance liquid chromatography (HPLC) (Metrohm, 2003). It was introduced in 1975 and was firstly used to analyze the organic ions, but in a short time it has been developed to encompass all HPLC methods in determining inorganic and organic ions.

Several analytical techniques that are available, fast and sensitive such as AAS, ICP, Polarography and others are used for analysis of cations. On the other hand there was a lacking of sensitive methods for the analysis of anion. In addition to the wet chemical methods such as titration, gravimetry, photometry, colorimetry, and turbidimetry are all time and chemical consuming, labor-intensive and troublesome. In contrast ion chromatography with a short time of analysis(few minutes),high sensitivity and selectivity, simultaneous detection, and stability of the separator columns advantages, makes it very widely applied in several fields such as Environmental analysis, in Power Plant Chemistry, in Food and Beverages Industry and others.(Weiss,1995)

Ion Chromatography was first successfully applied for environmental studies in Bahrain to analyze the anions and cations of aerosol water-soluble inorganic particulate matter and water samples. Example (Ali-Mohamed 2004, Ali-Mohamed

and Matter 1996, Ali- Mohamed and Ali 2001, Ali-Mohamed and Jaffar 2000). It has been used by other scientists for the same purpose in different parts of the world such as the study conducted by Perrino et al, 1999 for monitoring atmospheric pollution in background networks.

1.5. 1. The ion chromatographic system

The pump, injection valve, separator column, detector, and recorder are the basic components of an ion chromatograph.

Two types of pump are used; single position pump and dual position pump with a function of pumping the eluent through the chromatographic system. The dual position pump is a high pressure pump therefore it is more preferable. An example of this type is Metrohm 697 IC pump used in this research.

The sample is injected into the system by a three way injection valve with two ports connected to the sample loop. A sample of 10 μl to 100 μl is carried out at atmospheric pressure to the separator by the mobile phase (eluent) after switching the injection valve.

The separator column is the most important component of the IC system where ion exchange reaction takes place between ions from the sample and the functional group ions in the stationary phase. The quality of analysis depends on the separation efficiency of the separator column. The outer tube is made of inert material such as Tefzel or epoxy resins while the stationary phase (inside solid) varies depending on the application needed.

Another important part of IC system is the Detector. Sensitivity, linearity, resolution and noise are criteria used to assess the detector performance. Conductivity detector with or without suppressor system is most commonly used than UV/Vis, fluorescence,

and amperometric detectors. Suppressor system is responsible for the chemical reduction of high conductivity of eluent electrolytes and making the sample ions more conductive.

The last part is the Recorder where chromatograph signals are displayed as peaks and by getting the peak area or peak height the concentration of the analytes can be calculated. Modern detectors are connected to computer with chromatograph software where automated operation of chromatograph system is controlled by PC (Weiss, 1995).

1.6. Bahrain and Air Pollutions

Bahrain is an archipelago of 33 islands with a total area of 707 km² in the Arabian Gulf. It lies 22 km away from the eastern coast of Saudi Arabia and 28 km away from the western coast of Qatar peninsula. The largest island is Bahrain with an area of 586 km² (Ali-Mohamed and Jaffar, 2000). It has a desert climate. It is very hot most of the year, especially from June to September where temperature reaches above 40°C, with very humid air and low rainfall.

The ambient air of Bahrain is contaminated with both natural and anthropogenic aerosols. The natural aerosols are of two types, marine (sea spray) and desert (gypsum calcite, clay, feldspars, quartz, and dolomite) (Ali- Mohamed, 2004).

Air pollutants, especially airborne particles, are of great concern to scientists in different parts of the world due to their impacts on human health and environment. Monitoring of these particles and their composition had been conducted in several studies of rural and urban areas of Bahrain. Examples of these studies are (Ali-

Mohamed, 1991), (Ali-Mohamed et al, 1995), (Ali- Mohamed and Matter, 1996), (Ali-Mohamed, 2004), (Ali-Mohamed and Jaffar,2000), (Ali- Mohamed and Ali, 2001).

The emission of pollutant gases in Bahrain's atmosphere and their effect on human health was also studied. For example, the study of "Concentration of nitrogen dioxide throughout the state of Bahrain" by Danish and Madany in 1992 showed marked spatial variation of NO₂ concentration throughout Bahrain and NO₂ concentration decrease from the north to the south where heavy traffic also decrease in the same direction indicating that the NO₂ level from traffic is higher than from industry and airport areas.

Another example is the study of "Carboxyhemoglobin levels in blood donors in Bahrain" by Madany, 1992, to see the effect of carbon monoxide emissions in air on human health from different categories (smoking habits, sex, place of work, occupation, and residential area). It was found that there is an influence of the environmental levels of carbon monoxide on the COHb in the blood of Bahraini population.

The anthropogenic aerosols are mainly from fuel combustion, industry and landfill. The increase in vehicle number and in energy production is the main source of air pollution in the country (The Kingdom of Bahrain, Ministry of State, Municipals Affairs & Environmental Affairs, 2002). In general the air pollutants parameters in Bahrain did not exceed Ambient Air Quality Standard (AAQS) except for the ozone and inhaleable particulates. A spatial variation of concentration of pollutants across the island is reported.

Due to the limitation of land and the lack of proper planning, the industrial plants are present in the residential area of Bahrain. This had led to an increase in health problems to the residential people due to the direct breathing of high concentrations of

pollutants emitted from these plants. For example, by the end of April and till two weeks of May, 2005, people in Ma'amir suffered not only from unpleasant smells but also from irritating gases. These unknown irritating gases caused burning of their eyes and suffocation. This made some people leave their homes especially those who previously had breathing problems such as asthma .Because of this problem, the government now is trying to find solutions for these people and to put more strict rules and control on the emissions from factories and industrial plants in Bahrain (Alwasat Newspaper, 2005).

Objectives of the Study:

1. The main objective in the present study is to conduct a comparative estimate of dry fall deposition of suspended particulate matter in heavy polluted industrial area (Ma'amir Village), in urban area (Manama City), and in rural area (Al-Hamalah Village) of Kingdom of Bahrain. As it is mentioned above Ma'amir village is a residential area as well as an industrial one. The oil refinery, aluminum smelter, Gulf Petrochemical Industries Company, and power station are few kilometers from residential area. Whereas Manama city is the capital like any other cities in the world where most of activities takes place and is congested with people and vehicles. Al-Hamalah village is a rural area and very near to the sea shore (the location of these sites is shown in fig 1).
2. To collect samples from these three areas using deionized water traps and performing analysis for the chemical composition of water soluble matter using ion chromatography method, in which the ion chromatograph is a very precise instrument in measuring the concentrations of cations and anions and to use AAS and ICPS techniques to measure the concentrations of trace metals in these samples.

3. To analyze the organic composition of tarry matter using MS-GC device.
4. Finally, to correlate the data obtained with meteorological and surface characteristics of Bahrain.

Figure 1. Bahrain map showing the three Stations under study; Ma'amir, Hamalah, and Manama.



2. Experimental & Methods

2.1. Sampling

Three one liter beakers filled with ultra pure deionized water (Barnstead, Easypure RF compact ultra pure water systems, USA) were placed in three areas representing the area under study. Each beaker was placed on the roof of an 8m high building for one week.

2.2. Suspended Matter Determination

The water sample was filtered on a previously dried and weighed 0.45 μm micro membrane filters (Supelco Nylon 66 membranes, 58067). Then the micro membrane filters were placed in an oven of 80 $^{\circ}\text{C}$ for about twenty minutes to dry and finally reweighed. The total suspended solid was obtained by subtracting the weight of the micro membrane filter before filtration from that after filtration. The filtrate was diluted to one liter using deionized water and was thoroughly mixed and saved for analysis.

2.2.1 Anions and Cations analysis

The anions (F^- , Br^- , Cl^- , NO_2^- , NO_3^- , and SO_4^{2-}) and the cations (Li^+ , Na^+ , NH_4^+ , K^+ , Mg^{2+} , and Ca^{2+}) were determined by a Metrohm Ion Chromatograph (IC-690). Injection of a 100 μl of sample into a Super-Sep anion 6.1009.000 column (Manufactured by Hamilton, Reno, NV, USA) using 0.0025 mol dm^{-3} phthalic acid eluent (pH = 4, TRIS-(hydroxymethyl aminomethane) (puriss, Fluka) and conductivity was approximately 140 $\mu\text{S/cm}$) will separate the above anions in about 20 min. The chart recorder recorded the presence of the anions in form of peaks. Each peak

represents certain anion. The concentration of the above anions will be determined by comparing the peak height of the anions with the peak height of the standards.

Separation of the stated cations was conducted by injection of 10 μ l of the sample into a Metrosep cation 1-2 column 6.1010.000(manufactured by Hamilton PRP-X100) using 4 mmol/L tartaric acid and 0.75 mmol/L of dipicolinic acid eluent (PH= 2-7 and conductivity approximately 500 μ S cm^{-1}) that had been prepared previously. A comparison between the height of the cations peaks and the height of the standard peak enable us to determine the concentration of the cations in the sample.

2.2.2. Conductivity and pH Determination

The pH and conductivity measurements of the water trap samples were measured using a Hanna 210 Microprocessor pH meter and Jenway CE 470 conductivity meter with carbon conductivity electrode(cell constant =1.16).

2.2.3. Preparation of 2.5mmol/L Phthalic Acid Eluent

A 0.260g of Phthalic acid (puriss, Fluka chemika) was placed into two liter volumetric flask and dissolved to 1.9 liters using ultra pure deionized water and warming. The pH of the eluent was adjusted to be equal to pH 4 by using TRIS (hydroxymethyl-aminomethane MM=121.14g/mol puriss, Fluka chemika) and the conductivity was adjusted to approximately 140 μ S cm^{-1} . The solution was then diluted with deionized water to the mark of two liter and filtered through 0.45 μ m micromembrane filter. Finally the filtrate was connected to a vacuum line for de-gassing for two hours before using in the Metrohm ion chromatograph (IC-690) device.

2.2.4. Preparation of 4.0mmol/L Tartaric acid and 0.750 mmol/L Dipicolnic Acid Eluent (Pyridine-2,6-dicarboxylic acid)

A 1.20g of Tartaric acid (puriss Fluka chemika) and 0.25068g of Dipicolnic acid (puriss Fluka chemika) were placed into a 2.0 L volumetric flask and dissolved by using 1.90L deionized water. The pH of the eluent was 3.4 (the pH should be above 2 and less than 7) and the conductivity was approximately $500 \mu\text{Scm}^{-1}$. Then the solution diluted with deionized water to the mark and thoroughly mixed and filtered using $0.45\mu\text{m}$ micromembrane filter. Finally the filtrate was connected to a vacuum line for de-gassing for two hours before using in the Metrohm ion chromatograph devise.

2.2.5. Preparation of the Anions Standard Solution

A preparation of mix standard solution of anions (5 ppm F^- , 10 ppm Br^- , 5 ppm Cl^- , 5 ppm NO_2^- , 10 ppm NO_3^- , and 10 ppm SO_4^{2-}) was prepared by placing 2.5 ml of 1.000g/L F^- (Fluka chemika), 2.5ml of 1.000g/L Cl^- (Fluka chemika), 2.5 ml of 1.000 g/L NO_2^- (Fluka chemika), 5.0 ml of 1.000g/L Br^- (Fluka chemika), 5.0 ml of 1.000g/L NO_3^- (Fluka chemika), and 5.0 ml of 1.000g/L SO_4^{2-} (Fluka chemika) standards into 500 ml volumetric flask and diluted to the mark using ultra pure deionized water by thoroughly mixing.

2.2.6 Preparation of the Cations Standard Solution

A preparation of mix standard solution of cations (10 ppm Ca^{2+} , 10 ppm Mg^{2+} , 5 ppm NH_4^+ , 1.0 ppm K^+ , 1.0 ppm Li^+ , and 5.0 ppm Na^+) was conducted by pipetting of 5.0 ml of 1.000g/L Ca^{2+} (Fluka chemika), 2.5 ml of 1.000g/L NH_4^+ (Fluka chemika), 5.0 ml of 1.000g/L Mg^{2+} (Fluka chemika), 5.0 ml of 1.000g/L K^+ (Fluka chemika),

0.50 ml of 1.000g/L Li^+ (Fluka chemika) , and 2.5 ml of 1.000g/L Na^+ (Fluka chemika) standards solutions into 500 ml volumetric flask and diluted to the mark using ultra pure deionized water by thoroughly mixing.

2.3. Tarry Matter Determination

To dissolve the tarry matter, ten milliliter of chloroform (puriss, Fluka chemika) was placed on the micromembrane filter containing the total suspended particulates (TSP) and a filtration was conducted. Then the filtrate was placed into small screw bottles(Perkin-Elmer Auto sampler Crimp-top sample vial, clear glass, 2 ml volume.) and cooled in fridge for analyzing the crude component of the tarry matter using Perkin-Elmer GC-MS (TurboMass-Auto SystemXL Gas, EI electron ionization +ve source, USA).

2.4 Determination of trace metals

In order to determine the concentrations of the trace metals, Shimadzu AA-6800 atomic absorption and Shimadzu ICPS-5000 Sequential Plasma Spectrophotometer were used. Two milliliters of 40% fluoric acid (puriss, Fluka chemika) and four milliliters of 65% nitric acid (puriss, Fluka chemika) were added to 0.2500g of dryfall particulate matter and wet digested in a “Milestone” ETHOS 900 Microwave LabStation. The digested solution was filtered on a vacuum line using a Buchner funnel to determine the weight of residue. The filtrate was transferred to a 100ml volumetric flask and diluted to the mark with deionized water of high purity obtained by deionizing double-distilled water in Barnstead easy pure RF compact ultra pure water systems maximum electrical conductivity test ($0.1\mu\text{S cm}^{-1}$ at 25°C). Then the concentrations of Ni^{2+} , Cd^{2+} , Pb^{2+} , Mn^{2+} , Zn^{2+} and Cu^{2+} were measured using a Shimadzu AA-6800 atomic absorption spectrophotometer and both As and Sb

concentrations obtained by using the hydrated system of Shimadzu AA-6800 atomic absorption spectrophotometer. The ICPS-5000 Shimadzu Sequential Plasma Spectrophotometer was used to measure the concentrations of $\text{Cr}^{3+} / \text{Cr}^{+6}$, Si, Fe^{2+} , Al^{3+} and V^{2+} .

2.5 Detecting the presence of Asbestos

The Olympus microscope was used to find out the presence of any type of asbestos by placing a small amount of suspended particles on a slide and covered by cover slip which was then magnified ten times.

3. Results and Discussion

Pollutants are usually carried hundred of miles away from the source and some common pollutants are transformed while moving through the atmosphere by chemical reaction with sunlight into more hazardous one such as photochemical oxidant. This research study on transport of air particulates from natural sources has been mainly concerned with movement of the inorganic aerosols. The major particulates ions (Li^+ , Na^+ , K^+ , NH_4^+ , Mg^{2+} , Ca^{2+}), H^+ are generally related to weathering reactions involving common minerals (dust reactions). H^+ , Cl^- , SO_4^{2-} ions are related to natural and anthropogenic sources, and NH_4^+ ions are associated with nitrogen cycle as well as anthropogenic source. These particles of aerosol collected by sampling the dry deposition are clearly associated with transport and dispersion of such inorganic particulate material in the atmosphere.

Table 1 shows the weekly concentrations of physical and chemical parameters during the study period as well as the mean concentrations of total suspended solid, dry suspended solid, tarry matter (ppm); total dissolved solid (ppm); Li^+ , Na^+ , K^+ , Mg^{2+} , Ca^{2+} , and NH_4^+ (ppm), and F^- , Br^- , Cl^- , NO_2^- , NO_3^- and SO_4^{2-} (ppm).

Both pH and conductivity of water-soluble particulate matter were relatively high in moderate weather. During Dec.2004- June 2005, both parameters were higher in Manama than in Ma'mir and Hamalah and the conductivity mean value of Ma'mir area was almost doubled the amount of that in Hamalah during the period of study (Table 1&4). The mean values of pH for the three areas were 6.95, 6.92, and 6.44, for Manama, Ma'amir and Hamalah respectively.

In the first and last week of April, high values of conductivity for the water-soluble components ($188\mu\text{S}/\text{cm}$, $157\mu\text{S}/\text{cm}$) and pH (7.15, 7.53) was found for the Ma'amir,

whereas the high values of conductivity (113.6 $\mu\text{S}/\text{cm}$) and pH (7.25) was found in the first week of May for Hamalah area.

The total suspended solid(TSS) shows relatively high mass, whilst the tarry matter airborne on aerosol particulates solids makes up on the average 3.6% of the total suspended solid. However, there are exceptional days where the percentage exceeds this result. For example, in Hamalah May 2005, the percentage was high during the whole month reaching 60.98 % of total suspended solid. In addition high values were recorded in Ma'amir and Manama in different months (Table 1 & 2). Tarry matter shows relatively low mass in the atmosphere which indicate that the major component of these aerosol particulates matter are mainly components of soil material transported across semi-arid region of Bahrain and the Arabian peninsula by prevailing winds (Table 3). These sediments ranged from silting clay to coarse particulate matter.

The highest deposition of total suspended solid (TSS) was recorded reaching 673.1 mg/l (Ma'amir), 163 mg/l (Hamalah), 92 mg/l (Manama) in April 2005. This value of TSS found in Ma'amir (673.1 mg/l) is much higher than the one previously recorded for this area by Ali-Mohamed A.Y. and Matter H.A. during second week of March 1991 (133.5 mg/l).

The relationship between TSS and Conductivity in the three areas of study was investigated using Pearson product-moment correlation coefficient (see appendix table 6). There was a strong, positive relationship between these two variables in Hamalah and Ma'amir($r=0.936$ and $n=26$, $r= 0.587$ and $n= 27$). This relation indicates that high levels of TSS are associated with high levels of conductivity (fig. 6). Furthermore, there was strong, positive relationship between TSS and pH ($r= 0.639$, $n =26$) in Hamalah, and medium positive relation between these two variables in Ma'amir ($r= 0.443$, $n=27$).The same relation mentioned above can be clearly seen by referring to the line-graph (fig. 8), which represents the data of pH, conductivity, TSS and TM.

Table 1. Physical and chemical parameters during the study period

Station	Date	Condu- ctivity ($\mu\text{S cm}^{-1}$)	Anions (ppm)										Cations (ppm)					
			PH	TSP (g/L)	TM (g/L)	DSS (g/L)	F ⁻	Cl ⁻	Br ⁻	NO ₂ ⁻	NO ₃ ⁻	SO ₄ ²⁻	Li ⁺	Na ⁺	K ⁺	NH ₄ ⁺	Mg ²⁺	Ca ²⁺
Ma'amir	10-16 Dec 04	42.3	6.74	0.0393	0.0072	0.0321		2.12					2.39	1.54	1.09	0.19	0.88	17.27
	17-23 Dec 04	62.7	7.2	0.0459	0.0009	0.045	0.57	3.72		0.085	0.18	4.96	2.87	1.30	0.19	0.88	21.36	
	24-30 Dec 04	40.5	7.05	0.0374	0.0014	0.036	0.38	2.23				3.04	1.68	0.44	0.06	53.51	16.82	
	31 Dec-6 Jan 04	55.9	6.79	0.0325	0.0005	0.032	0.38	2.32				3.2	1.33	66.30	0.13	0.88	18.41	
	07-13 Jan 05	55.1	6.88	0.0342	0.0007	0.0335		2.33				2.68	1.75	0.65	0.06	0.70	18.41	
	14-20 Jan 05	36	6.69	0.0213	0.0008	0.0205		1.58				2.68	1.26	0.22	0.25	0.53	11.82	
	21-27 Jan 05	45.2	6.6	0.051	0.0005	0.0505	0.76	1.58				1.27	1.26	0.54	0.06	0.53	14.09	
	28 Jan-3 Feb 05	65.1	7.05	0.0371	0.0005	0.0366		3.32				3.66	2.20	0.44	0.13	0.75	16.82	
	04-10 Feb 05	50.9	6.76	0.0428	0	0.0428		1.99				1.55	1.30	0.65	0.31	0.70	13.18	
	11-17 Feb 05	60.4	6.82	0.0234	0.0006	0.0228							0	0	0	0	0	
	18-24 Feb 05	28.1	6.6	0.0419	0	0.0419		1.30				1.20	1.01	0.22	0.06	0.26	9.55	
	25 Feb-3 Mar 05	22.1	6.55	0.0641	0	0.0641		1.16				0.70	0.84	0.22	0.06	0.35	7.61	
	4-10 Mar 05	51.2	7.35	0.0911	0.0015	0.0896	0.51	3.84				4.96	2.41	0.22	0	0.53	12.96	
	11-17 Mar 05	21.8	6.71	0.0145	0	0.0145	0.13	1.74				1.6	1.29	0.44	0.16	0.61	5.91	
	18-24 Mar 05	37	6.41	0.1425	0.0016	0.1409	0.32	11.46			0.05	5.6	7.41	0.54	0.13	1.05	9.55	
	25-31 Mar 05	57.8	7.33	0.1384	0.0044	0.134	0.44	4.77			0.05	4.16	2.94	0.44	0.13	0.88	15.57	
	1-7Apr.05	188.8	7.15	0.0598	0.0015	0.0583		27.56			0.71	24.32	15.53	1.63	0.31	3.33	24.87	
8-14 Apr 05	51.9	6.67	0.0737	0.0031	0.0706	0.35	4.88			0.11	3.04	3.11	0.54	0.25	0.61	12.16		
15-21 Apr.05	32	6.69	0.1184	0.0134	0.105	0.19	2.99			0.05	1.52	1.89	0.44	0.38	0.35	8.75		
22-28 Apr 05	157.7	7.53	0.6731	0.037	0.6361	1.01	26.34				9.6	14.76	2.07	0.91	1.84	21.02		
29 Apr-5 May 05	100.1	7.27	0.2726	0.0044	0.2682	0.57	12.68			0.15	8.48	8.08	1.20	0.38	1.40	18.98		
6-12 May 05	38.8	6.71	0.0549	0.0018	0.0531		9.11				3.10	0.56	0.22	0.13	0.53	9.89		
13-19 May 05	50.5	7.28	0.0475	0.0007	0.0468		3.63			0.071	2.68	2.31	1.20	0.13	0.88	16.82		
20-26 May 05	52.5	7.15	0.065	0.0012	0.0638		3.22			0.099	2.82	2.03	0.76	0.13	0.88	17.05		
27 May-2 Jun.05	80.3	7.39	0.0809	0.0005	0.0804		6.58				3.94	4.69	1.20	0.31	1.23	22.05		
3-9 Jun 05	102.8	6.89	0.2323	0.0046	0.2277		15.27				9.30	9.30	1.09	0.31	1.75	17.50		
10-17 Jun 05	43.1	6.55	0.0708	0	0.0708		3.22			0.057	3.38	1.82	0.65	0.09	0.53	13.18		

