

**APPLICATION OF INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS
FOR THE DETERMINATION OF ELEMENTAL CONSTITUENTS AND OTHER
PARAMETERS OF HARMATTAN DUST AROUND KANO**

BY

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(PhD/SCIE/15572/07-08)**

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DECLARATION

I, MAMUNU, Muhammadu Inuwa, hereby declare that the work in this dissertation titled, “Characterisation of Harmattan Dust and Application of Instrumental Neutron Activation Analysis for the Determination of Its Elemental Constituents,” was performed by me in the Department of Physics, Faculty of Science, Ahmadu Bello University, Zaria, under the supervision of Dr. Rabi’u Nasiru, Professor, S. A. Jonah and Dr. Umar Sadiq. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation has been presented elsewhere for the award of another degree or Diploma at any institution around the world.

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Date

CERTIFICATION

This dissertation titled, “Characterisation of Harmattan dust and application of instrumental neutron activation analysis for the determination of its elemental constituents,” by Mamunu, Muhammadu Inuwa meets the regulations governing the award of the degree of Doctor of Philosophy (Physics) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation in its entirety has been dedicated to Sheikh Isma'ila Khalifa, Zangon Barebari, Kano, for his immense service to humanity.

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ABSTRACT

The Sahara desert is the world's largest hot desert and one of the harshest environments on the planet Earth. Intense heating over the desert causes convective forces to uplift sand and dust particles into the atmosphere, and carried by north-east Trades (winds) to distant places worldwide. When it reaches Guinea Coast in West Africa, the prevailing wind is locally called the Harmattan. Ubiquitous deposition of the dust in Kano State ($11^{\circ} 59' \text{N}$, $8^{\circ}30' \text{E}$), is most eminent from November to March. Harmattan dust was, therefore, collected from 20 sites around Kano in January and February, 2009. The parameters established during the period included average gravimetric concentration of the dust, the absorbance of atmosphere, atmospheric turbidity, air density, absolute viscosity of air, and kinematic viscosity. The Coriolis force was also determined, while the average wind speed was found. In determining the turbulent nature of the wind, the Reynolds number was established; and the resulting wind power density during the season was computed. Instrumental Neutron Activation Analysis (INAA) technique was applied for elemental analysis of the Harmattan dust. And it was found to be composed of 21 elements which included Al, Ca, Fe, Mn, Mg, Na, Ti, K, Br, Cr, Zn and V. Other trace elements in the dust were Sb, La, Th, Co, Ta, Sm, Sc, and U. Aluminium, Calcium, and Iron featured prominently with concentrations above 1000 ppm in the dust. The health hazards of these elements in humans have been highlighted.

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DEFINITION OF TERMS

- 1. Major element:** Any element detected with concentration greater or equals to 100 parts per million (100ppm).
- 2. Minor element:** Any element detected with concentration less than 100 parts per million (100ppm).
- 3. Harmattan:** The prevailing wind carrying the Sahara dust, when transported to Guinea Cost, West Africa, it is called the Harmattan.
- 4. Sahara desert: Desert** is a term applied to a region of the earth that is characterized by less than 254 mm (10 in) of annual rainfall, an evaporation rate that exceeds precipitation, and, in most cases, a high average temperature. The **Sahara Desert** is the largest hot desert in the world and occupies ten percent of the African continent (Bjorn, 2006).
- 5. Extinction Characteristics:** These are the characteristics of an aerosol which bring about the diminution of light as it passes through the aerosol.
- 6. Atmospheric Turbidity:** This is the extinction characteristic of the atmosphere as a beam of light passes through it.
- 7. Coriolis Force:** Because of the rotation of the earth, there is an apparent deflection of all moving objects including air to the right of their line of motion in the northern hemisphere and to the left in the southern hemisphere as viewed by an observer on the earth's surface. This deflective force is defined as Coriolis force.
- 8. Reynolds Number (Re):** This is a dimensionless quantity whose approximate value determines whether the sheared flow of fluid in a pipe is laminar or turbulent. For air, the value of Re has to be greater than 6000 to produce turbulent flow.
- 9. Instrumental neutron activation analysis (INAA):** Neutron activation analysis (NAA) is a nuclear analytical technique based on the nuclear reactions that occur in the atomic nucleus due to irradiation with neutrons. If NAA is conducted directly on irradiated samples it is termed Instrumental Neutron Activation Analysis (INAA).
- 10. Transmittance:** Transmittance is defined as the ratio of the transmitted intensity of beam of light passing through an aerosol to the incident intensity of the beam at the top of the aerosol.
- 11. Absorbance:** Absorbance is defined as the logarithm of the reciprocal of transmittance of an aerosol.

CHAPTER ONE

1.1 Introduction

About 4.6 billion years ago, a cloud of disk-shaped mass of dust and gas, called the primitive solar nebular (PSN), was perturbed by material from a supernova explosion. The cloud then condensed and its mass was greater near the centre. The resulting concentration of matter comprised the sun, with the planets forming by accretion from the remaining material. Small particles moved close to one another, and were drawn together by their mutual gravitational attraction and the whole system rotated then (Descartes, 1644). The presence of elements such as zinc, gold, mercury and uranium on Earth is an indication of a supernova source; thus, confirming the presence of the material which perturbed the primitive solar nebular. And as the masses of the planets increased, they gathered more particles and continue to grow. At some point in time, it is believed that a collision between the proto - Earth and a very large body disrupted the planet, the material reforming as two bodies rather than one, the Earth - Moon system (Allaby, 2000). This plus the discovery of lunar rocks 4.6 billion years old explains why the Earth and the Moon are considered to be of the same age. The overall elements that compose the Earth are presented in Table (1.1).

Table 1.1: Overall elemental composition of the earth (% by weight)

(Source: Mason, B. H., 1958)

Our planet Earth (Plate 1.1), as it exists, has a mean radius of 6371 km; equatorial circumference of 40,077 km; polar circumference of 40,009 km; total mass of 5976×10^{24} g, and mean density of 5.517 g cm^{-3} . Out of its surface area, $149 \times 10^6 \text{ km}^2$ is land, $15.6 \times 10^6 \text{ km}^2$ glaciers and ice sheet, and $361 \times 10^6 \text{ km}^2$ oceans and seas (Holmes, 1965). However, there is much more land in the northern hemisphere than in the southern, but at the poles the reverse is the case.

Fe 35.39	S 2.74	Co 0.20	Ti 0.04
O 27.79	Ni 2.70	Na 0.24	P 0.03
Mg 17.00	Ca 0.61	Mn 0.09	Cr 0.01
Si 12.64	Al 0.44	K 0.08	



Plate 1.1: Our planet Earth as it exists today

As a globe, the p (Source: Microsoft Encarta, 2009) , but also air and all other substances that, through gravity, are held tightly together within the system. This thin envelop of air around the earth which is referred to as its atmosphere, has a mass estimated at about 10^{22} g or 10^{10} megatons (Twomey, 1977). It is most frequently polluted by some gaseous compounds and small particulate matter. People, governments and individuals are, today, becoming more concerned of air pollutants. The pollutants could be anthropogenic, which are pollutants caused by the activities of man in relation to transportation, electric power generation, manufacturing processes (Plate 1.2), or refuse disposal. Whitlow – Gray, in 1932, apparently coined the term “aerosol”, to mean a dispersed system of particles suspended in a gas (Cadle, 1975).

INDUSTRIAL POLLUTION



Plate 1.2: Factory smoke polluting the air at Czech Republic (Encarta, 2009)

Man-made pollutants are mostly due to rapid growth in urbanization/industrialization. This fact was substantiated in the recent incidence of smog in Beijing, China (Plate 1.3). The whole city was enveloped in thick smog that a hospital known as Beijing Shijitan Hospital reported receiving 20 percent more patients daily than usual at its Respiratory Health Department, most of them coughing and seeking treatment for bronchitis, asthma and other respiratory ailments (Huang, 2013). Therefore, air pollution problem as observed by Huang (2013) became compounded in Beijing, China due to the country's rapid pace of industrialization, reliance on coal power, explosive growth in vehicle ownership and disregard for environmental laws, with development often taking priority over health.



1.2 , Plate 1.3: Air Pollution in China caused by rapid growth in Industrialization

There are naturally occurring air pollutants, over which man has little or no control. These mostly originate from activities such as volcanic eruption, bush fire and sea spray, wind erosion/dust storms (Plate 1.4). Desert dust-storms world-wide whip up and disperse an estimated 2.4 billion tons of soil and dried sediments throughout the Earth's atmosphere annually (Bjorn, 2006). The world prominent deserts are listed in Table 1.2 with their respective areas and locations. The Sahara desert is the largest hot desert and occupies approximately ten percent of the African continent (Bjorn, 2006)

Table 1.2: List of Largest Deserts in the World

S/No.	Largest Deserts in the World		Approximate Area	
	Desert	Location	sq km	sq mi
1.	Sahara	northern Africa	9,100,000	3,500,000
2.	Gobi	Mongolia/northeastern China	1,300,000	500,000
3.	Patagonian	Argentina	670,000	260,000
4.	Rub' al Khali	southern Arabian peninsula	650,000	250,000
5.	Great Sandy	northwestern Australia	390,500	150,000
6.	Great Victoria	southwestern Australia	390,500	150,000
7.	Chihuahuan	Mexico/southwestern United States	360,000	140,000
8.	Takla Makan	northern China	360,000	140,000
9.	Sonoran	Mexico/southwestern United States	310,000	120,000
10.	Kalahari	southwestern Africa	260,000	100,000
11.	Kyzyl Kum	Uzbekistan	260,000	100,000
12.	Thar	India/Pakistan	260,000	100,000
13.	Simpson	Australia	100,000	40,000
14.	Mohave	southwestern United States	52,000	20,000

Thousands of years ago, the Sahara had enough water so that people and animals were able to survive on the edge of the desert. There is evidence that the area was able to sustain river animals such as crocodiles. Fossils of dinosaurs, including Afrovenator, Jobaria and Ouranosaurus, have also been discovered in the desert. Prehistoric rock paintings also depict cattle, giraffes, elephants and lions that roamed a once-lush Sahara. However, today, there is little water or vegetation to sustain life in most part of the area. The change occurred in about 1600 B.C., after shifts in the Earth's axis increased temperatures and decreased precipitation. The northeasterly winds blowing over the surface can reach hurricane level and often give rise to [sand storms and dust devils](#). The desert is 1,610 km wide and 5, 150 km long from east to west. It covers an estimated area of about 9.1 million square kilometers, of which some 207, 000 km² consist of partially fertile oases; and it generates about 300 million metric tons of airborne dust each year (Microsoft Encarta, 2009), twelve and a half percent of the worldwide

total.



Plate 1.5: Sand dunes in the Sahara desert (Source: Encarta, 2009)

F Morocco, Western Sahara, Tunisia, Algeria, Mauritania, Mali, Libya, Egypt, Niger, Chad, Eritrea and Sudan (Plate 1.6). Other distinct regions in the Sahara desert are the Central Ahaggar Mountains and the Tibesti massif, a plateau region; and the Libyan Desert in the east. The Western Sahara is an area of rock-strewn plains and sand deserts of varying elevation. And the Libyan Desert is considered the most arid part of the Sahara. Moisture is almost totally absent in the desert (Plate 1.7).