[illegible]

Table 2. Percentage of the dry suspended solid (DSS) to that of tarry matter(TM) during the study period

Date	Stations					
	Ma'amir DSS (%)	TM (%)	Hamalah DSS (%)	TM (%)	Manama DSS (%)	TM (%)
10.12.04	81.68	18.32	81.82	18.18		
17.12.04	98.04	1.96	65	35	100	0
24.12.04	96.26	3.74	78.65	21.35	100	0
31.12.04	98.46	1.54	39.02	60.98	100	0
07.01.05	97.95	2.05	100	0	96.59	3.41
14.01.05	96.24	3.76	100	0		
21.01.05	99.02	0.98	100	0		
28.01.05	98.65	1.35	100	0	96.88	3.12
04.02.05	100	0	100	0	95.83	4.17
11.02.05	97.44	2.56	100	0	100	0
18.02.05	100	0	99.38	0.62	100	0
25.02.05	100	0	91.15	8.85	89.78	10.22
4.03.05	98.35	1.65	100	0	98.51	1.49
11.03.05	100	0	100	0	93.60	6.40
18.03.05	98.88	1.12	100	0	91.72	8.28
25.03.05	96.82	3.18	100	0	84.85	15.15
1.04.05	97.49	2.51	95.95	4.05	92.46	7.54
8.04.05	95.79	4.21	100	0	96.55	3.45
15.04.05	88.68	11.32	95.29	4.71	96.72	3.28
22.04.05	94.50	5.50	100	0	92.28	7.72
29.04.05	98.39	1.61	96.99	3.01	97.51	2.49
6.05.05	96.72	3.28	100	0	100	0
13.05.05	98.53	1.47	100	0	44.44	55.56
20.05.05	98.15	1.85	99.12	0.88	87.18	12.82
27.05.05	99.38	0.62	72.41	27.58	76.60	23.40
3.06.05	98.02	1.98	100	0	100	0
10.06.05	100	0			97.83	2.17
Mean	97.16	2.84	92.59	7.41	92.24	7.76

Table 3
Mean weekly climatologically summary of the studied period

Week No.	Month	Date	Temp (°C)	Temp(°C)	RH mean	Press	Evap (mm)	Wind(Knot)	Gust(knot)	Sun (Hrs)	Rain (mm)	Visibility
no.			Dry bulb mean	Wet bulb mean		(hPa mean)	mean	Mean spd	Max spd	Sum	Sum	Km
1	Dec,04	10-16/12/04	19.4	17.5	81.9	1,016.6	3.2	9.7	20.9	4.6	1.4	9.9
2	Dec,04	17-23/12/04	16.4	13.2	67.5	1,018.1	4.0	11.0	20.9	7.9	-	17.4
3	Dec,04	24-30/12/04	17.0	13.9	69.0	1,017.0	3.0	10.2	21.1	6.2	0.8	15.3
	Mean		17.6	14.9	72.8	1,017.2	3.4	10.3	21.0	6.3	0.8	14.2
4	Jan,05	31-06/01/05	17.8	13.9	63.1	1,018.1	3.6	7.6	17.0	8.8	-	14.9
5	Jan,05	07-13/01/05	15.7	12.4	65.0	1,020.4	4.5	11.3	23.6	6.3	0.5	9.7
6	Jan,05	14-20/01/05	16.3	13.7	72.5	1,017.6	4.5	7.8	18.0	5.6	1.7	13.3
7	Jan,05	21-27/01/05	15.9	13.0	69.8	1,018.5	4.3	10.9	22.9	8.3	2.1	13.7
	Mean		16.4	13.2	67.6	1,018.7	4.2	9.4	20.4	7.2	1.1	12.9
8	Feb,05	28-3/02/05	16.6	14.0	74.4	1,017.4	3.4	9.1	18.1	8.7	-	10.7
9	Feb,05	04-10/02/05	17.0	13.1	62.0	1,014.7	3.2	8.4	19.0	8.2	-	16.3
10	Feb,05	11-17/02/05	15.5	12.2	65.4	1,018.5	3.5	12.1	23.3	5.8	0.8	16.1
11	Feb,05	18-24/02/05	18.1	15.7	77.8	1,016.5	3.6	7.1	16.6	7.8	0.2	10.4
	Mean		16.8	13.8	69.9	1,016.8	3.4	9.2	19.3	7.6	0.2	13.4
12	Mar,05	25-3/03/05	19.4	16.9	77.2	1,013.4	2.2	5.8	18.7	7.3	2.5	12.1
13	Mar,05	4-10/03/05	22.2	17.6	62.0	1,014.8	5.8	7.2	16.1	7.9	-	11.4
14	Mar,05	11-17/03/05	21.2	17.5	68.3	1,013.7	4.3	11.6	28.9	4.8	1.9	14.9
15	Mar,05	18-24/03/05	21.0	15.8	55.9	1,013.0	5.2	9.5	21.6	8.2	0.5	18.4
16	Mar,05	25-31/03/05	21.1	14.9	48.2	1,016.1	7.3	10.5	20.4	7.1	-	19.0
	Mean		21.0	16.5	62.3	1,014.2	5.0	8.9	21.1	7.0	1.0	15.2
17	Apr,05	01-07/04/05	24.2	17.8	51.1	1,012.9	8.4	12.5	24.0	9.8	-	15.0
18	Apr,05	08-14/04/05	24.3	19.9	65.7	1,012.9	5.7	6.6	14.9	8.4	-	12.9
19	Apr,05	15-21/04/05	26.1	20.0	56.2	1,012.6	7.0	7.2	17.9	8.0	-	14.3
20	Apr,05	22-28/04/05	27.4	21.5	58.2	1,008.8	7.1	7.5	17.0	9.4	-	12.7
	Mean		25.5	19.8	57.8	1,011.8	7.1	8.5	18.4	8.9	-	13.7
21	May,05	29-5/05/05	28.0	21.0	52.6	1,005.9	6.3	7.4	24.6	8.7	0.2	12.9
22	May,05	06-12/05/05	27.2	20.2	51.9	1,009.3	8.6	7.7	18.0	9.5	-	12.7
23	May,05	13-19/05/05	30.9	24.1	55.8	1,005.9	7.6	5.8	14.6	8.8	-	12.6
24	May,05	20-26/05/05	32.4	23.8	47.5	1,005.1	8.3	6.9	17.3	8.1	-	12.3
	Mean		29.6	22.3	51.9	1,006.5	7.7	7.0	18.6	8.8	0.2	12.6
25	Jun,05	27-2/06/05	32.6	23.6	45.7	1,005.9	10.7	9.4	19.6	11.4	-	16.3
26	Jun,05	3-9/06/05	33.3	24.7	48.6	1,002.3	11.1	10.7	21.3	11.6	-	12.0
27	Jun,05	10-17/06/05	32.7	24.6	50.7	1,002.2	7.3	6.6	15.7	10.3	-	9.9
26	Mean		32.8	24.5	49.5	1,002.3	9.2	8.0	17.6	9.7	0.5	11.8
	Total Mean		22.0	17.7	61.6	1,013.1	5.7	8.7	19.5	8.1	1.5	13.5

Mean weekly climatologically summary over the studied period

Table 4
Descriptive for conductivity, pH, TSS, and Tarry matter

		N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Conductivity ($\mu\text{S cm}^{-1}$)	Ma'amir	27	60.39	38.17	45.29	75.49	21.80	188.80
	Hamalah	26	30.03	20.78	21.63	38.42	8.50	113.60
	Manama	24	87.33	270.31	-26.81	201.47	6.35	1355.00
	Total	77	58.538	152.62	23.96	93.18	6.35	1355.00
pH	Ma'amir	27	6.919	0.31	6.80	7.04	6.41	7.53
	Hamalah	26	6.445	0.32	6.32	6.57	5.88	7.25
	Manama	24	6.952	1.04	6.51	7.39	6.24	11.71
	Total	77	6.769	0.67	6.62	6.92	5.88	11.71
Total suspended solid(mg)	Ma'amir	27	96.533	130.34	44.97	148.10	14.50	673.10
	Hamalah	26	18.904	31.32	6.25	31.56	2.00	163.10
	Manama	24	19.283	21.59	10.16	28.40	0.90	92.00
	Total	77	46.243	87.52	26.38	66.11	0.90	673.10
Tarry matter (mg)	Ma'amir	27	3.289	7.32	0.39	6.19	0.00	37.00
	Hamalah	25	0.692	1.38	0.12	1.26	0.00	5.00
	Manama	24	0.933	1.57	0.27	1.60	0.00	7.10
	Total	76	1.691	4.63	0.63	2.75	.000	37.00

Table 5
ANOVA for conductivity, pH, TSS, and Tarry matter

		Sum of Squares	df	Mean Square	F	Sig.
Conductivity ($\mu\text{S cm}^{-1}$)	Between Groups	41115.323	2	20557.662	.880	.419
	Within Groups	1729254.824	74	23368.308		
	Total	1770370.147	76			
pH	Between Groups	4.151	2	2.075	5.117	.008
	Within Groups	30.011	74	.406		
	Total	34.162	76			
Total suspended solid (mg)	Between Groups	105163.106	2	52581.553	8.158	.001
	Within Groups	476987.063	74	6445.771		
	Total	582150.169	76			
Tarry matter (mg)	Between Groups	107.665	2	53.833	2.623	.079
	Within Groups	1498.178	73	20.523		
	Total	1605.844	75			

Fig.2. Mean plot of anions in the three stations of Ma'amir, Hamalah, and Manama.(a) F^- , (b) Cl^- , (c) NO_2^- , (d) Br^- , (e) NO_3^- , and (f) SO_4^{2-} .

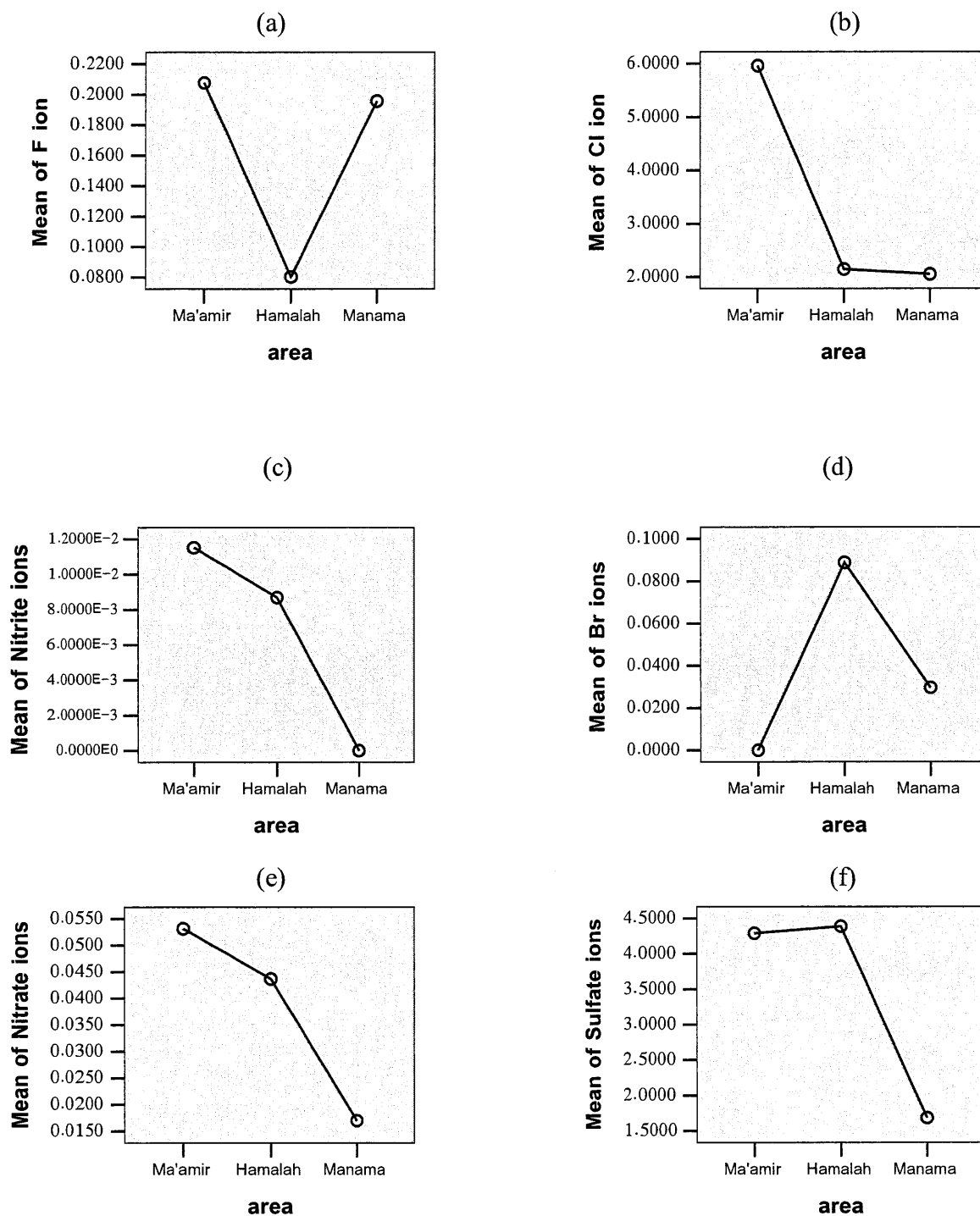


Fig.3

Means Plots of Cations in the three stations of Ma'amir, Hamalah, and Manama. (a) K^+ , (b) Na^+ , (c) Mg^{2+} , (d) Li^+ , (e) NH_4^+ , and (f) Ca^{2+} .

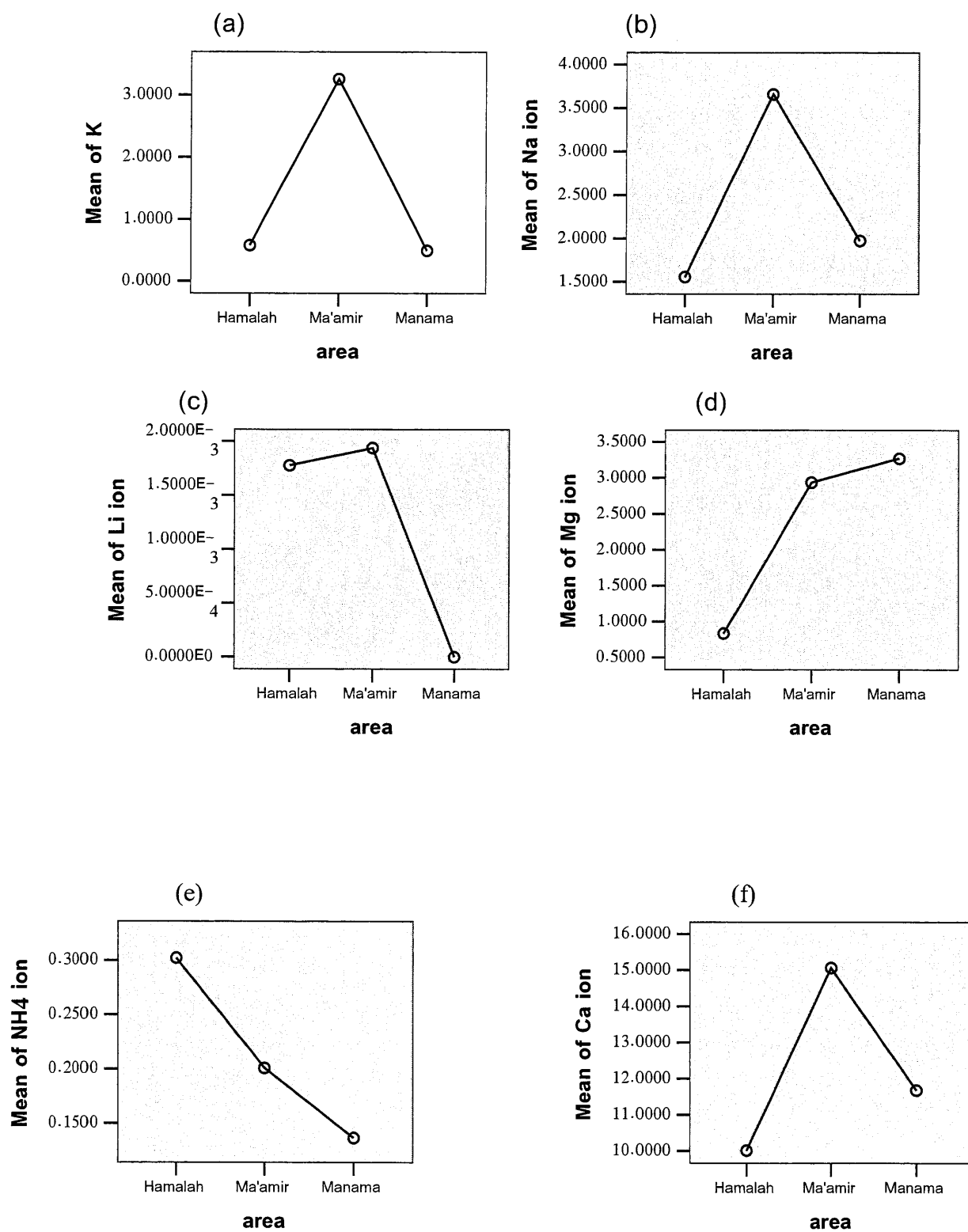


Fig. 4.
Mean plot of (a) conductivity, (b) pH, (c) Tarry matter, and (d) TSS

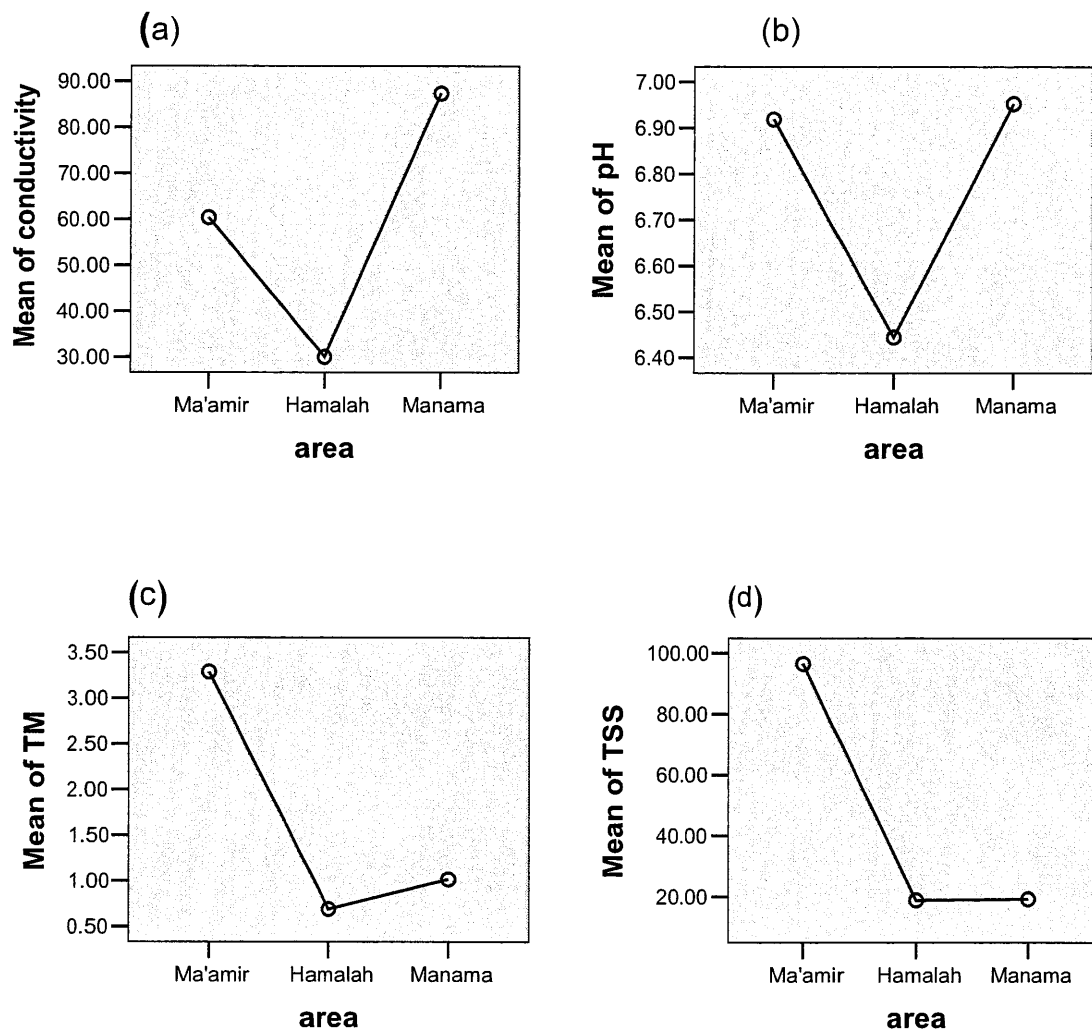


Fig. 5
Mean plot of trace metals in the three stations of Ma'amir, Hamalah, and Manama. (a) Zn^{2+} , (b) Fe, (c) Al, and (d) Si.