Plate 1.6: The Sahara desert on the Map of Africa (Source: Microsoft Encarta, 2009)



Plate 1.7: Dried Libyan Desert in the Sahara (Source: blogspot.com, 2011)

Intense heating over the Sahara desert causes sand and dust particles to be uplifted into the atmosphere by convective forces, and the dust reach great heights estimated at 6.0km above the surface (Jaenicke, 1976). The north – east Trades (Winds) blowing over the desert carry the dust with it and cover distances of thousands of kilometers worldwide. The dust

combining with the hot dry air of the desert often forms an atmospheric layer called the Saharan Air Layer. Due to long trajectory over the desert, the prevailing Northerly/North – East Trades regime are often dry and dust laden, accounting for a massive deposition of fine silts/clayey particles all over the region, extending right to the Gulf of Guinea.

The Sahara dust transported to northwestern Africa comes from Bodélé region in the dried-up lake Megachad of the Sahara desert (Plate 1.8), which once measured about 400,000 square kilometres at its largest (Bristow *et al.*, 2010). According to Bristow, Megachad was bigger than all the Great Lakes of North America put together; but today only a small remnant of the lake exists in the 1,350-square-kilometre modern-day Lake Chad. On the basis of the height of wind-eroded ridges called yardangs, Bristow *et al.* (2009) had calculated that up to 4 metres depth of dust have been removed from across the lakebed of Megacad in the past 1,000 years. And at current rates of dispersal, the dust in the basin will last for perhaps another 1,000 years or more.



Plate 1.8: The Bodélé depression in Africa is part of a vast dried-up lakebed.
 (Source: *Modis/NASA*)

In 2005 scientists went to Bodélé and took atmospheric measurements to learn how the dust travels. They also took dust samples to learn about its composition. The team was led by Charlie Bristow, a sedimentologist at Birkbeck, University of London. As reported by Washington and Todd (2005), after analyses, the dust turned out to contain substantial amounts of iron and phosphorous, the key plant nutrients. Phosphorus, a major element of commercial fertilizer, is essential for plant growth, respiration and energy transfer, and for storage. Iron is a micronutrient that plants use to make an enzyme critical for photosynthesis. According to Richard (2010), Charlie Bristow's team estimated the dust to be 38 times richer in these minerals than formerly thought.

When the Sahara dust reaches Guinea Coast in West Africa, the prevailing wind is locally called the Harmattan. The Saharan dust (also known as Harmattan dust) interacts with the

atmosphere and the oceans, and it undergoes bio-geochemical processes with adverse implications on its particulate composition, climatic changes and ecological systems. The resulting atmospheric haze and occasional early morning/evening fogs prevalent during the Harmattan season, lead to frequent cancellation of flights in some northwest African countries including Nigeria, resulting in a heavy loss of revenue annually. Air safety too is most often threatened during the period. For instance, Nigeria's worst aviation accident to date in which 183 lives were lost, occurred when a plane carrying pilgrims from Jeddah force-landed during the Harmattan period of November - 1973 at the time a thick haze besieged Kano international airport. And recently, on July 27, 2011, a Moroccan military plane, Hercules C-130, crashed on the edge of the Sahara desert in the Morocco's worst military aviation disaster, killing 83 people on board, with no survivor. In all cases, the accidents were attributed to fog and bad weather conditions.

With respect to health, aggravation of conditions among those suffering from lung diseases such as bronchitis, pneumonia, tuberculosis and other respiratory ailments, all have been attributed to increased air pollutants (Wallace and Hobbs, 1977). Okunade (2000) provided the threshold limit values for some elements and their effects on the lungs (Table 1.3).

Table 1.3: Threshold Limit Values (TLV) for some elements and their effects on the lungs

	Elements	TLV (μm^{-3})	Effects on the Lungs
1.	Al	-	Pulmonary fibrosis ($95,000 \mu\text{m}^{-3}$ respiratory dust)
2.	Fe	1000	Siderosis: increased risk of lung cancer
3.	Cu	100	Acute irritation in the upper respiratory tract
4.	Mn	5000	Pneumonia, bronchitis
5.	V	500	Irritation in the upper respiratory tract
6.	Zn	5000	Pneumonia, bronchitis

(Source: Okunade, 2000)

Many aerosols are known to be toxic or mutagenic. However, aerosols greater than 10 – 15 μm in diameter are effectively stopped by the upper respiratory tract because of its convolution and sticky mucous lining (Lee and Mudd, 1979). Utah and Ngadda (1994) had, therefore, suggested that it would be beneficial to identify and quantify such components in the Sahara dust particles because of the incidence of respiratory and other ailments.

1.3 Previous Work in the Area of Study

Ibeanu (1993) used a 6-stage cascade impactor air sampler for eight hours on top of a building to collect dust samples in January, 1989 in Kano State for characterisation of air particulates. January to February is the period of intense Harmattan dust in the State. Electron Microprobe Analyzer/Scanning Electron microscope (EMPA/SEM) was used in analysing the samples of the dust, detecting a total of 12 elements of varying concentrations

along the cascade impactor (Appendix 1). The findings showed that calcium was the most abundant element detected while copper was the least abundant. The author concluded that calcium abundance in Kano was in agreement with the result obtained by previous investigators (Beavington and Cawse, 1979; McTainsh, 1980).

In another investigation on elemental composition of Harmattan dust collected in Kano State, Nigeria, Adepetu *et al.*, (1988) also analysed the dust using XRF technique and presented their findings with Aluminium having the highest concentration (6110ppm), while uranium was the least (6.48ppm). Twenty two elements were identified in the dust.

Utah (1993) had found the value of the turbidity of air in Jos, Nigeria during the Harmattan period as 0.37. Adeyefa *et al.*, (1995a) also obtained the turbidity of the spectrum of December, 1991 at Ile – Ife, Nigeria as 0.34; while Adedokun *et al.* (1989) obtained air density during Harmattan season in the same location as 2.65kgm^{-3} . Adetunji *et al.*, (1979) established the positive aspects of Harmattan Dust season for enriching the farmland with nutrients at Zaria, Nigeria.

1.4 Statement of the problem

Dust in the atmosphere constitutes an aspect of air pollutants, which contaminate the atmosphere. However air pollutants have many sources; and in Nigeria the sources generally include vehicular movements, wind, bush burning, home heating and cooking, electric power plants and industrial boilers. The pollutants include carbon dioxide, hydrocarbons, and heavy metals (United Nation, 1998). The amount of dust particles released into the air annually by the country's motor vehicles had been typically estimated at 612, 000 tons and 187, 000 tons for unpaved and paved roads respectively. Bush burning that swept through about 260, 000 hectares of land emitted 871, 000 tons per annum. Home heating and cooking were estimated to release into the atmosphere 584, 000 tons of smoke particles annually from the burning of about 80 billion cubic metres of fuel wood (Nigerian Environmental Study/Action Team, NEST, 1991).

The implications of the presence of dust in the atmosphere or the lack of it are many. When abundantly present, it increases the amount of sunlight reflecting off Earth into space, potentially offsetting global warming. It could also affect cloud formation, and even induce regional climatic changes. Yaalon and Ganor (1979) had once estimated that about 50% of annual dust emission into the troposphere might originate from the Sahara Desert. Prospero and Carlson (1992) had also determined a dust concentration of up to $61\mu\text{gm}^{-1}$ and estimated that 25 – 37 million tons of the Sahara dust was transported annually through the longitude of Barbados at an average speed of 25 km per hour. In Nigeria, Adetunji *et al.* (1979) examined visibility for 11 dry seasons in Samaru, Zaria (11.06°N, 7.7°E) and showed that January and February recorded the highest number of Harmattan hazy days. By application of XRF technique, he also found that aluminium has the highest concentration (5, 800ppm) among the Harmattan dust elemental constituents. The next in concentration after aluminium was calcium (4, 600ppm).

Scientists once thought that diseases were mostly transmitted by people or animals but now see dust clouds as possible transmitters of some diseases; and it is seen as increasingly

responsible for respiratory diseases (John, 2009). For instance, a rise in the number of asthma cases in children on Caribbean islands was linked to an increase in the dust blown across the Atlantic from Africa. And when a major African drought began, the rate of asthma cases in Barbados in 2008 was 17 times greater than what it was in 1973 (Microsoft Encarta, 2009). Saharan dust storms are also considered to be responsible for spreading lethal meningitis spores throughout semi-arid central Africa, where up to 250,000 people, particularly children, contract the disease each year and 25,000 die (Laurence, 2003).

The Harmattan season normally commences in the second week of November of every year in the entire northwestern Nigeria, which comprises Kano, Katsina, Jigawa, Sokoto, Zamfara, and Kebbi States; and the season lasts up to the second or third week of March in the following year. During the dustier period of the season (January/February) every year, people become more susceptible to diseases like common cold, nasal congestion, cough, muscular aches, head ache, painful watery eyes and dizziness, accompanied with high body temperature. Therefore, as huge amount of dust in the atmosphere is known to have great impact on atmospheric absorbance, atmospheric turbidity, air density, and air viscosity, it was deemed important to carry out investigations in these and other aspects of the atmosphere particularly in Kano State where some scholars in the past have already shown interest for carrying out similar research work. Regular investigations on the characteristics of Harmattan dust and its implication cannot be over emphasized.

1.5 Justification of the study

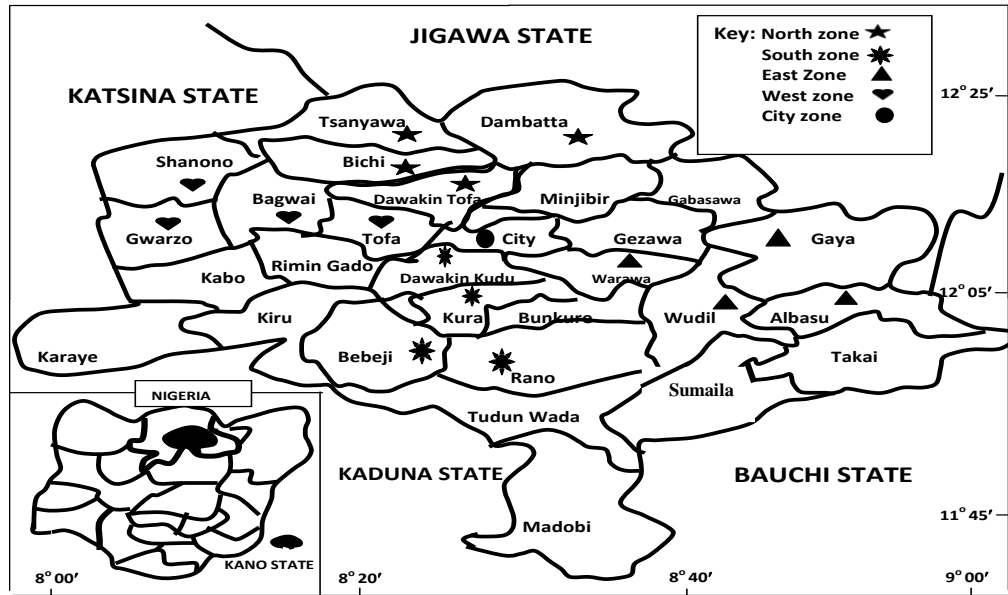
Harmattan dust storms – its mobilization and deposition – are natural phenomena controlled essentially by Meteorological factors completely outside human influence. The dust is generated by powerful winds blowing over the desert due to high atmospheric pressure gradients developed by excessive heating of the surface area by the sun (Jaenicke, 1976). The impact of the Harmattan wind is conspicuously felt in our homes as a result of the ubiquitous deposition of its in-borne dust which covers tables, windows, beds, plates, including our bodies; with our faces turned grey by the eminent colour of the dust. Therefore, the importance of addressing questions concerning the quantity, the origin, and the impact of the dust on the surroundings cannot be overemphasized.