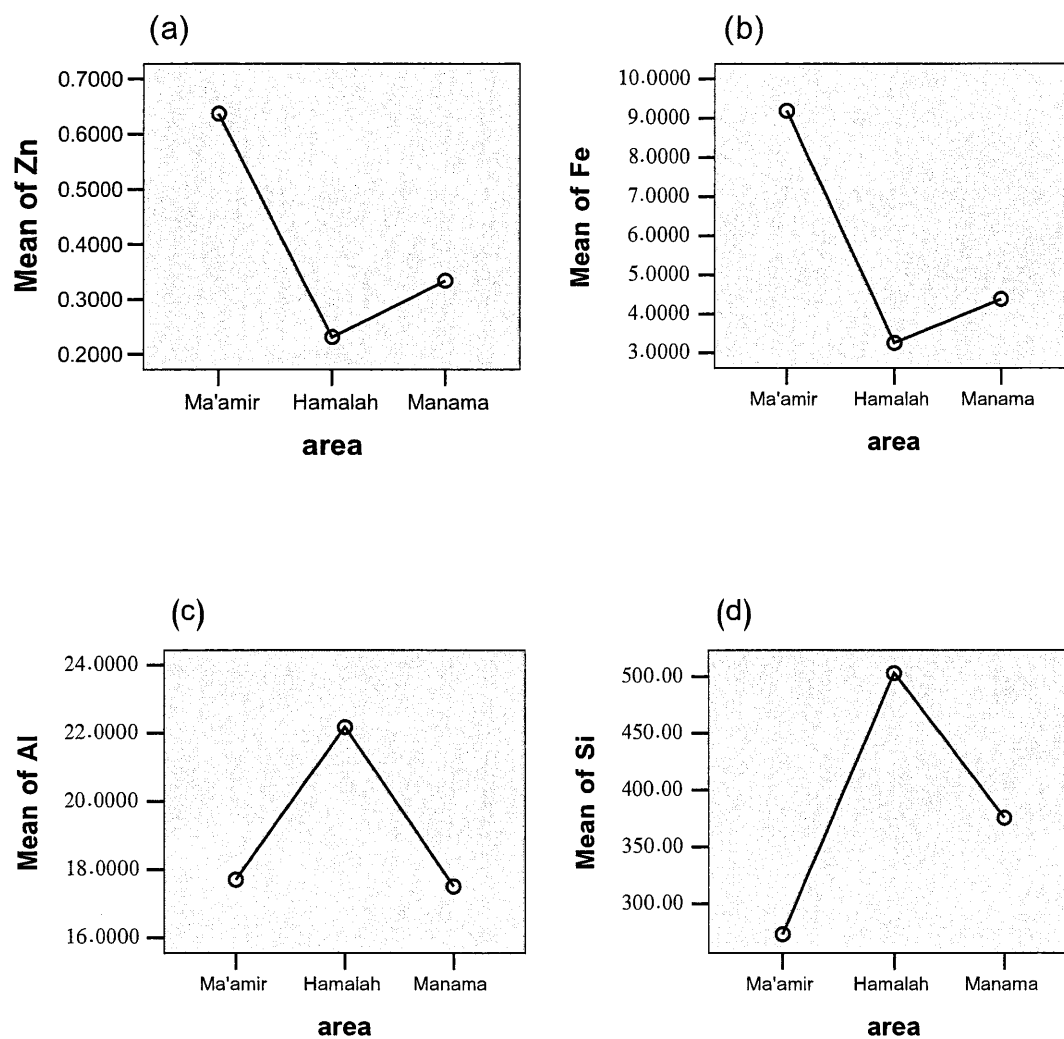


Fig. 6
The difference of means concentration of conductivity, pH, TSP, and Tarry matter in Ma'amir, Hamalah, and Manama.

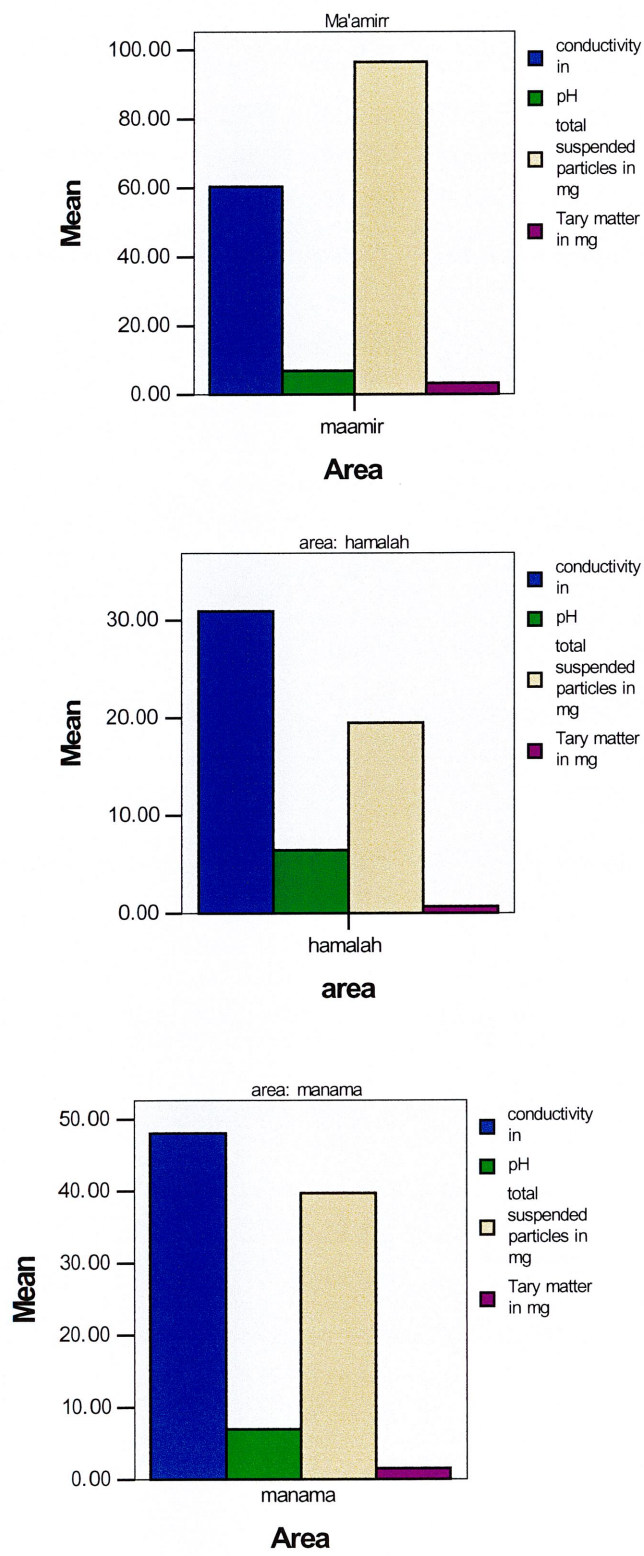
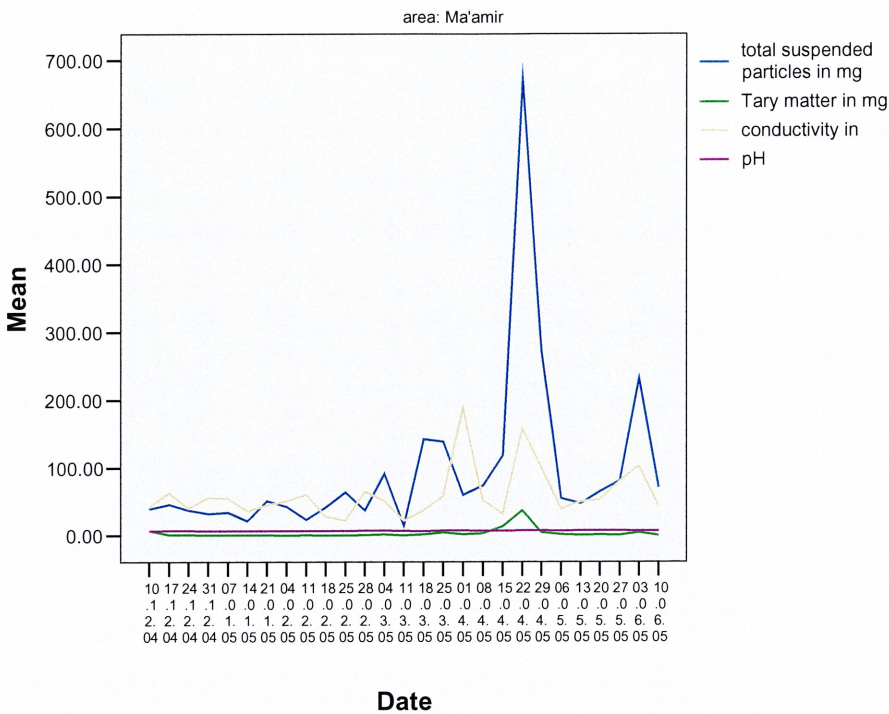
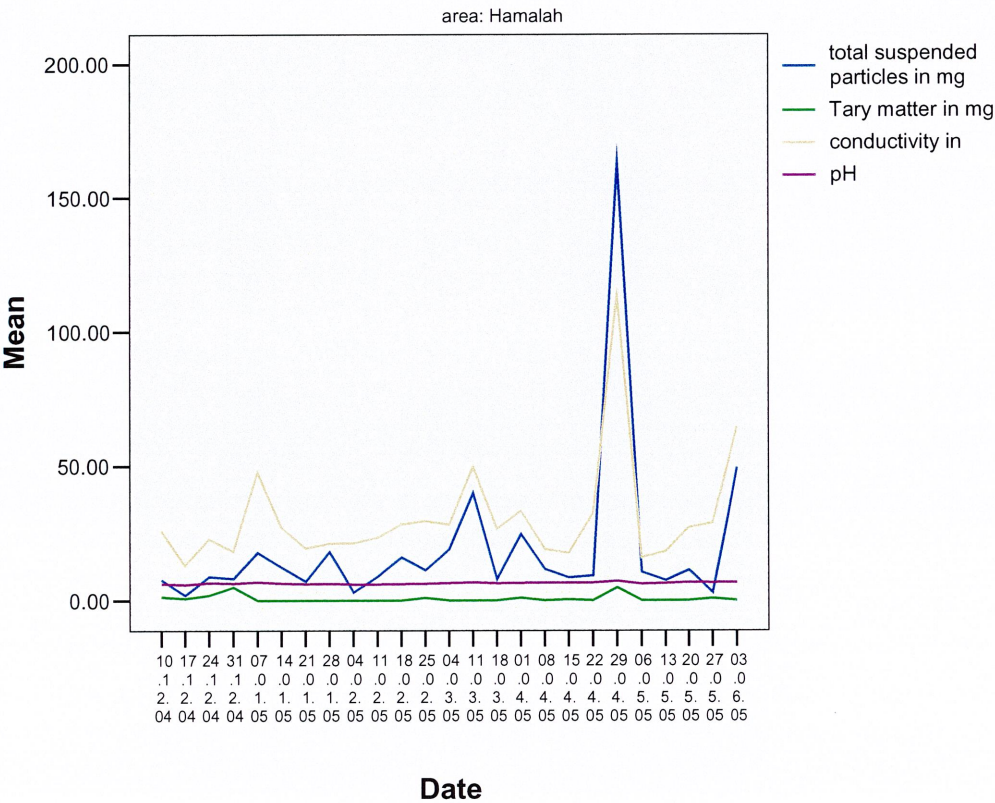


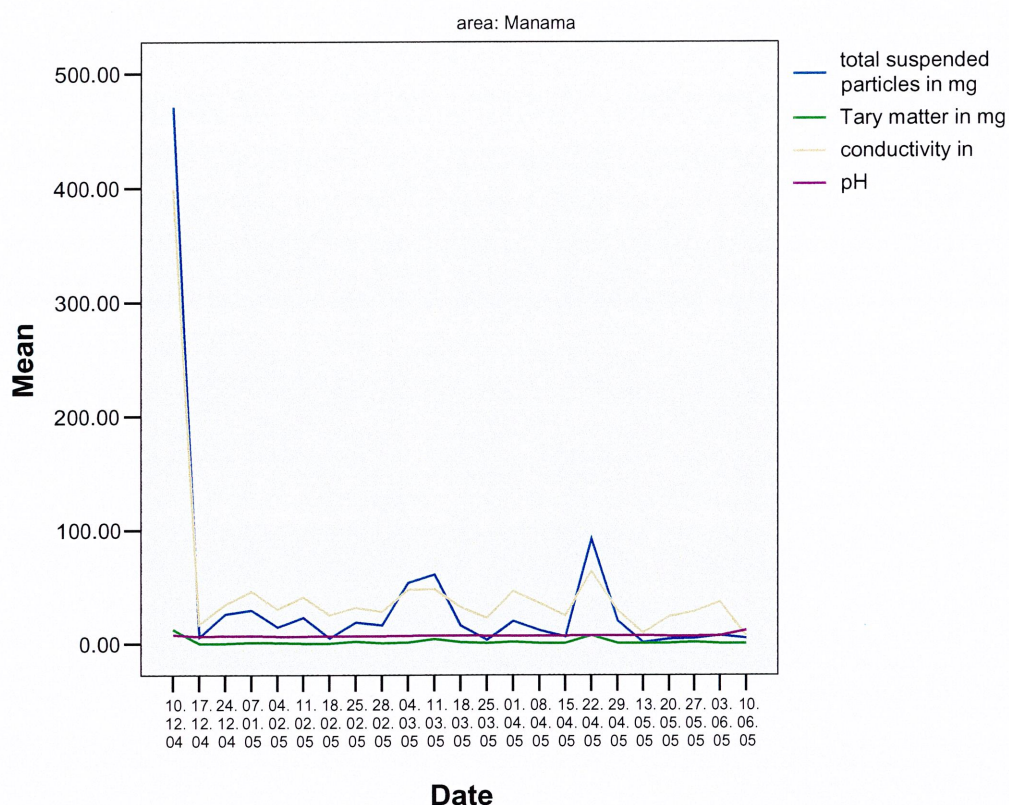
Fig. 8 Comparison of mean concentration of conductivity, pH, TSP, and Tarry matter over (a) Ma'amir, (b) Hamalah, and (c) Manama by using line graph
(a)



(b)



(c)



The shape of the histogram provides information about the distribution data of the pH, conductivity, TM, and TSP variables in the three areas of study (see appendix fig.7). Normal distribution data was found for the pH in the three areas of study. Positively skewed distribution was found for conductivity, TSP, and TM in the three areas of study.

The water-soluble inorganic materials comprises of major ionic compounds: Mg^{2+} , Ca^{2+} , Li^+ , Na^+ , K^+ , NH_4^+ , SO_4^{2-} , Cl^- , F^- , Br^- , NO_3^- , NO_2^- . The (Li^+ , Na^+ , K^+ , Mg^{2+} , Ca^{2+}) cations generally arise from weathering whereas the major proportion of Na^+ , Mg^{2+} and Cl^- arises from marine sources(Harrison 2001, Ali-Mohamed and Matter ,1996).

The chlorine (Cl_2) is emitted into atmosphere mainly as a result of its manufacturing process, manufacturing of associated compounds or as by-products or waste from other industrial activities (Deritt and Gerstl, 1971). Concentration data for samples are often adjusted assuming that Cl^- ion comes entirely from sea spray and that the composition of sea spray is the same as sea water in which HCl form as a secondary product. Man produced chlorides include PbCl_2 and PbBrCl_2 aerosols emitted from automobiles using petrol containing lead tetraalkyls and $\text{C}_2\text{H}_4\text{Cl}_2$, Cl_2Br_2 scavengers for Pb, HCl from the production of PVC, Cl^- from the combustion of coal which may contain up to 0.5 percent Cl^- incineration (Fergusson, 1982).

The chloride ion concentrations in the the water-soluble particulate matter were 5.96 ppm (Ma'amir), 2.145 ppm (Hamalah) and 1.98 ppm (Manama). The concentration of chloride in Ma'amir is comparatively higher than in Hamalah and Manama, because Ma'amir station is an industrial area and it is also near to the sea. The maximum concentration of Cl^- ion in the measured air samples was in first week of April 2005 in Ma'amir at 27.56 ppm. It is worth mentioning that another high concentration value 26.34 ppm was noticed on the last week of the same month in the same area. In general, this month has the highest sum concentration of Cl^- in the three areas of study.

A one-way between-groups analysis of variance, ANOVA (See appendix Table 8), was conducted to explore the concentration of Cl^- anions over the three areas of study. There was statistically significant difference at the $p < 0.05$ level for the concentration of chloride ions Cl^- between Ma'amir and Hamalah ($p = 0.006$), and Ma'amir and Manama ($p = 0.004$). These significant values are supported by getting the effect size, which was calculated by using eta squared, was 0.15 for Cl^- . Post-hoc comparisons using Tukey HSD test indicate that the mean value for Cl^- for Ma'amir ($M = 5.96$, $SD =$

7.10) was significantly different from Hamalah (M= 2.15, SD= 1.97) and Manama (M=2.05, SD= 1.80).

The major source of NO_3^- is atmospheric oxidation of NO_x to HNO_3 . This occurs naturally and also at accelerated rate in highly oxidizing atmosphere of "Photochemical smog". Analysis of NO_3^- in ambient air is becoming increasingly frequent due to the importance of nitrates in acid rain.

Relatively low concentration of NO_3^- ions was observed in the three stations with maximum concentration of 0.771 ppm in Ma'amir in the first week of April 2005. The mean concentrations of this ion were 0.05312 ppm, 0.04365 ppm, and 0.01697 ppm for Ma'amir, Hamalah, and Manama, respectively. The concentration of this ion in Ma'amir, which is an industrial area, is higher than that in Hamalah and Manama, and this suggest that the main source of NO_3^- in the ambient air is coming from the oxidation of NO_x that is emitted from the power station present in this area.

The major source of sulfate particles in western region of Bahrain is soil, while the minor source is considered to be the oxidation of SO_2 , emitted from cars using sulfur content fuel, to SO_4^{2-} (Ali-Mohamed and Jaffar, 2000). Emissions from industry such as power plant is an important source of SO_2 which then oxidizes to SO_4^{2-} and these sulfate particles can be transported to long distances away from industrial area to different areas of Bahrain. Since the gypsum is the major mineral in the bedrock of Bahrain, the dust haze can be raised into the atmosphere by winds, increasing the level of both SO_4^{2-} and Ca^{2+} ions.

The SO_4^{2-} ions concentration measured in the air samples were 4.386 ppm in Hamalah, 4.289 ppm in Ma'amir, and 1.681 ppm in Manama (table 7). By comparing

the mean concentration for these three areas (fig 1), it is clear that the sulfate ion concentration in Hamalah is almost equal values of mean concentration as Ma'amir but greater than double the amount of Manama. The high values of sulfates support the idea that most of the airborne particles are derived from soil by weathering processes, and it can also be as a result of transboundary movement by the prevailing NW winds.

A one-way between-groups analysis of variance, ANOVA (See appendix Table 8&9), was conducted to explore the concentration of SO_4^{2-} ions over the three areas of study. Statistical significant difference at the $p < 0.05$ level between Ma'amir and Manama ($p = 0.018$), and Hamalah and Manama ($p = 0.015$) for the concentration of sulfate ions SO_4^{2-} was recognized. These significant values are supported by getting the effect size, which was calculated by using eta squared, was 0.12.

The maximum concentration of Fluoride ion was 1.0127 ppm in Ma'amir in the third week of April 2005, and the mean concentrations of this ion were 0.2076 ppm, 0.1957 ppm, and 0.08033 ppm for Ma'amir, Manama, and Hamalah, respectively. A one way ANOVA between groups analysis of variance indicate that there is no statistically significant difference at the $p < 0.05$ level between mean concentrations of the three study areas (See appendix Table 8 &9).

In all the measured air samples, no concentration of bromide ion was found except for the second week of the study in December, two concentrations were found, 2.308 ppm and 0.7692 ppm in Hamalah and Manama, respectively.

Table 10 shows the relationship between anions in the three areas of study that was investigated using Pearson product-moment correlation coefficient. There was a strong, positive correlation between the F^- ion and Cl^- ion, NO_3^- ion and SO_4^{2-} ion in

Manama ($\underline{r} = 0.709, 0.605, \text{ and } 0.788$ respectively, and $\underline{n} = 26$). Another strong, positive correlation between the Cl^- ions and SO_4^{2-} ion was found ($\underline{r} = 0.903, 0.880, 0.741$ and $\underline{n} = 26, 27, 26$, in Hamalah, Ma'amir and Manama, respectively). Furthermore, a strong positive correlation between the NO_3^- ion and SO_4^{2-} ion, and Cl^- ions in Ma'amir ($\underline{r} = 0.840, 0.585$ respectively). A medium, positive correlation between the NO_3^- ion and SO_4^{2-} ion in Manama ($\underline{r} = 0.453, \underline{n} = 26$) was also recognized.

The shape of the histogram provides information about the distribution data of the F^- , Cl^- , NO_3^- , NO_2^- , and SO_4^{2-} anions variables in the three areas of study (See appendix fig.9). All of the F^- , Cl^- , NO_3^- , NO_2^- , and SO_4^{2-} anions variables are positively skewed distributed in the three areas of study.

The concentration of Na^+ and K^+ in Ma'amir station (3.66ppm and 3.26ppm) were high compared to Hamalah (1.56ppm and 0.58ppm), and Manama (1.79ppm and 0.49 ppm) respectively, whilst $\text{Li}^+ < 0.01$ ppm in all the stations, and it measured in the air samples, were 0.002 ppm in Ma'amir and 0.002 ppm in Hamalah.

The peak concentration for K^+ was found to be 66.30 ppm in the fourth week of the study period in Ma'amir, and the peak concentration for Na^+ was found to be 15.52 ppm in the first week of April 2005 in the same area. A one way anova between groups analysis of variance Table 12, shows that there was statistically significant difference at $p < 0.05$ level in concentration score between the three groups for Na^+ cations ($p=0.02$) but there was no statistically significant difference at $p < 0.05$ level in concentration score between the three groups for K^+ cations. Where the sea salt sprays is the main source expected for Na^+ , the main source expected of K^+ is soil particles.

The concentration of Mg^{2+} in the measured air samples in Manama was high (3.27 ppm) compared to 2.94 ppm in Ma'amir and 0.84 ppm in Hamalah. The peak concentration was found to be 53.5 ppm in the last week of study period in Manama and a one way ANOVA between groups analysis of variance shows that there was no statistically significant difference for this cation at $p < 0.05$ level in concentration score between the three groups ($p = 0.588$).

The measured concentration of Ca^{2+} ion in air samples were 15.06 ppm in Ma'amir, 11.68 ppm in Manama and 10.01 ppm in Hamalah, whilst the concentration of NH_4^+ measured in these samples < 1 ppm, were 0.302 ppm in Hamalah, 0.201 ppm in Ma'amir and 0.136 ppm in Manama. These results shows a high concentration of Ca^{2+} ion compared to the other cations measured in the air samples. The high concentration values of Ca^{2+} is generally indicative of dust contamination, whereas ammonium ions arise primarily from neutralization of natural atmospheric NH_4^+ by acidic substances in the atmosphere. It is believed that the concentration of NH_4^+ ion is major constituent of urban aerosols (Ali-Mohamed and Matter, 1996). These results could be correlated with the meteorological data shown in table 3. during Dec 4th Jun 2005. Unexpectedly the peak concentration for NH_4^+ ion was found to be 2.38 ppm in the first week of the study in Hamalah, that is probably due to the presence of the chicken farms in that village.

A one way ANOVA, Table 12 & 13, between groups analysis of variance shows that there was statistically significant difference for Ca^{2+} ion at $p < 0.05$ level in concentration score between the three groups ($p = 0.0001$). Post-hoc comparisons using Tukey HSD test indicate that mean score for Ma'amir ($\bar{M} = 15.061$, $\bar{SD} = 4.82$) was significantly different from Hamalah ($\bar{M} = 10.01$, $\bar{SD} = 4.25$). The Levene's test for homogeneity of variance shows that the concentration of Ca^{2+} ion scores is the same for the three groups (i.e. the assumption of homogeneity was not violated here).