The questions, therefore, include: which processes are responsible for transportation of the dust and what does it mean in terms of loss of productive soil by wind erosion in Africa; in terms of air pollution? What does it mean in terms of possible impact on climate; in relation to the supply of nutrients and soil particles to ocean and land areas under the dust trajectories? It is important to be addressing these and other questions regularly because better knowledge of dry land, dust storms and their ecological impact could contribute to more efficient counteraction of some natural disasters. In particular, for a proper understanding and quantification of the impact of the Saharan emissions on every aspect of the Earth system, a detailed knowledge on the dust physical, elemental and chemical characteristics is necessary.

1.6 Scope of the study

The scope of this study is limited to twenty Local Government Areas of Kano State, Nigeria, a representation of about 48% of the Local Government Areas of the State

(Fig.1.1); and would involve the determination of Harmattan dust characteristics in terms of the dust gravimetric concentration, atmospheric turbidity during Harmattan period, air density, absolute and kinematic viscosities, wind power density, Coriolis force acting in the area during the period, and the determination of turbulent effect of Harmattan wind by



C Fig. 1.1: Local Government Areas visited for Harmattan dust sampling in Kano State
 Gwale L. G. A.: B. U. K. Road Ungogo L. G. A.: Katsina Road
 Tarauni L. G. A.: Zaria Road Fagge L. G. A.: Sabon Gari (Bata)

1.7 Aim and objectives of the study

The aim is to determine elemental constituents of Harmattan dust and assess its impact around Kano State, Nigeria. The objectives are to:

1. determine elemental constituents of Harmattan dust
2. investigate the extent of Harmattan dust effects on some characteristics of the atmosphere which include atmospheric absorbance, atmospheric turbidity, air density, air viscosity, turbulent nature of the wind, and wind power density,
3. estimate the Coriolis force acting on all moving objects, including air, in the area under study,
4. Assess the possible health hazards related to the major elemental constituents of the dust.

1.8 Limitations of the study

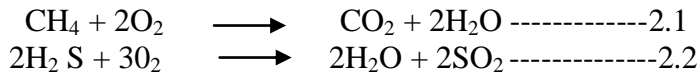
- I. The Harmattan dust collection in each of the twenty locations was conducted during the period of intense Harmattan dust (Jan/Feb), 2009. The early and late dates of the period (November, 2008 and March, 2009 respectively) were ignored because they were characterized with low - level dust concentration in the atmosphere in the area.
- II. The meteorological data for Kano State collected from Nigeria Meteorology, Abuja (NIMET), was for the period 1998 to 2003. All efforts to obtain latest data did not yield results.
- III. The Ministry of Health, Kano State, Nigeria, was contacted for some data on communicable and non-communicable diseases for assessment in relation to the possible toxic elements which may form components of the Harmattan dust, but the effort put in was not successful.

CHAPTER TWO (Theoretical Framework)

2.1 Introduction

When the planets in our solar system were forming by accretion from the remaining material of the Primitive Solar Nebula (PSN) that was perturbed by an explosion from a distant star, metallic cores began to develop within them and this resulted in overturning their interior which forced out the gases that had been trapped. The gases were H, He, CH₄, H₂O, N₂, NH₄ and H₂S, and they formed the early planetary atmospheres (Cesare, 1995). Like Venus, our planet Earth, lost H and He, but retained the other gases. Ultraviolet radiation from the sun broke up the molecules of H₂O, NH₄ and H₂S by a process called photolysis thereby setting oxygen, nitrogen and sulfur free. The hydrogen again escaped.

The free oxygen oxidized CH₄ and H₂S to form CO₂ and SO₂, respectively, as in these equations:



At this early stage there was no liquid water existing over the surface of the earth. This was because the temperature of the surface was maintained above the critical temperature of water. Therefore, the gases forming the atmosphere were in high temperature equilibrium with iron-nickel metal and with iron-magnesium silicates. However, at subsequent stages, the temperature dropped gradually and liquid water came into existence. CO₂ then reacted with silicates to form carbonates; hence, this resulted in the gradual removal of CO₂ from the atmosphere. It has been estimated that the oceans contain dissolved CO₂ about 58 times more than the atmosphere and, at present, the gas enters the atmosphere mainly by the action of living organism in oceans and on land even though, photosynthesis helps to maintain a balance by removing about 3% of the world's total CO₂ annually (Belinskii, 1961).

The Principal constituents of the atmosphere of Earth today are nitrogen (78 per cent) and oxygen (21 per cent). The remaining 1 per cent is constituted of argon (0.9 per cent), carbon dioxide (0.03 per cent), some varying amounts of water vapour, and trace amounts of hydrogen, ozone, methane, carbon monoxide, helium, neon, krypton, and xenon (Microsoft Encarta, 2009). Cadle (2005), however, has given the atmospheric constituents (see appendix 2). Up to an altitude of 100 km the atmosphere is uniform in terms of the three major gases (N₂, O₂, Ar). Above this level, the composition begins to change with progressive increase of the lighter gases. And some gaseous compounds as well as small particulate matter pollute this air.

2.2 Light extinction

The amount of light that passes through a given length of aerosol in the atmosphere is, of course, the difference between the amount of incident light and the amount of scattered and absorbed light by the particles. The Lambert - Beer law (which Hodgkinson called the Bouguer law since it was discovered much earlier by Bouguer) relates the incident, **I**₀, and transmitted, **I**, intensities of beam of light passing through an aerosol to the length (*l*) of the aerosol as:

$$\mathbf{I} = \mathbf{I}_0 \exp (-k l) \text{}2.3$$

k is called the extinction coefficient of the aerosol; the product *kl* is its turbidity, (**I**/**I**₀) is the transmittance. Absorbance is defined as log (**I**₀/**I**). It is directly proportional to the

concentration of the particles in an aerosol and is the quantity often indicated by instruments designed to determine concentration by light extinction (Cadle, 2005).

2.3 Air Density during Harmattan period

The usual way of measuring air density is to record the pressure, temperature, relative humidity and the atmospheric composition. The air density is then calculated by means of a formula. Most standard laboratories have their own formulae, often significantly different from others. However, Giacomo (1982) produced a formula (equation 2.4), which could be used by all laboratories:

$$\rho = \left(3.48353 + 1.44(X_{CO_2} - 0.00049) \right) \times 10^{-3} \frac{P}{ZT} (1 - 0.3780X_v) \dots\dots\dots 2.4$$

where $X_v = h \frac{p_{sv}(t)}{p}$

$$f(p, t) = 1.00062 + 3.14 \times 10^{-8}p + 5.6 \times 10^{-7}t^2$$

$$p_{sv}(t) = \exp (1.2811805 \times 10^{-5}T^2 - 1.9509874 \times 10^{-2}T + 34.04926034 - 6.3536311 \times 10^3/T)$$

u = relative humidity in %

h = u/100

p = pressure in Pa (1 mb = 10² Pa)

T = 273.15 + t = air temperature in Kelvin

t = air temperature in °C

X_{CO_2} = the molar fraction of carbon dioxide present which can, to sufficient accuracy, be set equal to 0.0033.

Z = the compressibility factor given by:

$$Z = 1 - \frac{P}{T} [1.62419 \times 10^{-6} - 2.8969 \times 10^{-8}t + 1.088 \times 10^{-10}t^2 + (5.757 \times 10^{-6} - 2.589 \times 10^{-8})X_v + (1.9297 \times 10^{-4} - 2.8969 \times 10^{-6}t)X_v^2] + \frac{P^2}{T^2} (1.73 \times 10^{-11} - 1.034 \times 10^{-8}X_v^2)$$

2.4 Atmospheric Motion

Atmospheric motion is the sum of two components – movement relative to the earth’s surface (i.e. wind) and movement as a whole with the earth spinning on its axis. In motion relative to the earth’s surface, there are two dimensions to the motion of the atmosphere -

horizontal and vertical motions. The basic underlying cause of atmospheric motion (horizontal and vertical) is the imbalance in net radiation, moisture, and momentum between the low and high latitudes on one hand, and between the earth's surface and the atmosphere, on the other. Other factors, which influence atmospheric circulation, are topography, distribution of land and water surfaces, and ocean currents. Thus, powerful storms can bring strong winds gusting to several kilometres per hour, propelling dust across the Earth's surface. Near the earth's surface, within the troposphere region of the Earth's atmosphere, the four major controls on the horizontal movement of wind are: (1) Pressure gradient, (2) Coriolis force, (3) Centripetal acceleration, and (4) Frictional force.

2.4.1 Atmospheric Motion due to Pressure Gradient

The development and maintenance of a horizontal pressure gradient, which serves as the motivating force for air to move away from areas of high pressure towards areas with low pressure, is the primary cause of air motion. Horizontal differences in pressure are created by thermal and/or mechanical causes, although these are not distinguishable. For a unit mass, the pressure force is expressed as:

$$F = - 1/\rho (dp/dn) \text{ ----- (2.5)}$$

where ρ is the air density, and dp/dn is the horizontal pressure gradient.

2.4.2 The effect of Coriolis force

Once air is forced to move by the pressure gradient force, it is immediately affected by the Coriolis or deflective force due to the earth rotation. Because of the rotation of the earth, there is an apparent deflection of all moving objects including air to the right of their line of motion in the northern hemisphere and to the left in the southern hemisphere as viewed by an observer on the earth's surface. This deflective force per unit mass is expressed as:

$$F = 2\omega v \sin \theta \text{ -----2.6}$$

where ω is the angular velocity of spin of the earth on its axis (about 15° per hour or 7.29×10^{-5} radians per second), v is the velocity of the mass and θ is latitude.

2.4.3 The Centripetal Acceleration

If a body is moving round a circular path, it experiences a force pulling it towards the center of the circular path. The acceleration associated with the force is called centripetal acceleration. The force is given by:

$$F = mv^2/r \text{ ----- 2.7}$$

where m is the mass of the moving body, v is its velocity and r is the radius of curvature. Thus v^2/r is the centripetal acceleration. The magnitude of centripetal acceleration is small for winds, so it only becomes important where high velocity winds move in very much curved paths as in intense low - pressure system.

2.4.4 The frictional force experienced by Winds

Close to the earth surface is the frictional force that helps to control the speed and direction of horizontal air motion. This frictional force is due to the drag by the earth's surface on air

motion. Frictional force acts against the wind and reduces its speed. This also causes a decrease on the Coriolis force.

All the forces described above do not necessarily operate to control the wind direction and speed at a given time or place. When a wind is blowing parallel to the isobars and at right-angle to the pressure gradient, it is called a geostrophic wind, and is usually observed in the free atmosphere where friction is non-existent. The velocity of the geostrophic wind is given by:

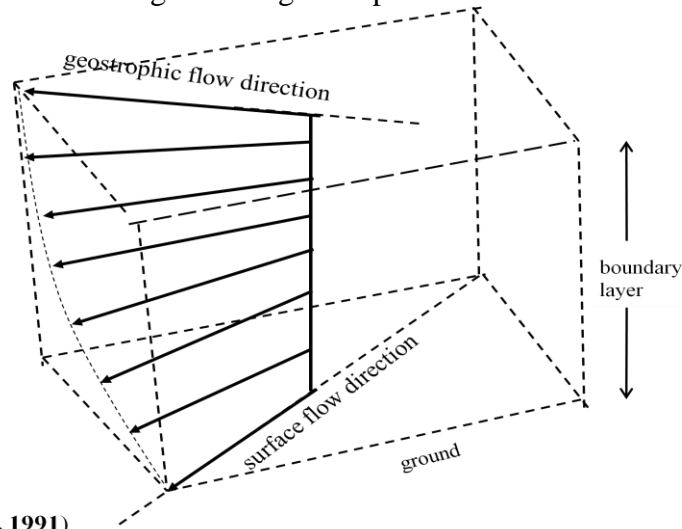
$$v_g = [1/\omega \sin\theta (\rho)] dp/dn \text{-----} 2.8$$