Table 14, shows the relationship between cations that was investigated using Pearson product-moment correlation coefficient. There was a strong, positive correlation between the concentrations of Ca^{2+} and Na^+ variables ($r=0.818$, $n=24$), ($r=0.555$, $n=26$), ($r=0.673$, $n=22$), in Hamalah, Ma'amir and Manama respectively, and between Ca^{2+} and K^+ ($r=0.841$, $n=22$) & ($r=0.506$, $n=24$) in Manama & in Hamalah respectively, and Ca^{2+} & Mg^{2+} ($r=0.657$, $n=24$) in Hamalah. In addition, a strong, positive correlation was found between the concentrations Na^+ and Mg^{2+} variables in Hamalah ($r=0.563$, $n=24$), between Na^+ and NH_4^+ variables in Ma'amir ($r=0.698$, $n=26$), and between NH_4^+ and K^+ ($r=0.719$, $n=22$) in Manama.

The distribution data of Na^+ , K^+ , Ca^{2+} , Mg^{2+} , and NH_4^+ cations were investigated (fig.10) by studying the shape of histogram. It has been found that all the distributions are positively skewed for the three areas of the study except for Ca^{2+} which is normally distributed in Ma'amir. Fig. 13 shows the percentage of cations in the three areas of the study.

Table 2 shows a comparison between the % of dry suspended solid (DSS %) and the % of tarry matter in total suspended solid (TSS %). This shows variation in percentage with highest weekly values in (Ma'amir), (Hamalah), and (Manama) during the months of Dec 2004- June 2005.

Although epidemiological studies link atmospheric (PM 10 or 2.5) particulate matter with excess morbidity and mortality. Pope et al, 2002, reported that fine particulate and sulfur oxide-related pollution were associated with all-cause, lung cancer, and cardiopulmonary mortality. Each $10 \mu\text{g}/\text{cm}^3$ elevation in fine particulate air pollution was associated with approximately a 4%, 6% and 8% increased risk of all-caused, cardiopulmonary, and lung cancer mortality, respectively. Measures of coarse particle

fraction and total suspended particles were not consistently associated with mortality. In their conclusion (Pope et al, 2002) reiterated that long-term exposure to combustion-related fine particulate air pollution is an important environmental risk factor for cardiopulmonary and lung cancer mortality. Little is known about the composition of organic particulate matter (PM) found in the atmosphere and little effort has been made to study the health effects produced by this complex fraction of atmospheric particulate matter (Turpin, 1999). "An understanding of critical chemical and physical properties responsible for the biological activity of particulate matter reported to be a must to ensure adequate public health protection. However, the complexity of the organic fraction of atmospheric particulate matter presents a substantial challenge to efforts to characterize biological activity" (Turpin, 1999). It is reported that the traditional toxicological studies using laboratory generated aerosols containing known particulate matter constituents have been unable to identify a plausible mechanism or the causal agents responsible for observed effects. Recent work with concentrated atmospheric aerosols using a Harvard particle concentrator showed alterations in canine electrocardiograms that suggest potentially total rhythm disorders following inhalation exposure to concentrated atmospheric PM_{2.5}. The magnitude of these effects varies considerably from day to day, presumably as a result of changes in particle composition or other particle properties (Turpin 1999, Godleski 1998).

Against this background of unresolved health effect issues and novel research initiatives, the organic fractions of tarry matter of the particulates solid were primarily measured. This shows that there is a variation in the tarry matter composition and amount in the three areas of the study. Table 19 present the probable composition of tarry matter as it is obtained by GC-MS. Probably the cyclic Octatomic Sulfur (S₈), and Butanone and Benzene compounds were found to be present in the tarry matter in

Ma'amir, while Sulfur dioxide and Butanone and Cyclohexane compounds were found in Manama. Only one Butene compound was found in one sample in Hamalah.

The amount of tarry matter was found to be present much more in industrial and in urban areas than in rural one. The sum amount of TM in Ma'amir was found to be 88.8 ppm compared to Manama 34.9 ppm and Hamalah only 17.3 ppm. These results are reasonable and expected, since Hamalah is an area of low traffic compared to Manama, and does not have industrial emissions like in Ma'amir, therefore most of atmospheric particulates found in this area are of natural origin.

Fine particles(less than 2.5 μm diameter) that arise from combustion process mainly comprising of elemental and organic carbon derived predominantly from road vehicle traffic in urban areas (Harrison R.M., 2001).

The most prevalent form of air pollution, not the main fraction of inhalable particles, but the other being made by particles containing various total elements. Metal containing particulates are made up of oxides, sulfates, and other salts or alloys (Paoletti et al, 1991).

Heavy metals are introduced in air naturally from dust particles of soil and from volcanoes. Anthropogenically, they are emitted from combustion of oil in industry and from vehicles' motors. As, Cr, Mn, Sb, and Ti are significantly produced from combustion of hard coal, lignites and brown coals, while combustion of oil is the most important source of V and Ni. The Cr and Mn metals are primarily emitted from iron and steel industry, however the non-ferrous industry accounts for the largest emissions of Pb, As, Cd, Cu, And Zn (Nriagu and Pacyna,2001). In addition, lead is emitted from combustion of gasoline, but using unleaded petrol has lowered the level of Pb in the atmosphere.

Table 15 in the appendix shows the analysis of trace metals (Al, Zn, Si and Fe dry fall/week) in the samples of dust (ppm) in the three stations. A comparison between the three stations shows that M'amir has the highest contents of Fe (9.18ppm)& Zn (0.64ppm) trace metals followed by Manama and Hamalah, and the Hamalah station has the highest contents of Si(502.85ppm) & Al (22.18ppm) followed by Manama and M'amir. These variations are reasonable since Ma'amir is an industrial area where Fe & Zn metals are mainly produced from ferrous and non ferrous industry. The high concentration of Si in Hamalah indicates that the main composition of atmospheric particulates in this area is soil particles. The concentration of Zn was found to be highest also in Ma'amir compared to other areas measured previously during March-May 1991 by Ali Mohamed A.Y. & Matter (1996).

The concentration of (Mn, Ni, Cd, V, Sb, Cu, As, Cr^{3+} , Cr^{6+} and Pb) heavy metal ions in the collected samples were found to be below detected level at < 0.1 ppm.

A one way ANOVA (See appendix table 16) between groups analysis of variance was conducted to explore the impact of trace metals concentration on the three areas of study. It shows that there was statistically significant difference at $p < 0.05$ level in concentration score between the three groups for Zn concentration ($p = 0.005$) (fig.4), Si concentrations ($p=0.006$) and Fe concentration ($p = 0.048$). Post-hoc comparisons using Tukey HSD test indicate that mean score of Zn and Si for Ma'amir ($(M = 0.637$ ppm, $SD= 0.398)$ and $(M=273.1$ ppm, $SD=182.4)$) was significantly different from Hamala ($(M = 0.231$ ppm, $SD = 0.149)$ and $(M=502.85$ ppm, $SD=217.3)$), and that the mean score of Fe for Ma'amir ($M = 9.19$ ppm, $SD = 4.69$) was significantly different from Hamala ($M = 3.26$ ppm, $SD = 2.16$). There was no statistically significant difference at $p < 0.05$ level in concentration score between the three groups for Al ion mean concentration ($p = 0.361$).

The relation between Al, Zn, Si and Fe concentration was investigated using Person product-moment correlation coefficient (See appendix table 18). There was a strong, positive correlation between Fe and Zn ions in Manama ($r = 0.708$, $n = 19$) and a medium positive correlation between these two ions in Ma'amir ($r = 0.481$, $n = 27$), with high levels of Fe ions concentration associated with high levels of Zn ions concentration. No correlation was found between these two ions in Hamalah. A strong, negative correlation between Al and Zn was recognized in Manama area ($r = -0.509$, $n = 18$). For Silicon ions concentration, a medium positive correlation with Fe and Al in Hamalah was found ($(r = 0.431, n = 23)$ and $(r = 0.492, n = 22)$), and with Al in Ma'amir ($r = 0.423$, $n = 22$), and medium, negative correlation with Al was found in Manama ($r = -0.464$, $n = 17$).

The shape of histogram of Al, Zn, Si and Fe trace metals gives information about distribution data in the three areas of study (fig.11). Normal distribution of Fe data in Ma'amir, Si data in Hamalah, and Al data in both Manama and Hamalah were found. The remaining distributions of these trace metals are positively skewed in the three area of study. Fig. 12 shows the percent sum of Fe, Si, Zn, and Al in the three area of the study.

As far as asbestos is concerned, examination of the suspended particulates samples under the microscope (magnified ten times), no Asbestos was found in the samples of the three areas of study.

Particulate Matter and Sustainable Development :

One would possibly link the air pollutants with sustainable development by looking at the definition of sustainable development with that of the health effects as well as with the ecological effects of particulate matter. As the definition of sustainable development states:. It is “ the development that meet, the needs of the present without compromising the ability of future generations to meet their own needs”.

Sustainable development does not focus solely on environmental issues. More broadly, sustainable development policies encompass three general policy areas : economic , environmental and social.

Considering the major sources of atmospheric particulates such as fossil - fuel combustion , industrial processes , transportation, wind and soil erosion (producing fugitive dust) , and photochemical reactions (complex chain reaction between sunlight and gaseous pollutants). Fugitive dust and particles from industrial processes tend to be larger in size ($> 1 \mu\text{m}$). Particles from combustion and photochemical reactions are usually smaller in size ($< 1\mu\text{m}$).

Because of the large number of sources, particulate matter may contain hundred of different chemical elements. Fine particles (PM_{10}) may contain substantial quantities of sulfate , ammonium , nitrate, elemental carbon and condensed organic compounds in addition to a “ heavy metal” that are also concentrated in these particles. Larger particles, such as soil particles , fly ash, road aggregates, etc. are composed primarily of minerals, including silicon, aluminum , potassium, iron, calcium and other alkaline elements as it has shown in this study. Studies of air pollution on health have linked particulate matter (alone or in combination with other air pollutants such as SO_x and NO_x) with a number of significant health effects. These include increased mortality

and aggravation of existing respiratory and cardiovascular disease , as evidenced by increased hospitalization, absentees from their work.

On the other hand particulate matter causes damage and soiling to materials, and is a major causes of visibility impairment. The same fine particles linked to serious health effects also affects our ability to see by scattering and / or absorbing light. Certain particles, such as sulfates and nitrates, grow in sizes as humidity increases, making them more effective as impairing visibility.

In addition to the above ecological effects, particulate matter can damages vegetation both directly and indirectly. All these effects of particulate matter PM_{10} and $PM_{2.5}$ would definitely has an impact on the sustainable development on the three general areas: economic, environmental and social development of human being. This study has shown there is a need to continue monitoring of the atmospheric particulate matter to protect our health, environment (ecology) and social activities as they are all related to one another.

Fig.12
The pie graph of the sum of Fe, Zn, Al, and Si trace metal ions in Hamalah, Ma'amir, and Manama

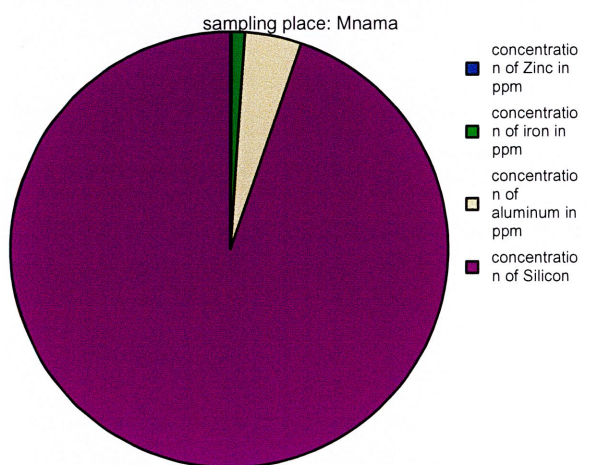
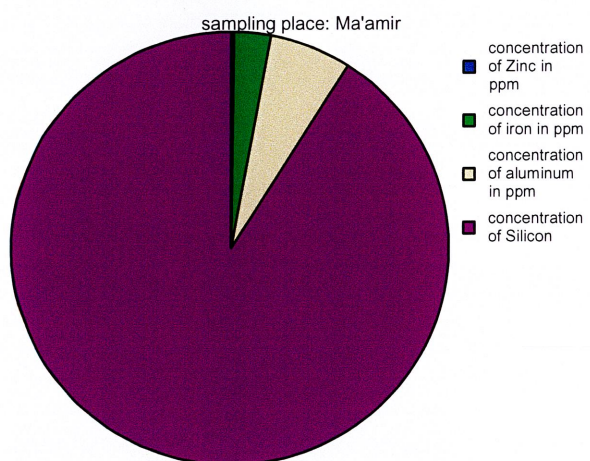
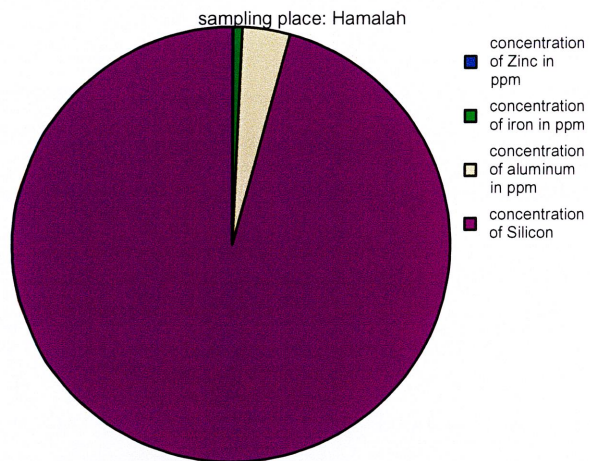
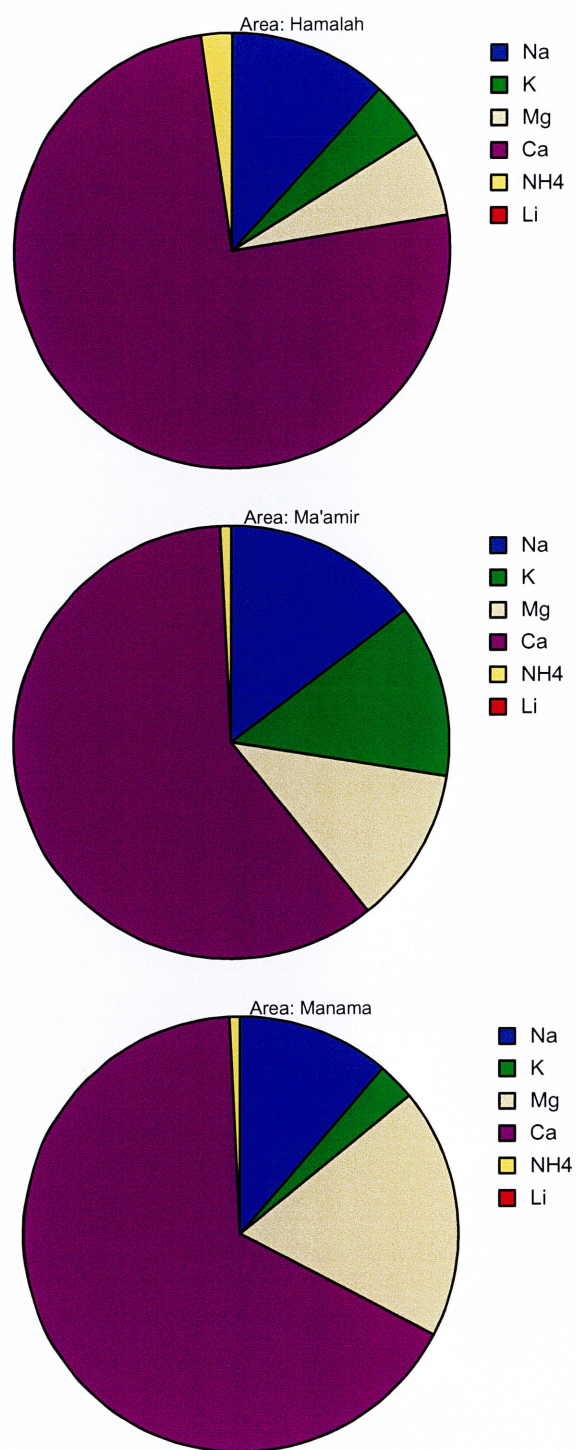


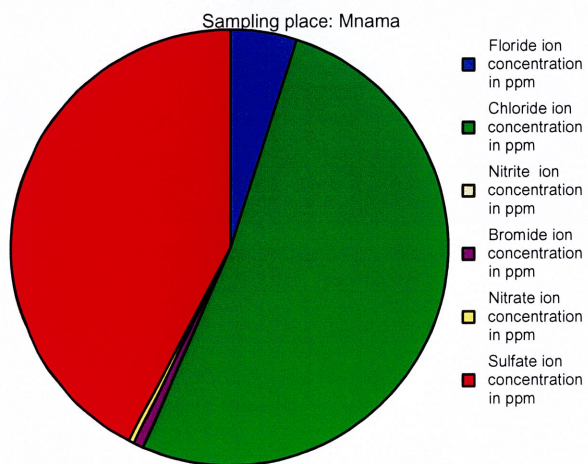
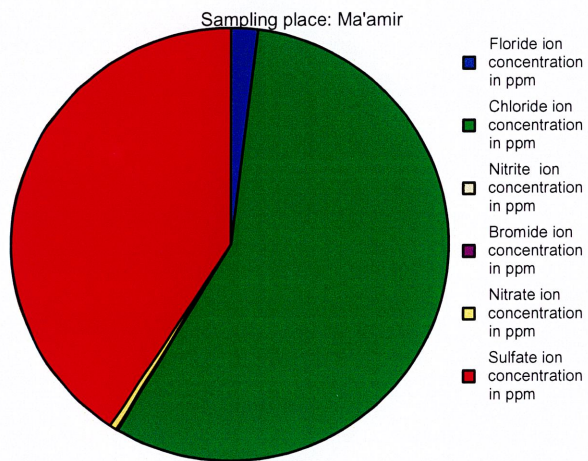
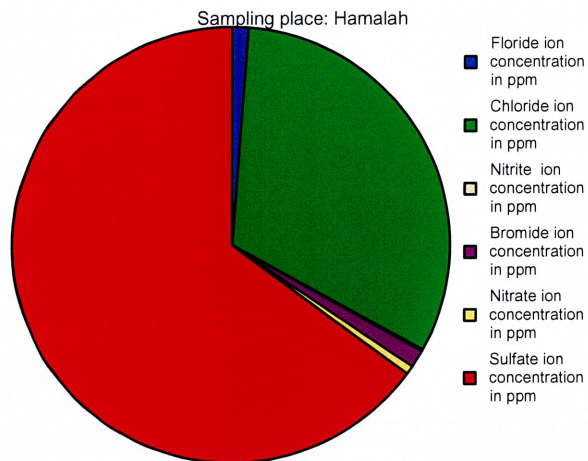
Fig.13

The pie graph of the sum of (a) Cations and (b) anions in Hamalah, Ma'amir, and Manama.

(a)



(b)



4. Conclusion

On the basis of results and discussions and on what is planned as an objective of this study, it can be concluded that;

1. The total deposition of suspended solid (TSS) is high in the three stations with the highest amount found in Ma'amir followed by Hamalah and Manama and by comparing the %DSS with %TM in TSS deposited aerosols, the %TM shows relatively low mass percent in the atmosphere which indicates that the major component of these aerosol particulates matter are mainly components of soil material.
2. The conductivity and pH of water-soluble particulate matter were shown to be relatively high in moderate weather. These were higher in Manama than in Ma'mir and Hamalah during the study period.
3. The chloride and sulfate ions are the dominant anions in the atmospheric particles of the three stations.
4. The total mean concentration for anions in the three studied areas follow the order; $\text{SO}_4^{2-} > \text{Cl}^- > \text{F}^- > \text{Br}^- > \text{NO}_3^- > \text{NO}_2^-$, and these are 3.42 ppm, 3.38 ppm, 0.16 ppm, 0.0384 ppm, 0.0376 ppm, and 0.0067 ppm respectively
5. The Ca^{2+} cation is the dominant cation in air water-soluble particulates samples, followed by Mg^{2+} , Na^+ , K^+ , and NH_4^+ .

6. The high amount of Ca^{2+} & SO_4^{2-} ions compared to other ions measured in the particulate matter indicates that these particles are mainly soil particles, therefore the major sources of ionic component were most probably natural.
7. The concentration of (Mn, Ni, Cd, V, Sb, Cu, As, Cr^{3+} , Cr^{6+} and Pb) "Heavy metals" in the collected samples were below detected level of $< 0.1\text{ppm}$.
8. M'amir has the highest contents of Fe (9.18ppm)& Zn (0.64ppm) trace metals followed by Manama and Hamalah, and the Hamalah station has the highest contents of Si(502.85ppm) & Al (22.18ppm) followed by Manama and M'amir. The increase amount of Fe &Zn is an indication of an industrial pollution.
9. Metrological factors; humidity, temperature, pressure, and wind direction and speed are effective factors in the spatial distribution of aerosols away from their original source.
- 10.Organic components airborne on inorganic particulate matter are important in estimating the health hazard and this study shows that industrial (Ma'amir) and urban area (Manama) are contaminated with these component much more than the rural area (Hamalah).
- 11.The atmosphere of the three stations is clean from asbestos since there was no presence for this material in the measured airborne particulates of the three stations.

5. Recommendations

- Further studies needed in monitoring the inorganic particulate matter in the atmosphere of Bahrain.
- A device such as high volume air sampler is needed to measure the concentration of different sizes of Particulate Matter PM_{10} – $PM_{2.5}$ suspended in atmosphere, especially the fine particulates to know their percentage in the TSS since these are the particles which hold organic compounds.
- Modern AA & ICPS device of high sensitivity for measuring low concentrations of trace metal ions at ppb level is needed in order to find the exact concentrations of 'heavy metals' present in the atmosphere of Bahrain.

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Appendix

Table 6

Correlations between conductivity, pH, TSS, and Tarry matter

Area			Conductivity ($\mu\text{S/cm}$)	PH	Total suspended solid (mg)	Tarry matter (mg)
Ma'amir	Conductivity	Pearson Correlation	1	.583(**)	.587(**)	.476(*)
		Sig. (2-tailed)		.001	.001	.012
		N	27	27	27	27
	PH	Pearson Correlation	.583(**)	1	.443(*)	.360
		Sig. (2-tailed)	.001		.021	.065
		N	27	27	27	27
	Total suspended particles in mg	Pearson Correlation	.587(**)	.443(*)	1	.895(**)
		Sig. (2-tailed)	.001	.021		.000
		N	27	27	27	27
	Tarry matter in mg	Pearson Correlation	.476(*)	.360	.895(**)	1
		Sig. (2-tailed)	.012	.065	.000	
		N	27	27	27	27
Hamalah	Conductivity	Pearson Correlation	1	.755(**)	.936(**)	.436(*)
		Sig. (2-tailed)		.000	.000	.029
		N	26	26	26	25
	PH	Pearson Correlation	.755(**)	1	.639(**)	.295
		Sig. (2-tailed)	.000		.000	.153
		N	26	26	26	25
	Total suspended particles in mg	Pearson Correlation	.936(**)	.639(**)	1	.546(**)
		Sig. (2-tailed)	.000	.000		.005
		N	26	26	26	25
	Tarry matter in mg	Pearson Correlation	.436(*)	.295	.546(**)	1
		Sig. (2-tailed)	.029	.153	.005	
		N	25	25	25	25
Manama	Conductivity in	Pearson Correlation	1	0.551 (**)	-0.147	0.701(**)
		Sig. (2-tailed)		0.008	0.515	.001
		N	22	22	22	23
	PH	Pearson Correlation	0.551 (**)	1	0.248	0.448*
		Sig. (2-tailed)	0.008		0.266	0.048
		N	22	22	22	20
	Total suspended particles in mg	Pearson Correlation	-0.147	0.248	1	0.840(**)
		Sig. (2-tailed)	0.515	0.266		.000
		N	22	22	22	20
	Tarry matter in mg	Pearson Correlation		0.448*	0.840(**)	1
		Sig. (2-tailed)		0.048	.000	
		N	20	20	20	20

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

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

Table 7

Descriptive Table of F^- , Br^- , Cl^- , NO_2^- , NO_3^- , and SO_4^{2-} anions concentrations (ppm) in three studied stations.