Except in the low latitudes where Coriolis deflection approaches zero, the geostrophic wind is a close approximation to the observed motion in free atmosphere (Kalu, 2001). And Balogun (1991) has indicated that the wind at 10m is proportional to geostrophic wind; and that over the land and the sea, the respective wind speeds are related as:

$$u(10) = 0.5u_G \text{ (over the land)} 2.9$$

$$u(10) = 0.8u_G \text{ (over the sea)} 2.10$$

However, there is progressive decrease in velocity with decreasing height (Fig 2.6); and the wind is also backed at an angle to the geostrophic direction.



(Source: Balogun, 1991)

Fig. 2.1: Wind speed and direction changing with height

2.4.5 The influence of on atmospheric Motion

The fact that the surface of the earth affects the flow of the atmosphere in the lower edge of the troposphere has been used in defining the region to be the atmospheric boundary layer. A very turbulent flow of the atmosphere is produced over the rough earth's elements such as building and vegetation. Even over a very smooth plain, the flow in the atmospheric layer is turbulent.

The viscosity of air is an important aspect in its flow in the lowest layer of the atmosphere. It has the value of 1.82×10^{-4} poise (dyne s cm^{-2}) or 1.82×10^{-5} Nsm^{-2} at 15°C (Nelkon, 1983). Pruppacher and Klett (1980) gave a formula for determining absolute air viscosity at any temperature (T):

$$\eta = (1.718 + 0.0049T) \times 10^{-5} \text{ Nsm}^{-2} \text{.....} 2.11$$

Because of its existence in a fluid, a shear flow is always established in the space between any two parallel plates of a fluid wherever one of the plates moves at constant speed while the other remains fixed. Many fluid plates exert a shear force on the moving plate. The force varies directly as the plate velocity and inversely as the separation distance,

$$\tau = \mu \frac{U_o}{h} \dots\dots\dots 2.12$$

where U_o is the velocity of the moving plate and h is the plate separation distance. The constant of proportionality μ is called the absolute viscosity. Fluids which obey this simple law are called Newtonian fluids. These include water, all ideal gases and mixtures of the ideal gases such as air.

When the rate of strain, U/h , is not constant but varies with the distance from the surface as in the boundary layer, the above definition is generalized to:

$$\tau = \mu \frac{du}{dz} \dots\dots\dots 2.13$$

The absolute viscosity, μ , of liquids and ideal gases is a function of temperature. The kinematic viscosity is consequently used very often, and is defined as:

$$\nu = \frac{\mu}{\rho} \dots\dots\dots 2.14$$

The kinematic viscosity of gases and their mixtures depends on both pressure and temperature, and its value for air is $14.8 \times 10^{-6} \text{ m}^2/\text{s}$ when $T = 15^\circ\text{C}$ and $P = 1013 \text{ mb}$.

2.4.6 Reynolds equations for Atmospheric flow

Because the value of any property in a turbulent flow possesses complex time dependence, it is often advantageous to deal with the values of the various properties that are averaged over a suitable period. For example, the time - averaged value of the x - component of velocity, designated as \bar{u} , is defined by:

$$\bar{u} = \frac{1}{T} \int_{t-T/2}^{t+T/2} u(t) dt \dots\dots\dots 2.15$$

where T is the averaging time. The value of T must be carefully chosen. Quasi-steady is the term used in describing the case of a turbulent flow whose time-averaged quantities are constant even though their instantaneous values are highly time-dependent. The difference between the instantaneous and the time - averaged values is the fluctuation:

$$u'(t) = u - \bar{u} \dots\dots\dots 2.16$$

For a fluid that is incompressible – a fluid whose parcel densities remain constant with time, $\frac{D\rho}{Dt} = 0$; and the continuity equation has the form:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \dots\dots\dots 2.17$$

where u, v and w are instantaneous values of the velocity components.

And since $u = \bar{u} + u'$, we have:

$$\frac{\partial \bar{u}}{\partial x} + \frac{\partial u'}{\partial x} + \frac{\partial \bar{v}}{\partial y} + \frac{\partial v'}{\partial y} + \frac{\partial \bar{w}}{\partial z} + \frac{\partial w'}{\partial z} = 0 \dots\dots\dots 2.18$$

With the major controls on horizontal movement of the atmosphere near the earth's surface as pressure gradient, Coriolis force, centripetal acceleration and frictional force, we can employ the vector of Euler's equation which is of the form:

$$\frac{Dq}{Dt} = \nabla p / \rho + f_m \dots\dots\dots 2.19$$

The quantity $\frac{Dq}{Dt}$ is the acceleration of the fluid particle. ∇p is the gradient of the pressure, ρ is the fluid density, which may vary with position and time, and f_m is anybody force expressed in terms of its magnitude per unit mass of fluid.