Anions conc. (ppm)		N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Fluoride ion concentration (ppm)	Ma'amir	27	0.208	0.285	0.095	0.32	0.00	1.01
	Hamalah	26	0.080	0.092	0.043	0.12	0.00	0.32
	Manama	26	0.196	0.151	0.13	0.26	0.00	0.59
	Total	79	0.162	0.201	0.12	0.21	0.00	1.01
Chloride ion concentration (ppm)	Ma'amir	27	5.961	7.100	3.15	8.77	0.00	27.56
	Hamalah	26	2.145	1.967	1.35	2.94	0.00	9.33
	Manama	26	2.051	1.793	1.33	2.77	0.00	7.05
	Total	79	3.418	4.740	2.36	4.48	0.00	27.56
Nitrite ion concentration (ppm)	Ma'amir	27	0.012	0.029	0.000116	0.02	0.00	0.10
	Hamalah	26	0.009	0.019	0.000938	0.02	0.00	0.06
	Manama	26	0.000	0.000	0.00	0.00	0.00	0.00
	Total	79	0.007	0.020	0.002210	0.01	0.00	0.10
Bromide ion concentration (ppm)	Ma'amir	27	0.000	0.000	0.00	0.00	0.00	0.00
	Hamalah	26	0.0888	0.453	-.094	0.27	0.00	2.31
	Manama	26	0.0295	0.151	-.031	0.09	0.00	0.77
	Total	79	0.0390	0.273	-.022	0.10	0.00	2.31
Nitrate ion concentration (ppm)	Ma'amir	27	0.0531	0.141	-.0027	0.11	0.00	0.71
	Hamalah	26	0.0436	0.0809	0.011	0.08	0.00	0.40
	Manama	26	0.0170	0.0447	-.001086	0.04	0.00	0.18
	Total	79	0.0381	0.0980	0.016141	0.06	0.00	0.71
Sulfate ion concentration (ppm)	Ma'amir	27	4.290	4.673	2.441087	6.14	0.00	24.32
	Hamalah	26	4.386	3.714	2.886131	5.89	1.83	19.04
	Manama	26	1.681	1.1860	1.202376	2.16	0.00	4.37
	Total	79	3.463	3.705	2.633094	4.29	0.00	24.32

Table 8
ANOVA statistical analysis for anions

		Sum of Squares	df	Mean Square	F	Sig.
Fluoride ion concentration (ppm)	Between Groups	0.259	2	0.129	3.409	0.038
	Within Groups	2.887	76	0.038		
	Total	3.146	78			
Chloride ion concentration (ppm)	Between Groups	265.302	2	132.651	6.778	0.002
	Within Groups	1487.326	76	19.570		
	Total	1752.628	78			
Nitrite ion concentration (ppm)	Between Groups	0.002	2	0.001	2.339	0.103
	Within Groups	0.031	76	0.000		
	Total	0.033	78			
Bromide ion concentration in ppm	Between Groups	0.108	2	0.054	0.720	0.490
	Within Groups	5.691	76	0.075		
	Total	5.799	78			
Nitrate ion concentration in ppm	Between Groups	0.019	2	0.009	0.961	0.387
	Within Groups	0.732	76	0.010		
	Total	0.750	78			
Sulfate ion concentration in ppm	Between Groups	123.137	2	61.569	4.937	0.010
	Within Groups	947.746	76	12.470		
	Total	1070.883	78			

Table 9
Post Hoc Tests for anions, multiple comparisons Tukey HSD

Dependent Variable	(I) area2	(J) area2	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound Upper Bound	
Fluoride ion concentration (ppm)	Ma'amir	Hamalah	.1272464	.0535416	.052	-.000711	.255203
		Manama	.0191509	.0530341	.931	-.107593	.145895
	Hamalah	Ma'amir	-.1272464	.0535416	.052	-.255203	.000711
		Manama	-.1080955	.0535416	.114	-.236052	.019861
	Manama	Ma'amir	-.0191509	.0530341	.931	-.145895	.107593
		Hamalah	.1080955	.0535416	.114	-.019861	.236052
Chloride ion concentration (ppm)	Ma'amir	Hamalah	3.8154872(*)	1.2092540	.006	.925537	6.705438
		Manama	3.9861159(*)	1.1977916	.004	1.123559	6.848673
	Hamalah	Ma'amir	-3.8154872(*)	1.2092540	.006	-6.705438	-.925537
		Manama	.1706287	1.2092540	.989	-2.719322	3.060579
	Manama	Ma'amir	-3.9861159(*)	1.1977916	.004	-6.848673	-1.123559
		Hamalah	-.1706287	1.2092540	.989	-3.060579	2.719322
Nitrite ion concentration (ppm)	Ma'amir	hamalah	.0028301	.0054959	.864	-.010304	.015964
		Manama	.0115185	.0054438	.093	-.001491	.024528
	Hamalah	Ma'amir	-.0028301	.0054959	.864	-.015964	.010304
		Manama	.0086885	.0054959	.260	-.004446	.021823
	Manama	Ma'amir	-.0115185	.0054438	.093	-.024528	.001491
		Hamalah	-.0086885	.0054959	.260	-.021823	.004446
Bromide ion concentration (ppm)	Ma'amir	Hamalah	-.0887692	.0747045	.464	-.267303	.089764
		Manama	-.0284889	.0739963	.922	-.205330	.148352
	Hamalah	Ma'amir	.0887692	.0747045	.464	-.089764	.267303
		Manama	.0602803	.0747045	.700	-.118253	.238814
	Manama	Ma'amir	.0284889	.0739963	.922	-.148352	.205330
		Hamalah	-.0602803	.0747045	.700	-.238814	.118253
Nitrate ion concentration (ppm)	Ma'amir	Hamalah	.0094728	.0267900	.933	-.054552	.073497
		Manama	.0367796	.0265361	.353	-.026638	.100197
	Hamalah	Ma'amir	-.0094728	.0267900	.933	-.073497	.054552
		Manama	.0273069	.0267900	.567	-.036718	.091331
	Manama	Ma'amir	-.0367796	.0265361	.353	-.100197	.026638
		Hamalah	-.0273069	.0267900	.567	-.091331	.036718
Sulfate ion concentration (ppm)	Ma'amir	Hamalah	-.0968355	.9653678	.994	-2.403932	2.210261
		Manama	2.6703848(*)	.9562172	.018	.385157	4.955612
	Hamalah	Ma'amir	.0968355	.9653678	.994	-2.210261	2.403932
		Manama	2.7672203(*)	.9653678	.015	.460124	5.074316
	Manama	Ma'amir	-2.6703848(*)	.9562172	.018	-4.955612	-.385157
		Hamalah	-2.7672203(*)	.9653678	.015	-5.074316	-.460124

* The mean difference is significant at the .05 level.

Table 10
Correlations of anions

Sampling Place			Floride ion conc. in ppm	Chloride ion conc. in ppm	Nitrite ion conc. in ppm	Bromide ion conc. in ppm	Nitrate ion conc. in ppm	Sulfate ion conc. in ppm
Hamalah	floride ion conc. in ppm	Pearson Correlation	1	-.042	-.006	.384	-.177	.024
		Sig. (2-tailed)	.	.837	.977	.053	.386	.907
		N	26	26	26	26	26	26
	chloride ion conc. in ppm	Pearson Correlation	-.042	1	-.112	-.064	-.351	.903(**)
		Sig. (2-tailed)	.837	.	.587	.755	.079	.000
		N	26	26	26	26	26	26
	nitrite ion conc. in ppm	Pearson Correlation	-.006	-.112	1	-.092	-.031	-.148
		Sig. (2-tailed)	.977	.587	.	.654	.881	.471
		N	26	26	26	26	26	26
	bromide ion conc. in ppm	Pearson Correlation	.384	-.064	-.092	1	-.110	-.048
		Sig. (2-tailed)	.053	.755	.654	.	.592	.817
		N	26	26	26	26	26	26
	nitrate ion conc. in ppm	Pearson Correlation	-.177	-.351	-.031	-.110	1	-.222
		Sig. (2-tailed)	.386	.079	.881	.592	.	.275
		N	26	26	26	26	26	26
	sulfate ion conc. in ppm	Pearson Correlation	.024	.903(**)	-.148	-.048	-.222	1
		Sig. (2-tailed)	.907	.000	.471	.817	.275	.
		N	26	26	26	26	26	26
Ma'amir	floride ion conc. in ppm	Pearson Correlation	1	.299	-.076	.(a)	-.023	.126
		Sig. (2-tailed)	.	.130	.708	.	.908	.532
		N	27	27	27	27	27	27
	chloride ion conc. in ppm	Pearson Correlation	.299	1	-.090	.(a)	.585(**)	.880(**)
		Sig. (2-tailed)	.130	.	.656	.	.001	.000
		N	27	27	27	27	27	27
	nitrite ion conc. in ppm	Pearson Correlation	-.076	-.090	1	.(a)	-.008	-.038
		Sig. (2-tailed)	.708	.656	.	.	.967	.851
		N	27	27	27	27	27	27
	bromide ion conc. in ppm	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
		Sig. (2-tailed)	.	.	.	.	.	.
		N	27	27	27	27	27	27
	nitrate ion conc. in ppm	Pearson Correlation	-.023	.585(**)	-.008	.(a)	1	.840(**)
		Sig. (2-tailed)	.908	.001	.967	.	.	.000
		N	27	27	27	27	27	27
	sulfate ion conc. in ppm	Pearson Correlation	.126	.880(**)	-.038	.(a)	.840(**)	1
		Sig. (2-tailed)	.532	.000	.851	.	.000	.

Manama	fluoride ion conc. in ppm	N	27	27	27	27	27	27
		Pearson	1	0.709(**)	.(a)	0.078	.605(**)	0.788(**)
		Sig. (2-tailed)	.	.000	.	0.706	.001	.000
	chloride ion conc. in ppm	N	26	26	26	26	26	26
		Pearson	0.709(**)	1	.(a)	-.063	.227	.741(**)
		Sig. (2-tailed)	.000	.	.	0.758	.265	.000
	nitrite ion conc. in ppm	N	26	26	26	26	26	26
		Pearson	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
		Sig. (2-tailed)	.	.	.	.	.	.
	bromide ion conc. in ppm	N	26	26	26	26	26	26
		Pearson	0.078	-.063	.(a)	1	-.077	.069
		Sig. (2-tailed)	0.706	.758	.	.	.707	.739
	nitrate ion conc. in ppm	N	26	26	26	26	26	26
		Pearson	0.605	0.227	.(a)	-.077	1	.453(*)
		Sig. (2-tailed)	.001	.265	.	0.707	.	.020
	sulfate ion conc. in ppm	N	26	26	26	26	26	26
		Pearson	0.788(**)	.741(**)	.(a)	.069	.453(*)	1
		Sig. (2-tailed)	.000	.000	.	0.739	.020	.
		N	26	26	26	26	26	26

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

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

a Cannot be computed because at least one of the variables is constant.

Table 11

Descriptive Statistics of Na^+ , K^+ , Mg^{2+} , Ca^{2+} , NH_4^+ , and Li^+ Cations

		N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Na ⁺	Hamalah	24	1.556	1.31	1.00	2.11	0.42	6.29
	Ma'amir	26	3.66	4.06	2.02	5.30	0.56	15.52
	Manama	22	1.97	1.81	1.17	2.78	0.49	7.34
	Total	72	2.44	2.86	1.77	3.12	0.42	15.52
K ⁺	Hamalah	24	0.58	0.92	0.19	0.97	0.00	4.35
	Ma'amir	26	3.26	12.87	-1.94	8.45	0.22	66.30
	Manama	22	0.49	0.36	0.34	0.65	0.11	1.30
	Total	72	1.52	7.77	-0.31	3.34	0.00	66.30
Mg ²⁺	Hamalah	24	0.84	0.43	0.65	1.02	0.44	2.11
	Ma'amir	26	2.94	10.33	-1.24	7.11	0.26	
	Manama	22	3.27	11.22	-1.71	8.25	0.53	53.51
	Total	72	2.34	8.72	0.29	4.39	0.26	53.51
Ca ²⁺	Hamalah	24	10.01	4.25	8.22	11.81	5.23	21.70
	Ma'amir	26	15.06	4.82	13.11	17.01	5.91	24.89
	Manama	22	11.68	3.90	9.95	13.41	5.00	18.86
	Total	72	12.35	4.82	11.21	13.48	5.00	24.89
NH ₄ ⁺	Hamalah	24	0.302	0.47	0.10	0.50	0.00	2.38
	Ma'amir	26	0.201	0.18	0.13	0.27	0.00	0.91
	Manama	22	0.136	0.14	0.074	0.20	0.00	0.56
	Total	72	0.215	0.31	0.14	0.29	0.00	2.34
Li ⁺	Hamalah	24	0.002	0.005	0.00	0.00	0.00	0.02
	Ma'amir	26	0.002	0.005	0.00	0.00	0.00	0.02
	Manama	22	0.000	0.000	0.00	0.00	0.00	0.00
	Total	72	0.001	0.004	0.00	0.00	0.00	0.02

Table 12
ANOVA Statistical analysis of Cations

		Sum of Squares	df	Mean Square	F	Sig.
Na ⁺	Between Groups	62.2	2	31.092	4.128	0.020
	Within Groups	519.7	69	7.532		
	Total	581.9	71			
K ⁺	Between Groups	122.8	2	61.397	1.018	0.367
	Within Groups	4161.8	69	60.316		
	Total	4284.6	71			
Mg ²⁺	Between Groups	82.500	2	41.250	0.535	0.588
	Within Groups	5319.7	69	77.097		
	Total	5402.2	71			
Ca ²⁺	Between Groups	332.0	2	165.984	8.704	0.000
	Within Groups	1315.8	69	19.070		
	Total	1647.8	71			
NH ₄ ⁺	Between Groups	0.323	2	0.162	1.761	0.180
	Within Groups	6.335	69	0.092		
	Total	6.658	71			
Li ⁺	Between Groups	0.000	2	0.000	1.519	0.226
	Within Groups	0.001	69	0.000		
	Total	.0010	71			

Table 13

Post Hoc Tests for cations, multiple comparisons Tukey HSD

Dependent Variable	(I) area2	(J) area2	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Na ⁺	Ma'amir	Hamalah	-2.1032813	1.0529574	.120	-4.624652	.418090
		Manama	-1.3598358	1.0854191	.427	-3.958939	1.239267
	Hamalah	Ma'amir	2.1032813	1.0529574	.120	-.418090	4.624652
		Manama	.7434455	1.0647939	.765	-1.806269	3.293160
	Manama	Ma'amir	1.3598358	1.0854191	.427	-1.239267	3.958939
		Hamalah	-.7434455	1.0647939	.765	-3.293160	1.806269
K ⁺	Ma'amir	Hamalah	-2.6769788	2.1855902	.443	-7.910509	2.556551
		Manama	-.0630120	2.2529701	1.000	-5.457887	5.331863
	Hamalah	Ma'amir	2.6769788	2.1855902	.443	-2.556551	7.910509
		Manama	2.6139668	2.2101588	.467	-2.678394	7.906328
	Manama	Ma'amir	.0630120	2.2529701	1.000	-5.331863	5.457887
		Hamalah	-2.6139668	2.2101588	.467	-7.906328	2.678394
Mg ²⁺	Ma'amir	Hamalah	-2.1002587	3.1576193	.784	-9.661372	5.460855
		Manama	-5.0211353	3.2549660	.278	-12.815351	2.773081
	Hamalah	Ma'amir	2.1002587	3.1576193	.784	-5.460855	9.661372
		Manama	-2.9208766	3.1931146	.633	-10.566986	4.725232
	Manama	Ma'amir	5.0211353	3.2549660	.278	-2.773081	12.815351
		Hamalah	2.9208766	3.1931146	.633	-4.725232	10.566986
Ca ²⁺	Ma'amir	Hamalah	-	1.3824294	.001	-8.357296	-1.736672
		Manama	5.0469843(*)	1.4250485	.192	-5.912984	.911749
	Hamalah	Ma'amir	-2.5006176	1.4250485	.192	-5.912984	.911749
		Manama	5.0469843(*)	1.3824294	.001	1.736672	8.357296
	Manama	Ma'amir	2.5463667	1.3979695	.170	-.801157	5.893891
		Hamalah	-2.5006176	1.4250485	.192	-9.11749	5.912984
NH ₄ ⁺	Ma'amir	Hamalah	-2.5463667	1.3979695	.170	-5.893891	.801157
		Manama	.1013622	.1101944	.630	-.162505	.365229
	Hamalah	Ma'amir	.0738225	.1135916	.793	-.198180	.345825
		Manama	-.1013622	.1101944	.630	-.365229	.162505
	Manama	Ma'amir	-.0275397	.1114331	.967	-.294373	.239294
		Hamalah	-.0738225	.1135916	.793	-.345825	.198180
Li ⁺	Ma'amir	Hamalah	.0275397	.1114331	.967	-.239294	.294373
		Manama	.0019380	.0011895	.240	-.000910	.004786
	Hamalah	Ma'amir	-.0001615	.0011763	.990	-.002978	.002655
		Manama	.0017765	.0012125	.314	-.001127	.004680
	Manama	Ma'amir	-.0017765	.0012125	.314	-.004680	.001127
		Hamalah	-.0019380	.0011895	.240	-.004786	.000910

* The mean difference is significant at the .05 level.

Table 14
Correlations of cations

Area			Mg ²⁺	Ca ²⁺	Na ⁺	K ⁺	NH ₄ ⁺	Li ⁺
Hamalah	Mg ²⁺	Pearson Correlation	1	.657(**)	.563(**)	.470(*)	-.024	.157
		Sig. (2-tailed)		.000	.004	.021	.910	.463
		N	24	24	24	24	24	24
	Ca ²⁺	Pearson Correlation	.657(**)	1	.818(**)	.506(*)	.277	.241
		Sig. (2-tailed)	.000		.000	.012	.190	.256
		N	24	24	24	24	24	24
	Na ⁺	Pearson Correlation	.563(**)	.818(**)	1	0.188	.102	.082
		Sig. (2-tailed)	.004	.000		0.380	.635	.703
		N	24	24	24	24	24	24
	K ⁺	Pearson Correlation	.470(*)	.506(*)	.188	1	.508(*)	-.138
		Sig. (2-tailed)	.021	.012	.380		.011	.520
		N	24	24	24	24	24	24
	NH ₄ ⁺	Pearson Correlation	-.024	.277	.102	.508(*)	1	-.218
		Sig. (2-tailed)	.910	.190	.635	.011		.305
		N	24	24	24	24	24	24
	Li ⁺	Pearson Correlation	.157	.241	.082	-.138	-.218	1
		Sig. (2-tailed)	.463	.256	.703	.520	.305	
		N	24	24	24	24	24	24
Ma'amir	Mg ²⁺	Pearson Correlation	1	.117	-.044	-.044	-.127	-.077
		Sig. (2-tailed)		.568	.829	.832	.538	.709
		N	26	26	26	26	26	26
	Ca ²⁺	Pearson Correlation	.117	1	.555(**)	.171	.355	-.112
		Sig. (2-tailed)	.568		.003	.404	.075	.587
		N	26	26	26	26	26	26
	Na ⁺	Pearson Correlation	-.044	.555(**)	1	-.089	.698(*)	-.070
		Sig. (2-tailed)	.829	.003		.667	.000	.733
		N	26	26	26	26	26	26
	K ⁺	Pearson Correlation	-.044	.171	-.089	1	-.060	-.079
		Sig. (2-tailed)	.832	.404	.667		.771	.700
		N	26	26	26	26	26	26
	NH ₄ ⁺	Pearson Correlation	-.127	.355	.698(**)	-.060	1	-.048
		Sig. (2-tailed)	.538	.075	.000	.771		.818
		N	26	26	26	26	26	26
	Li ⁺	Pearson Correlation	-.077	-.112	-.070	-.079	-.048	1
		Sig. (2-tailed)	.709	.587	.733	.700	.818	
		N	26	26	26	26	26	26
Manama	Mg ²⁺	Pearson Correlation	1	-.114	-.165	-.168	-.217	.(a)
		Sig. (2-tailed)		.612	.463	.455	.332	.
		N	22	22	22	22	22	22
	Ca ²⁺	Pearson Correlation	-.114	1	.673(**)	.841(**)	.491(*)	.(a)
		Sig. (2-tailed)	.612		.001	.000	.020	.
		N	22	22	22	22	22	22
	Na ⁺	Pearson Correlation	-0.165	0.673(**)	1	0.558(**)	.363	.(a)
		Sig. (2-tailed)	.463	.001		.007	.097	.
		N	22	22	22	22	22	22
	K ⁺	Pearson Correlation	-.168	.841(**)	.558(**)	1	.719(**)	.(a)
		Sig. (2-tailed)	.455	.000	.007		.000	.
		N	22	22	22	22	22	22

NH ₄ ⁺	Pearson Correlation	-.217	.491(*)	.363	.719(**)	1	.(a)
	Sig. (2-tailed)	.332	.020	.097	.000		.
	N	22	22	22	22	22	22
Li ⁺	Pearson Correlation	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)
	Sig. (2-tailed)	.	.	.	.	.	.
	N	22	22	22	22	22	22

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

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

a Cannot be computed because at least one of the variables is constant.

Table15

Descriptive Statistics of the trace metals Fe, Zn, Al, and Si.

Concentration (ppm)		N	Mean	Std. Deviation	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Zinc	Ma'amir	27	0.64	0.40	0.48	0.79	0.11	1.74
	Hamalah	15	0.23	0.15	0.15	0.31	0.11	0.67
	Manama	19	0.33	0.20	0.24	0.43	0.11	0.86
	Total	61	0.44	0.34	0.35	0.53	0.11	1.74
Iron	Ma'amir	27	9.18	4.69	7.33	11.04	2.98	24.62
	Hamalah	26	3.26	2.16	2.38	4.13	1.11	11.76
	Manama	22	4.38	1.87	3.55	5.20	1.86	8.35
	Total	75	5.71	4.17	4.76	6.68	1.11	24.62
Aluminum	Ma'amir	26	17.70	13.76	12.14	23.26	1.35	51.70
	Hamalah	23	22.18	12.90	16.60	27.75	1.27	45.57
	Manama	21	17.50	9.64	13.12	21.89	3.29	37.84
	Total	70	19.11	12.38	16.16	22.06	1.27	51.70
Silicon	Ma'amir	23	273.10	182.36	194.25	351.96	48.10	709.39
	Hamalah	23	502.85	217.30	408.88	596.82	105.41	922.92
	Manama	17	375.48	312.77	214.68	536.30	39.86	1381.95
	Total	63	384.61	252.23	321.08	448.13	39.86	1381.95

Table 16

ANOVA Statistical analysis for the trace metals Fe, Zn, Al, and Si.

		Sum of Squares	df	Mean Square	F	Sig.
concentration of Zinc (ppm)	Between Groups	1.914	2	0.957	10.786	0.000
	Within Groups	5.146	58	0.089		
	Total	7.059	60			
concentration of iron (ppm)	Between Groups	521.96	2	260.982	24.639	0.000
	Within Groups	762.65	72	10.592		
	Total	1284.61	74			
concentration of aluminum (ppm)	Between Groups	322.19	2	161.096	1.053	0.355
	Within Groups	10248.86	67	152.968		
	Total	10571.05	69			
concentration of Silicon (ppm)	Between Groups	608953.99	2	304476.993	5.477	0.007
	Within Groups	3335597.4	60	55593.290		
	Total	3944551.4	62			

Table 17

Post Hoc Tests for trace metals, multiple comparisons Tukey HSD

Dependent variable	(I) area	(J) area	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	Upper Bound
concentration of Zinc in ppm	Ma'amir	Hamalah	.4056622(*)	.1215091	.004	.113524	.697800
		Manama	.2104422	.1113176	.150	-.057193	.478077
	Hamalah	Ma'amir	-.4056622(*)	.1215091	.004	-.697800	-.113524
		Manama	-.1952200	.1288799	.291	-.505079	.114639
	Manama	Ma'amir	-.2104422	.1113176	.150	-.478077	.057193
		Hamalah	.1952200	.1288799	.291	-.114639	.505079
concentration of iron in ppm	Ma'amir	Hamalah	5.9303958(*)	2.4165828	.043	.148878	11.711913
		Manama	1.7026332	2.4955800	.775	-4.267880	7.673147
	Hamalah	Ma'amir	-5.9303958(*)	2.4165828	.043	-11.711913	-.148878
		Manama	-4.2277626	2.5175595	.220	-10.250860	1.795335
	Manama	Ma'amir	-1.7026332	2.4955800	.775	-7.673147	4.267880
		Hamalah	4.2277626	2.5175595	.220	-1.795335	10.250860
concentration of aluminum in ppm	Ma'amir	Hamalah	-4.4770943	3.5165983	.415	-12.903163	3.948974
		Manama	.0228680	3.5587536	1.000	-8.504208	8.549944
	Hamalah	Ma'amir	4.4770943	3.5165983	.415	-3.948974	12.903163
		Manama	4.4999623	3.6635853	.441	-4.278299	13.278224
	Manama	Ma'amir	-.0228680	3.5587536	1.000	-8.549944	8.504208
		Hamalah	-4.4999623	3.6635853	.441	-13.278224	4.278299
concentration of Silicon	Ma'amir	Hamalah	-229.74783(*)	69.01581	.004	-395.5390	-63.9566
		Manama	-106.72522	73.65280	.323	-283.6555	70.2051
	Hamalah	Ma'amir	229.74783(*)	69.01581	.004	63.9566	395.5390
		Manama	123.02261	73.65280	.225	-53.9077	299.9529
	Manama	Ma'amir	106.72522	73.65280	.323	-70.2051	283.6555
		Hamalah	-123.02261	73.65280	.225	-299.9529	53.9077

Tukey HSD

* The mean difference is significant at the .05 level.

Table 18

Correlation between the trace metals Fe, Zn, Al, and Si.

Sampling place			Conc. of Zinc in ppm	Conc of iron in ppm	Conc.of aluminum in ppm	Conc. of Silicon
Hamalah	Conc. of Zinc in ppm	Pearson Correlation	1	-.049	-.164	-.343
		Sig. (2-tailed)		.862	.592	.275
		N	15	15	13	12
	Conc. of iron in ppm	Pearson Correlation	-.049	1	.203	.431(*)
		Sig. (2-tailed)	.862		.353	.040
		N	15	26	23	23
	Conc. of aluminum in ppm	Pearson Correlation	-.164	.203	1	.492(*)
		Sig. (2-tailed)	.592	.353		.020
		N	13	23	23	22
	Conc. of Silicon	Pearson Correlation	-.343	.431(*)	.492(*)	1
		Sig. (2-tailed)	.275	.040	.020	
		N	12	23	22	23
Ma'amir	Conc. of Zinc in ppm	Pearson Correlation	1	.481(*)	-.032	.369
		Sig. (2-tailed)		.011	.876	.083
		N	27	27	26	23
	Conc. of iron in ppm	Pearson Correlation	.481(*)	1	.060	.193
		Sig. (2-tailed)	.011		.773	.377
		N	27	27	26	23
	Conc. of aluminum in ppm	Pearson Correlation	-.032	.060	1	.423(*)
		Sig. (2-tailed)	.876	.773		.050
		N	26	26	26	22
	Conc. of Silicon	Pearson Correlation	.369	.193	.423(*)	1
		Sig. (2-tailed)	.083	.377	.050	
		N	23	23	22	23
Mnama	Conc. of Zinc in ppm	Pearson Correlation	1	0.708**	-.509*	-.073
		Sig. (2-tailed)		.001	0.031	.805
		N	19	19	18	14
	Conc. of iron in ppm	Pearson Correlation	0.708**	1	-.441*	.019
		Sig. (2-tailed)	.001		.045	.941
		N	19	22	21	17
	Conc. of aluminum in ppm	Pearson Correlation	-.509*	-.441*	1	-.464
		Sig. (2-tailed)	0.031	.045		.060
		N	18	21	21	17
	Conc. of Silicon	Pearson Correlation	-.073	.019	-.464	1
		Sig. (2-tailed)	.805	.941	.06	
		N	14	17	17	18

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

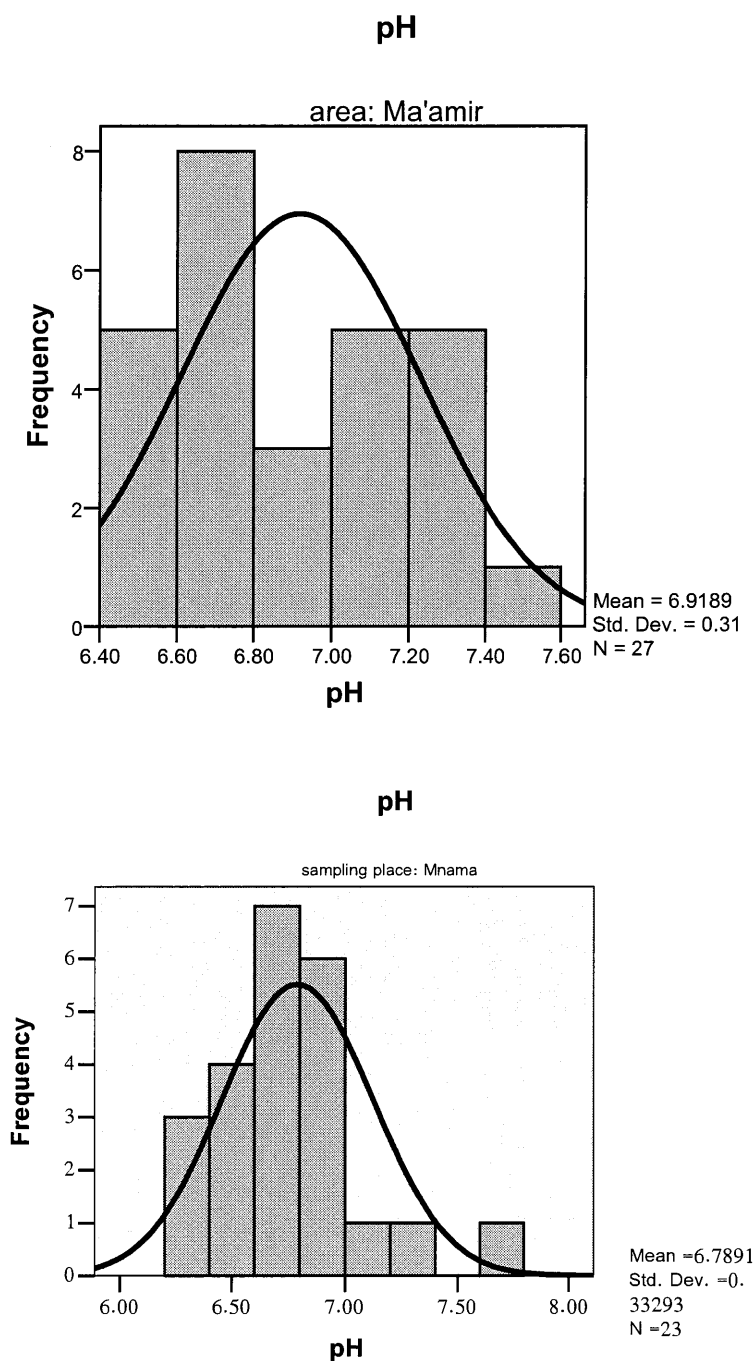
** Correlation is significant at the 0.01 level (2-tailed).

a Cannot be computed because at least one of the variables is constant.

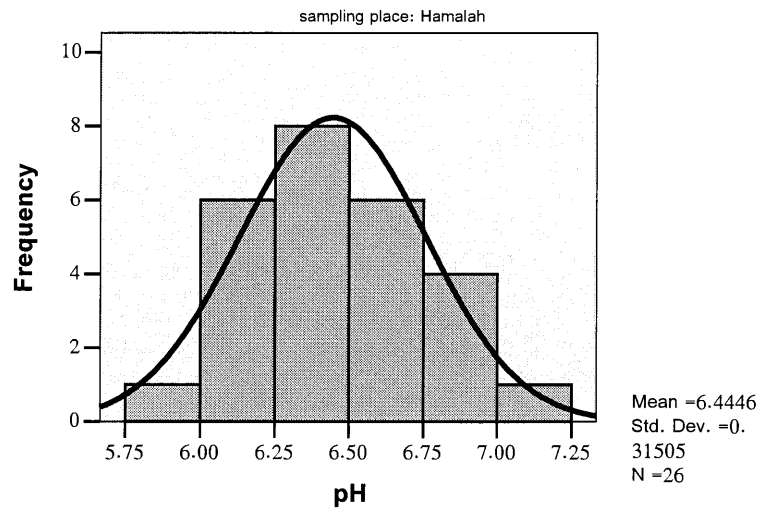
Table 19
The Tarry matter Organic compounds

No.	Date	Area	Mass percent	Time of appearance	Name of the product
1	28.01.05	Ma'amir	0.69	0.89	Benzenemethaneamine,N-Ethyl-N-phenyl
2	11.02.05	Ma'amir	64	0.59	Cyclic octaatomic sulfur
3	11.02.05	Ma'amir	69	0.87	3-cyclopentane-1,2-Diol,Cis
4	25.02.05	Ma'amir	69	0.87	2-Butanone,1-(2-Furanyle)-
5	25.02.05	Ma'amir	64	0.59	Ethyl chloride or Octaatomic sulfur
6	08.04.05	Ma'amir	64	0.59	Ethyl chloride or octaatomic sulfur
7	11.02.05	Manama	58	0.61	Bensenmethanol,.Alpha.-(1-(methylamino)ethyl)
8	11.02.05	Manama	83	0.87	3,trans-(1.1-Dimethyleethyl)-4,cis-methoxycyclohexane.
9	25.03.05	Manama	72	0.87	2-Butanone,1-(2-Furanyl)
10	25.03.05	Manama	64	0.59	Sulfur Dioxide
11	01.04.05	Manama	64	0.59	Sulfur Dioxide or Cyclic octaatomic sulfur
12	01.04.05	Manama	72	0.87	2-Buten-1-ol or 2-Butanone,1-(2-Furanyl)
13	08.04.05	Manama	58	0.61	1-Proanamine,3-dibenzo(B,E)thiepin-11(6H)-yli
14	03.06.05	Manama	58	0.61	1-Proanamine,3-dibenzo(B,E)thiepin-11(6H)-yli
15	31.12.05	Hamalah	69 64	0.87 0.59	Butane,-1-butoxy-,(E)-

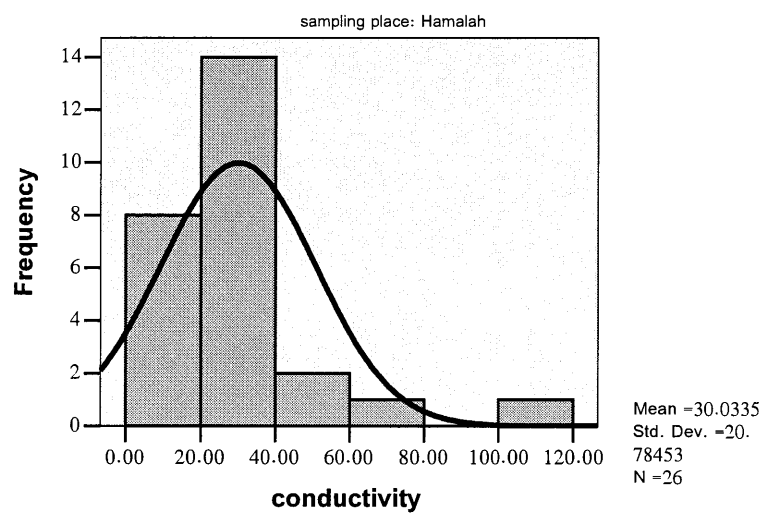
Fig. 7
The Distribution of conductivity, pH, TSP, and Tarry matter over Ma'amir, Manama, and Hamalah



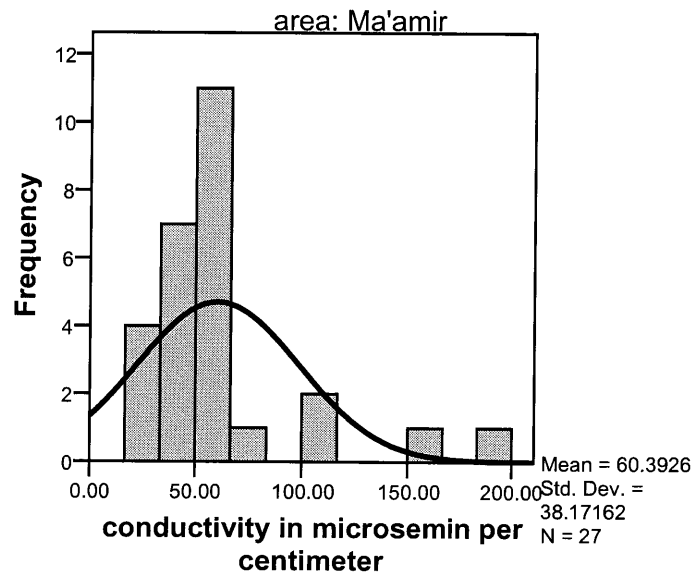
pH



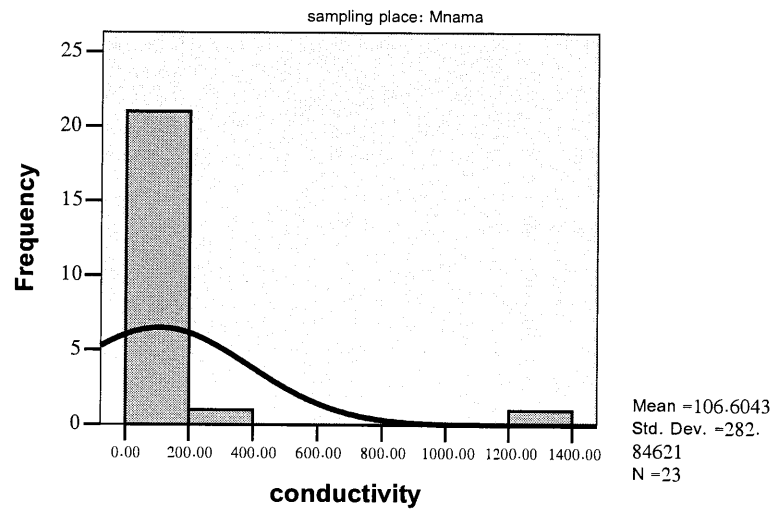
conductivity



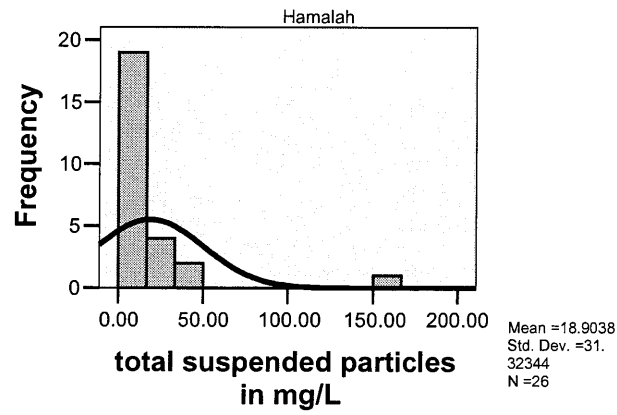
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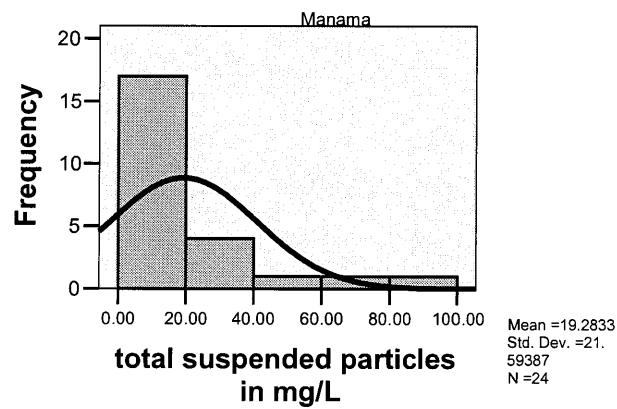
conductivity



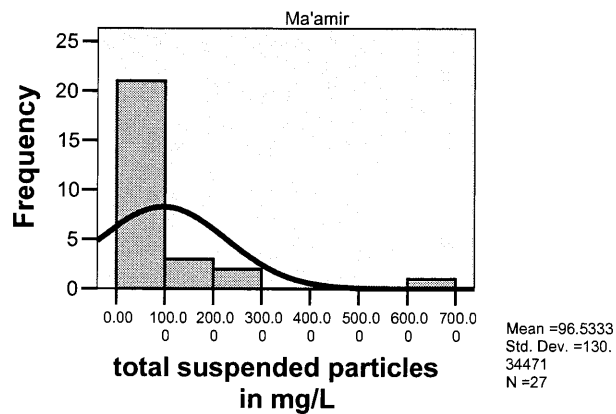
Total suspended particles in mg/L



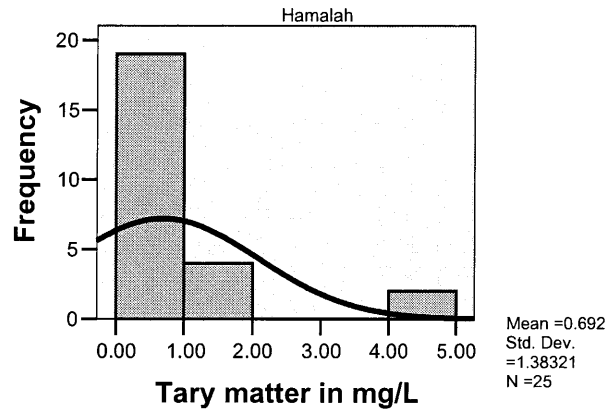
Total suspended particles in mg/L



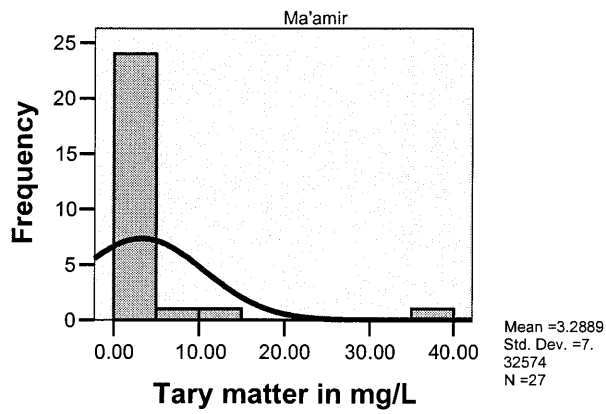
Total suspended particles in mg/L



Tary matter in mg/L



Tary matter in mg/L



Tary matter in mg/L

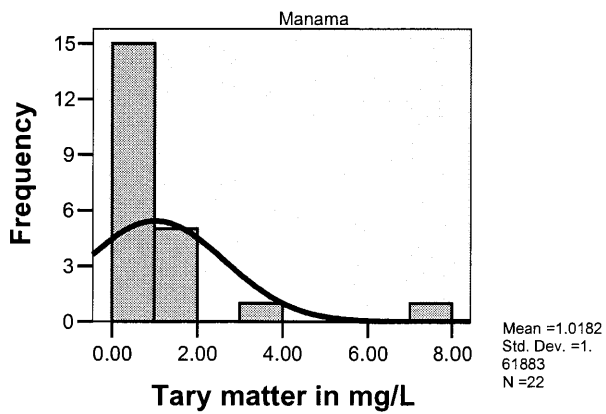
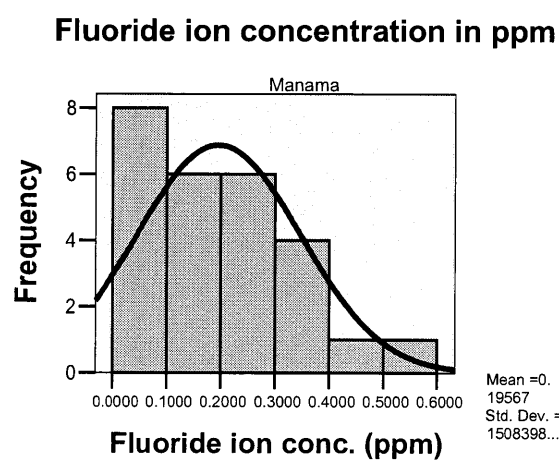
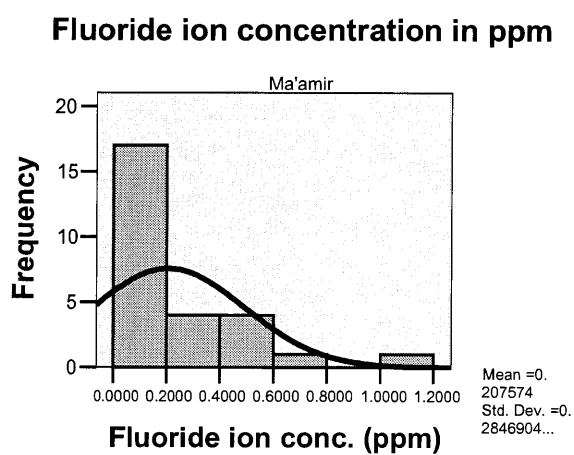
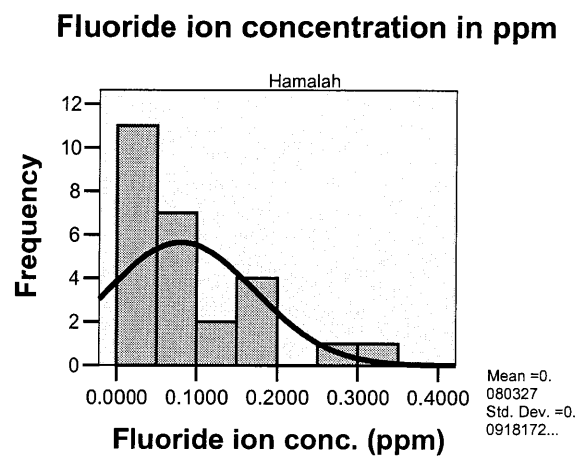
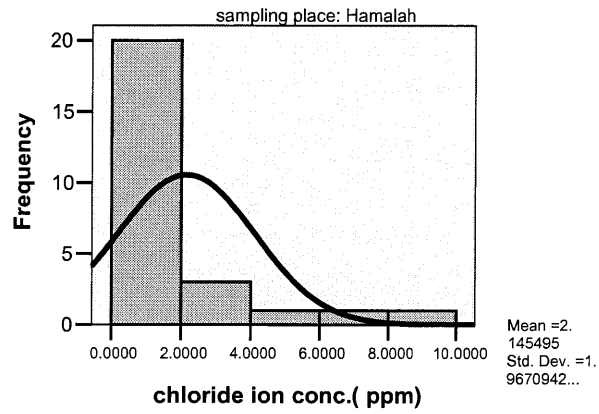


Fig.9

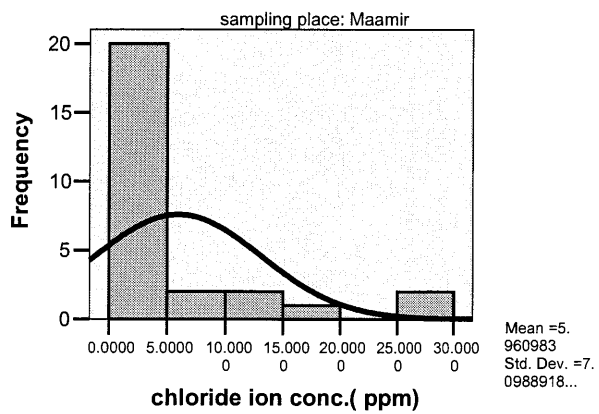
The distribution of anions in Hamalah, Ma'amir, and Manama



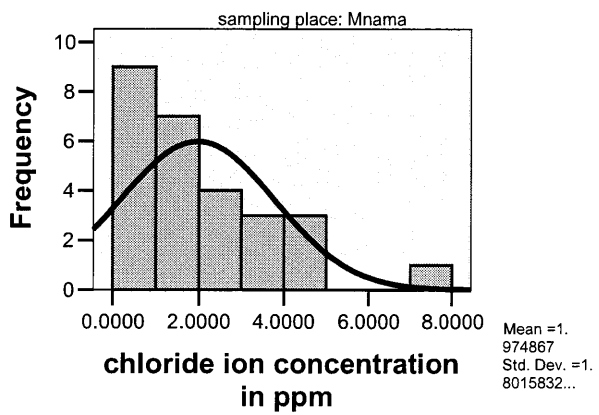
Chloride ion concentration in ppm



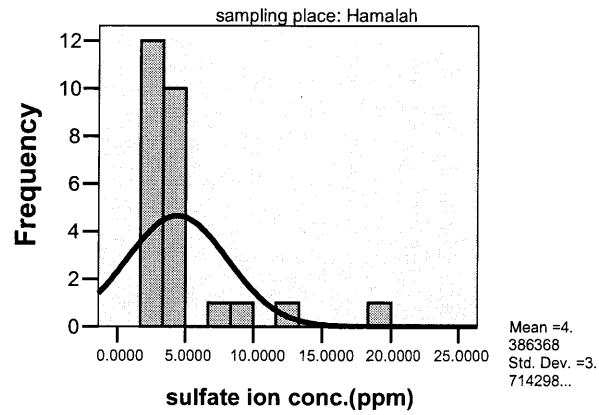
Chloride ion concentration in ppm



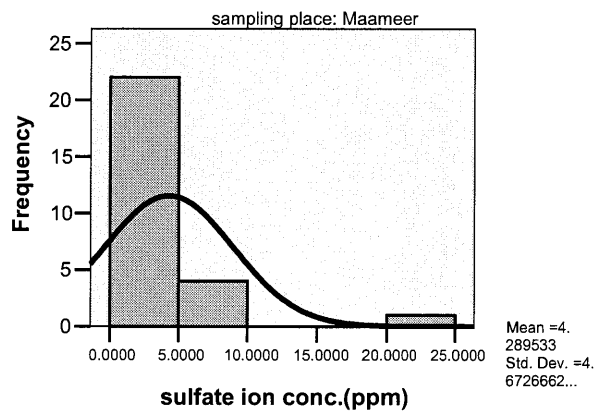
chloride ion concentration in ppm



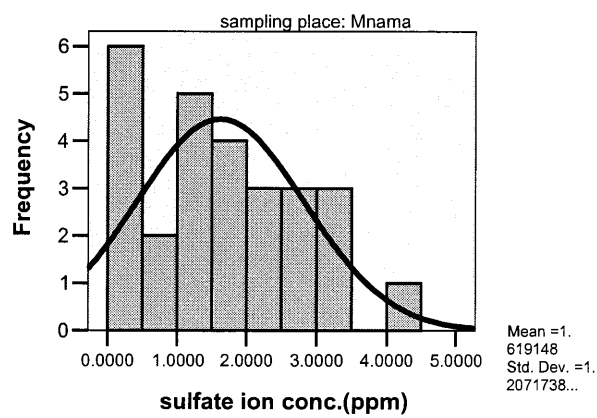
Sulfate ion concentration in ppm



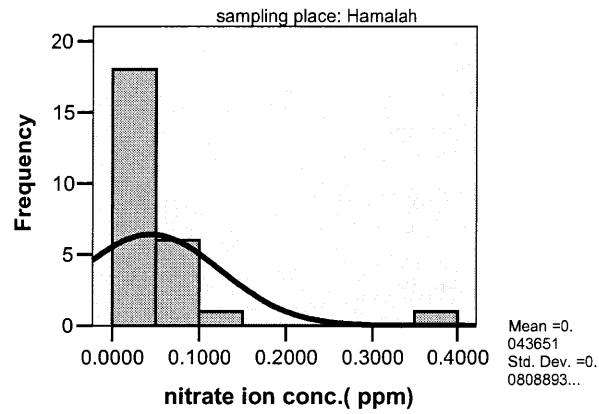
Sulfate ion concentration in ppm



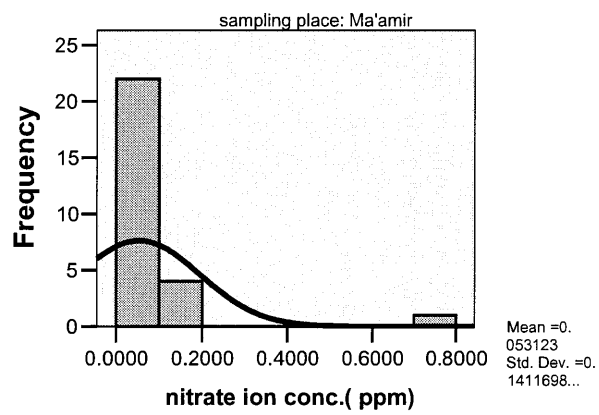
Sulfate ion concentration in ppm



Nitrate ion concentration in ppm



Nitrate ion concentration in ppm



Nitrate ion concentration in ppm

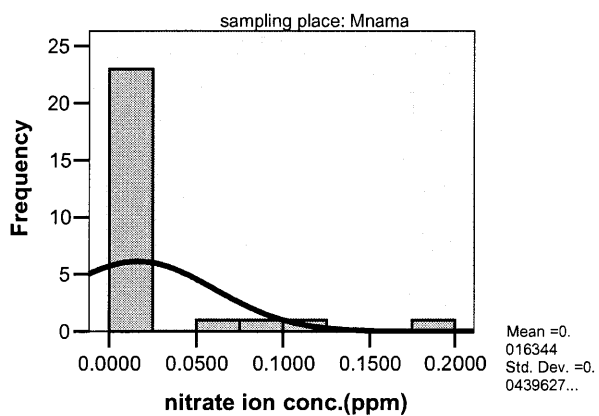
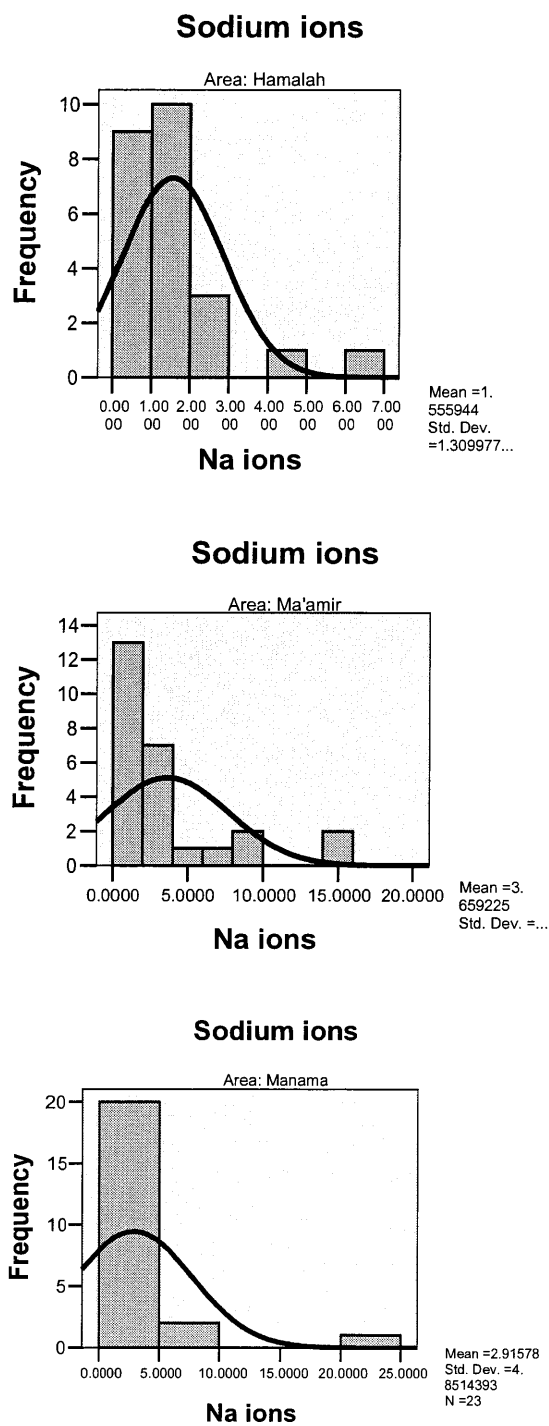


Fig.10

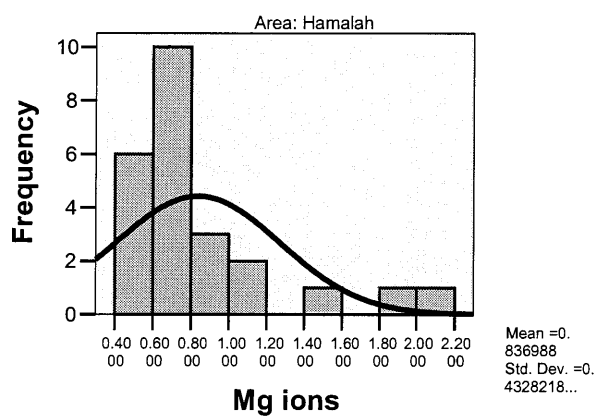
The distribution of (a) Na^+ , (b) Mg^{2+} , (c) Ca^{2+} (d) K^+ , and (e) NH_4^+ cations in the three stations of Hamalah, Ma'amir, and Manama.

(a)

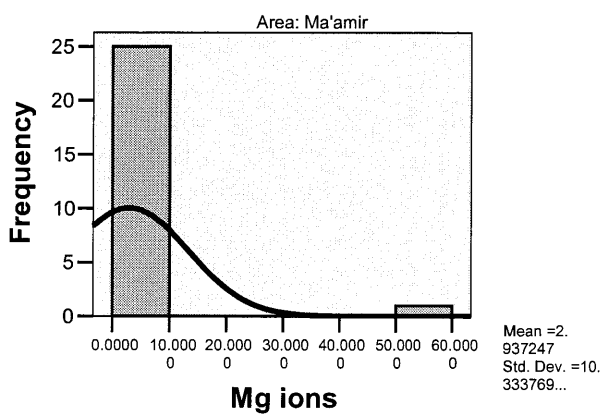


(b)

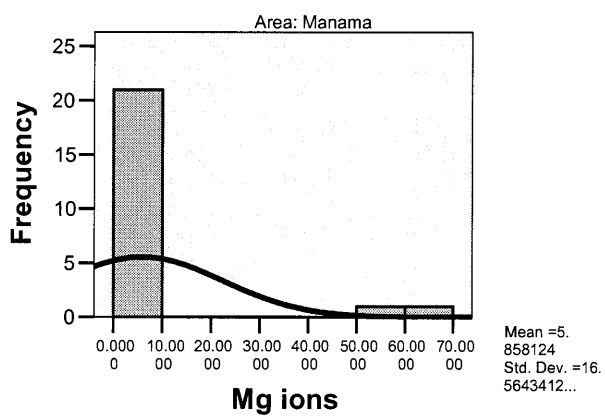
Magnesium ions



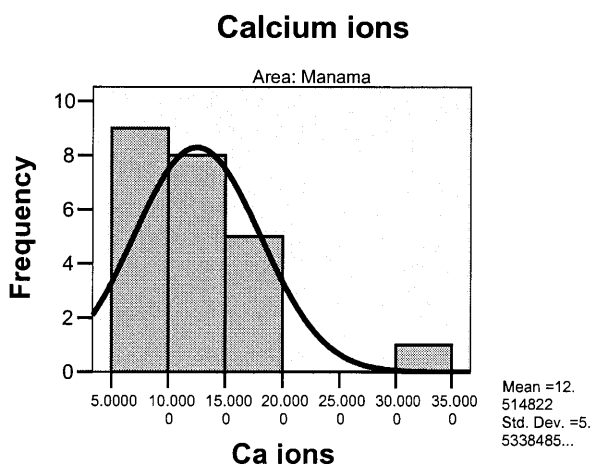
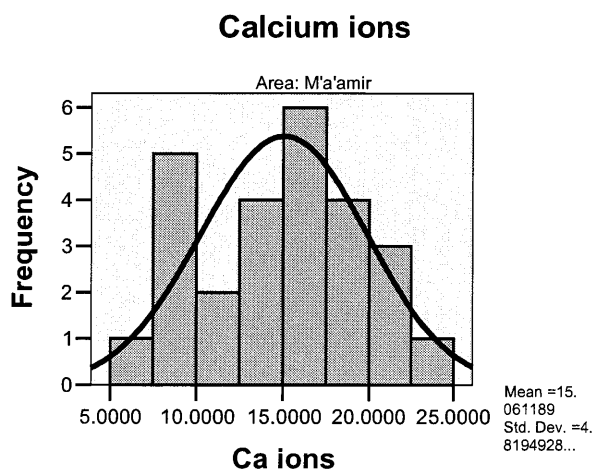
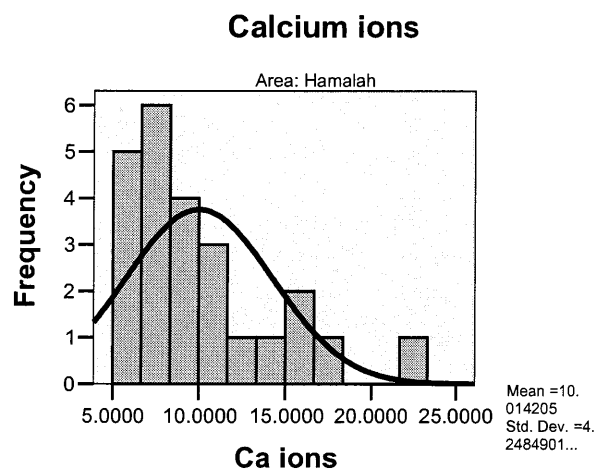
Magnesium ions



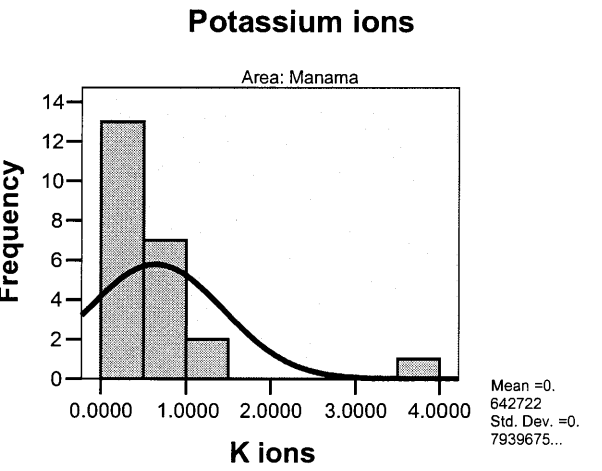
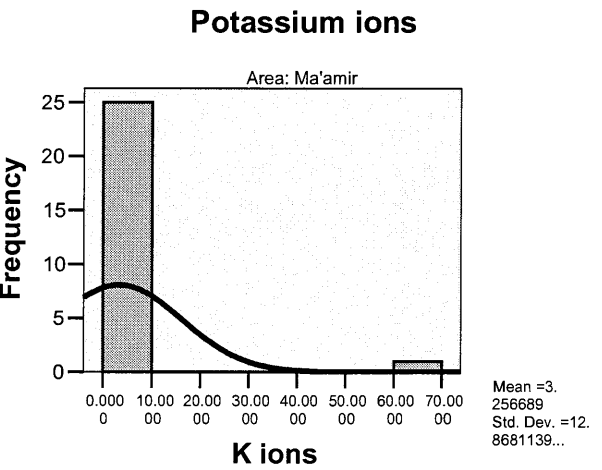
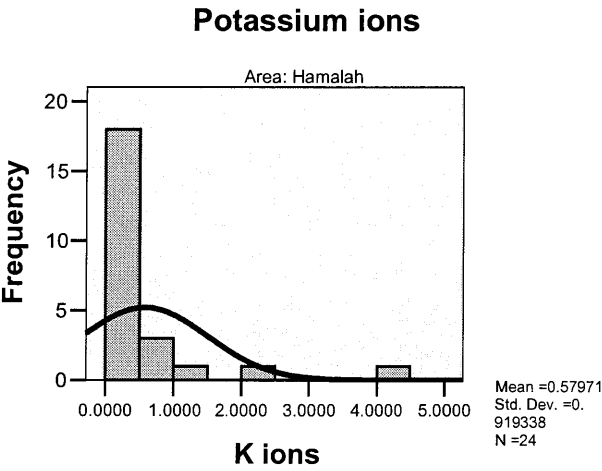
Magnesium ions



(c)



(d)



(e)

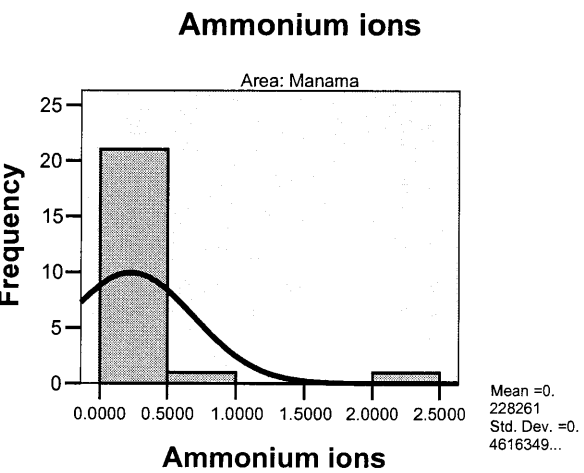
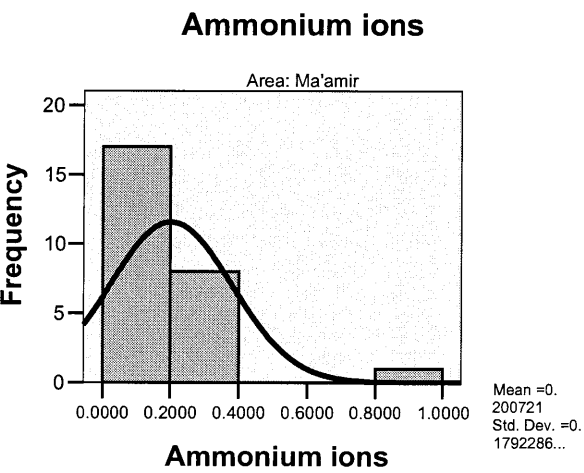
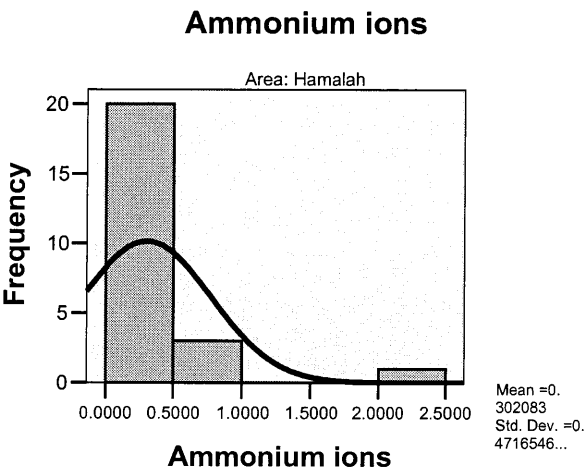
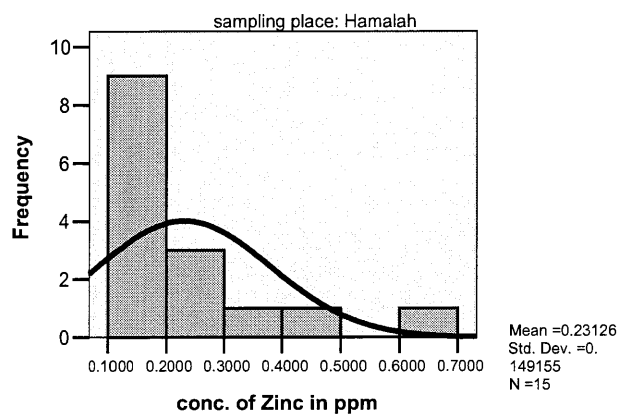
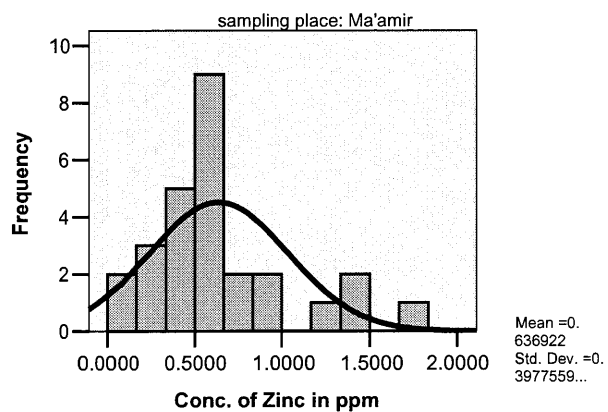


Fig.11 The distribution of trace metals (a) Zn, (b) Fe, (c) Al, and (d) Si in the three stations of Hamalah, Ma'amir, and Manama.

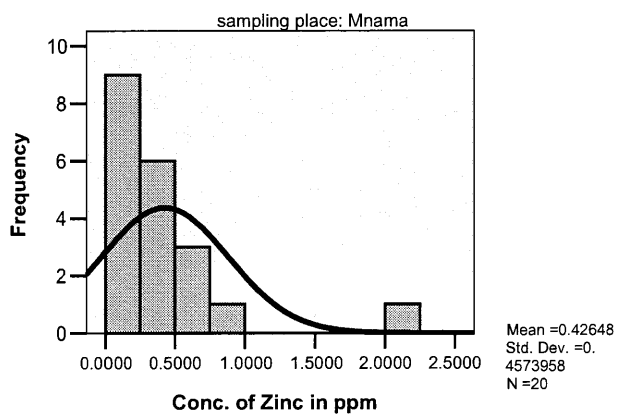
Concentration of Zinc in ppm



Concentration of Zinc in ppm

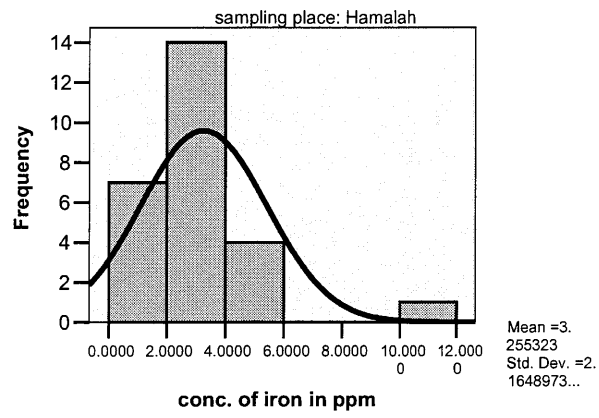


Concentration of Zinc in ppm

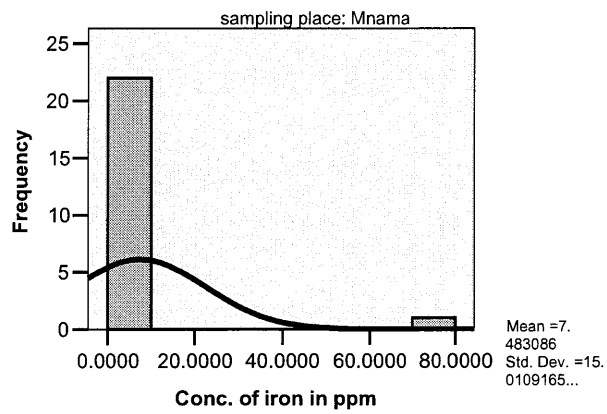


(a)

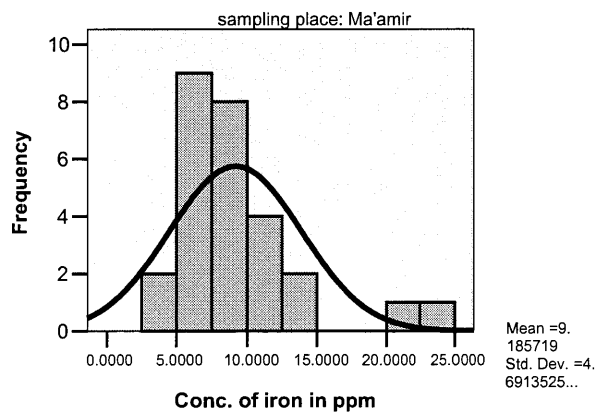
Concentration of iron in ppm



Concentration of iron in ppm

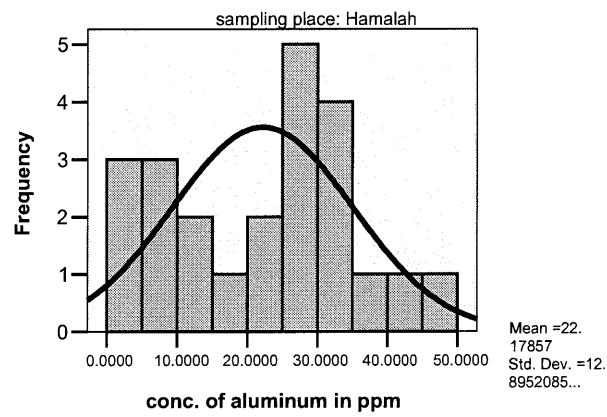


Concentration of iron in ppm

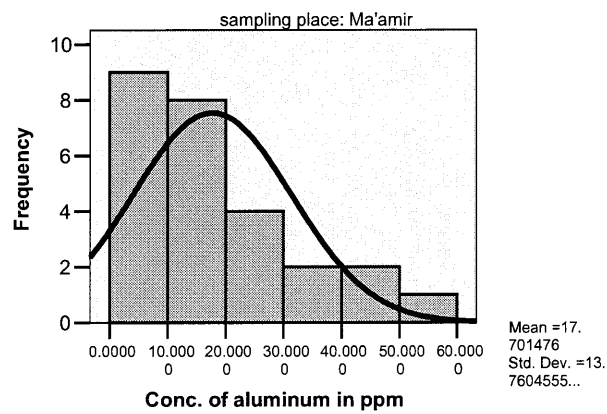


(b)

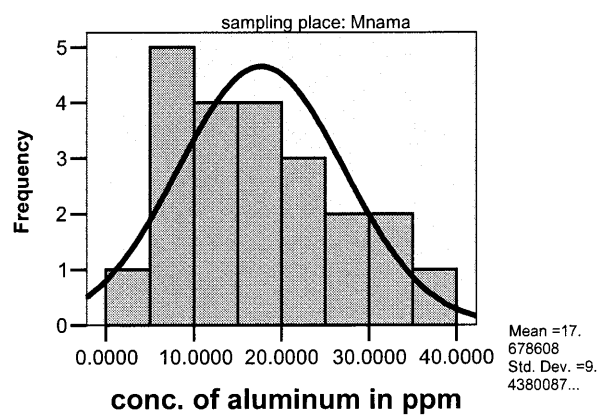
Concentration of aluminum in ppm



Concentration of aluminum in ppm

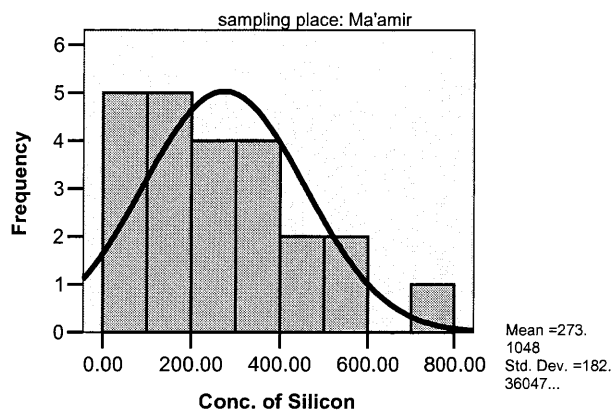


Concentration of aluminum in ppm

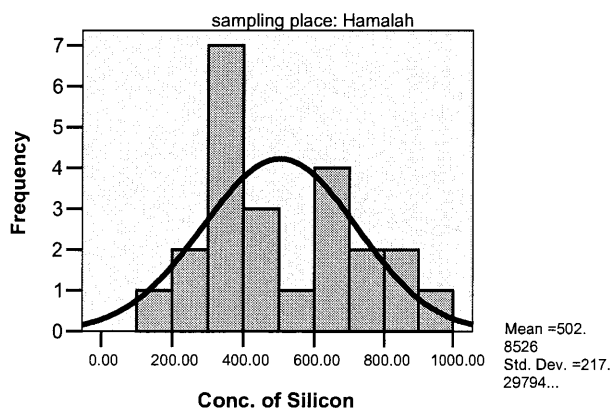


(c)

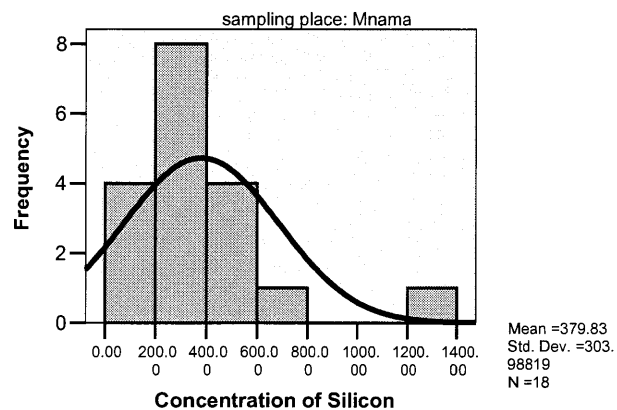
Concentration of Silicon



Concentration of Silicon



Concentration of Silicon



(d)

Fig 14
The concentration of anions represented by Boxplots

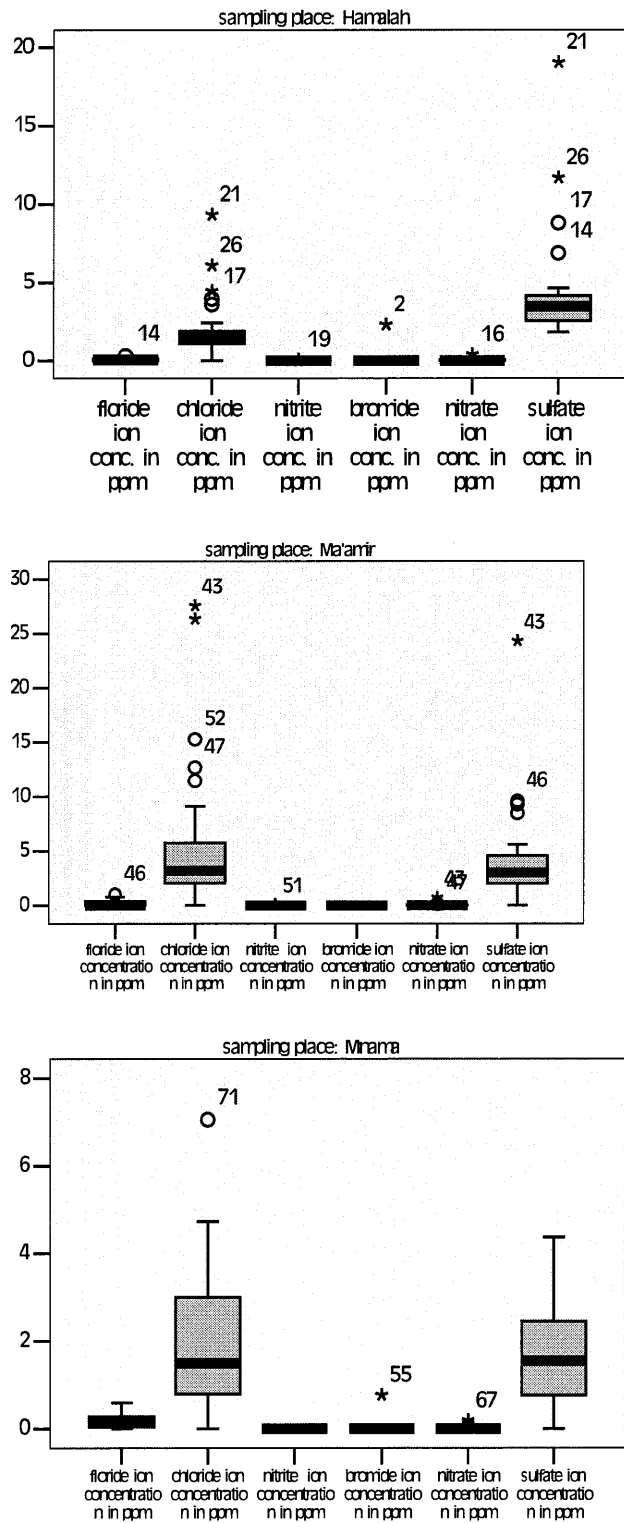


Fig. 15
The differences of mean concentrations of cations in the three areas of study.

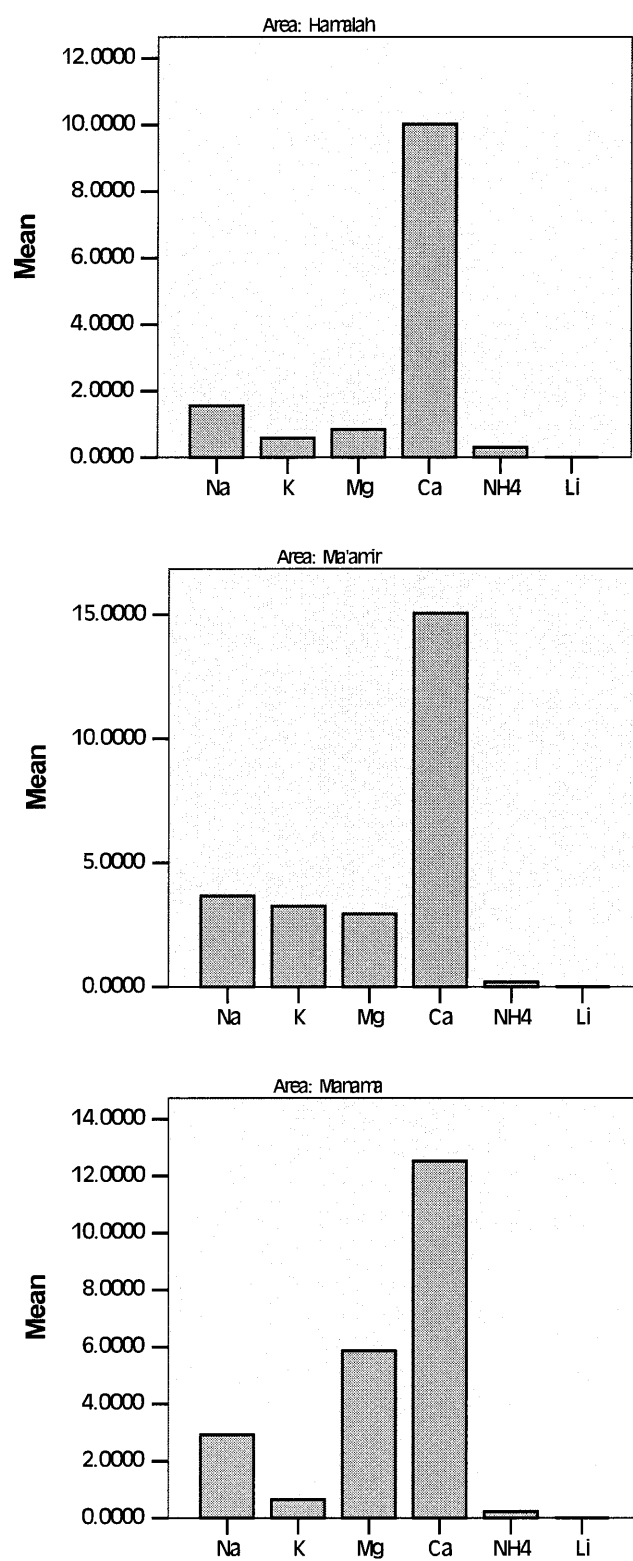
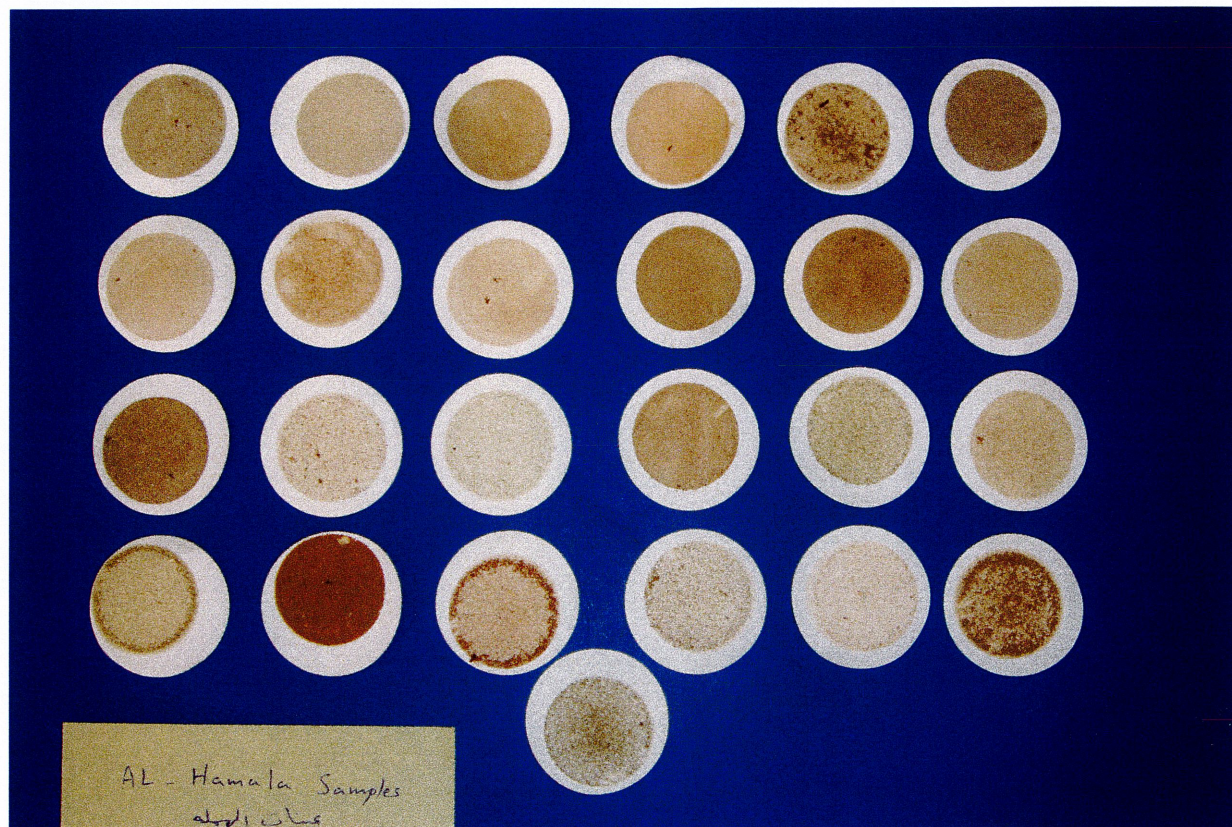


Fig 16.
The total suspended particles of Hamalah.



الملخص

تم إجراء هذه الدراسة لمعرفة نوعية الهواء وكيمياء الجسيمات المنقولة جواً وذلك بتعيين الجسيمات أو الدقائقات في جو ثلاث مناطق منها المنطقة الصناعية كالمعالمير ، و الحضرية كالمنامة، والريفية كالهملة في البحرين وعلاقتها بالأحوال الجوية.

وقد تم أخذ عينات من الجسيمات أو الدقائقات من الجو وذلك بوضع كأس بحجم لتر واحد يحتوي على مياه مقطرة على ارتفاع وقدره حوالي 8 أمتار عن سطح الأرض في الثلاث المناطق المذكورة أعلاه . وقد تم أخذ العينات في الفترة مابين 10 ديسمبر 2004م إلى 16 يونيو 2005م . وقد استخدم جهاز التحليل الكروماتوغرافي الأيوني لمعرفة تركيز الأيونات الموجودة في العينات المأخوذة للمناطق الثلاثة . أما جهاز الامتصاص الذري (ICPS) ، فقد استخدم لقياس تراكيز الأيونات الثقيلة . ولمعرفة محتوى العينات من المواد العضوية الموجودة في الجسيمات فقد استخدم جهاز (GC – MS) وتم مقارنة النتائج وربطها بالأحوال الجوية ونوعية تكوين السطح في البحرين.

أما بالنسبة للتحليل الإلكتروني للنتائج فقد استخدم نظام (SPSS) لمعرفة العلاقة بين النتائج وربطها ببعضها وكذلك لمعرفة العلاقة بين المقاييس المأخوذة.

وعلى ضوء النتائج والتحليل فقد وجد أن هناك علاقة بين مجموع الصلب المعلق (TSS) والتوصيل الكهربائي الذي دل على أن أي ارتفاع في المستوى لمجموع الصلب المعلق يصاحبه ارتفاع في مستوى التوصيل الكهربائي ، وأن هناك ارتفاع نسبي في مجموع الصلب المعلق بينما كان معدل نسبة جسيمات المواد القطرانية في مجموع الصلب المعلق قليلة نسبياً وتعادل 3.6% مما دل على أن معظم الجسيمات في جو المناطق المأخوذة هو ناتج من أصل التربة. وقد وجد أن أعلى تركيز لمجموع الصلب المعلق والمواد القطرانية موجود في منطقة المعالمير (96.53 ملج و 3.3289 ملج) مقارنة بالهملة (18.904 ملج و 0.692 ملج) والمنامة (19.283 ملج و 6.933 ملج) بالإضافة إلى أن أعلى محتوى من المعادن الثقيلة وجد في جو منطقة المعالمير ، أيضاً بالمقارنة لمنطقتي الهملة والمنامة ، المنطقة الصناعية كالمعالمير والمنطقة الحضرية كالمنامة تحتويان على مواد عضوية من الجسيمات أو الدقائقات في الجو أكبر بكثير من المنطقة الريفية كالهملة .