On the tangent plane coordinate system, equation (2.19) can be written as:

$$\frac{Dq}{Dt} = -\nabla p / \rho - G\nabla H - 2\Omega \times q \dots\dots\dots 2.20$$

where $-\nabla H$ is the conservative body force term, and H is the geopotential. $2\Omega \times q$ is the Coriolis acceleration term, which can be evaluated in the tangent plane coordinate system; and G is the acceleration due to gravity. Therefore, in components form:

$$2\Omega \times q = (2\Omega w \cos\theta - 2v\Omega \sin\theta) \mathbf{i} + (2u\Omega \sin\theta) \mathbf{j} - (2u\Omega \cos\theta) \mathbf{k}$$

The quantity $2\Omega \sin\theta$ is the Coriolis parameter and is represented by f. The gradient of the geopotential altitude, $G\nabla H$, is the acceleration of gravity times the perpendicular unit vector, $-g\mathbf{k}$. Therefore, in components form, equation (2.20) becomes:

$$Du / Dt = -1/\rho \partial p / \partial x + vf - wf \cot\theta \dots\dots\dots 2.21$$

$$Dv / Dt = -1/\rho \partial p / \partial y - uf \dots\dots\dots 2.22$$

$$Dw / Dt = 1/\rho \partial p / \partial z - g + uf \cot\theta \dots\dots\dots 2.23$$

These are the Euler's equations for the conservation of momentum, given in a tangent plane coordinate system. The angular velocity of the earth is given by $(2\pi / 86,164) \text{ s}^{-1}$ since the actual period to rotate 2π radians by the earth as it moves round the sun is

$$(24 \times 3600) \text{ s} \times \frac{365.25}{366.25} = 86,164 \text{ s}$$

For the mid latitude regions of the earth, the value $2 \sin\theta = 1.4$ and $f \approx 1.0 \times 10^{-4} \text{ s}^{-1}$.

We now expand the particle derivatives, equation (2.21), (2.22) and (2.23) in the following form:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + fv \dots\dots\dots 2.24$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial y} - fu \dots\dots\dots 2.25$$

$$\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = +\frac{1}{\rho} \frac{\partial p}{\partial z} - g \dots\dots\dots 2.26$$

When we time – average these equations, they take the forms:

$$\frac{\partial \bar{u}}{\partial t} + \bar{u} \frac{\partial \bar{u}}{\partial x} + \bar{v} \frac{\partial \bar{u}}{\partial y} + \bar{w} \frac{\partial \bar{u}}{\partial z} = - \frac{1}{\rho} \frac{\partial \bar{p}}{\partial x} + f \bar{v} - \frac{\partial (\overline{u'u'})}{\partial x} + \frac{\partial (\overline{u'v'})}{\partial y} + \frac{\partial (\overline{u'w'})}{\partial z} \dots\dots\dots 2.27$$

$$\frac{\partial \bar{v}}{\partial t} + \bar{u} \frac{\partial \bar{v}}{\partial x} + \bar{v} \frac{\partial \bar{v}}{\partial y} + \bar{w} \frac{\partial \bar{v}}{\partial z} = - \frac{1}{\rho} \frac{\partial \bar{p}}{\partial y} - f \bar{u} - \frac{\partial (\overline{u'v'})}{\partial x} + \frac{\partial (\overline{v'v'})}{\partial y} + \frac{\partial (\overline{v'w'})}{\partial z} \dots\dots 2.28$$

$$\frac{\partial \bar{w}}{\partial t} + \bar{u} \frac{\partial \bar{w}}{\partial x} + \bar{v} \frac{\partial \bar{w}}{\partial y} + \bar{w} \frac{\partial \bar{w}}{\partial z} = - \frac{1}{\rho} \frac{\partial \bar{p}}{\partial z} - g - \frac{\partial (\overline{w'u'})}{\partial x} + \frac{\partial (\overline{w'v'})}{\partial y} + \frac{\partial (\overline{w'w'})}{\partial z} \dots 2.29$$

These equations are Reynolds equations for a turbulent flow here written for a rotating tangent plane coordinate system; they contain nine new components each of two fluctuating quantities whose time – averaged products are non-zero.

2.4.7 Reynolds’ Number

When all elements of a fluid are moving along the direction of the fluid’s mean motion, the flow is Laminar and internal friction in the fluid will be due only to molecular viscosity.

When, however, individual elements are moving irregularly compared with the mean motion, the flow is turbulent. Reynolds demonstrated that the flow in a pipe could be Laminar at some occasions, while at other instances it would be turbulent. He demonstrated in an experiment that a dimensionless quantity whose approximate value determined whether the sheared flow in a pipe was Laminar or turbulent could be found. This quantity is known as Reynolds number, Re. For a fluid of kinematic viscosity ν , moving with velocity V, Reynolds number is given as:

$$Re = \frac{LV}{\nu} \text{ or } \frac{\rho LV}{\mu} \text{ with } \left(\frac{\rho}{\mu} = \frac{1}{\nu} \right) \dots\dots\dots 2.30$$

where L is a typical length scale of the motion (e.g. the diameter of the pipe). In the case of pipes with $Re > 2000$, the flow would be chaotic. For air, however, values of Re have to be greater than 6000 to produce turbulent flow. And for smaller values, the flow would result in laminar motion.

2.5 Concentration of species released into space

Suppose a finite amount of material is released instantaneously at the time $t = 0$ at the origin. The concentration, c, is a function of the radial distance and time (t) because the diffusion from an isolated source is uniform in all directions. Thus $c = c(r, t)$; and the boundary conditions are:

1. $c(r, 0) = 0$ at the initial time, for all space
2. At large distance from the origin, $c(r \rightarrow \infty, t) \rightarrow 0$
3. Total amount of material distributed throughout space at any time is equal to the amount released at the initial time.

$$4\pi \int_0^{\infty} c(r, t) r^2 dr = Q \dots\dots\dots 2.31$$

The problem has spherical symmetry, and the solution to this equation is found as:

$$c = \frac{Q}{(4\pi D)^{3/2}} \exp\left(-\frac{r^2}{4Dt}\right) \dots\dots\dots 2.32$$

where $r^2 = x^2 + y^2 + z^2$ and D is the diffusion coefficients.

Equation (2.32) satisfies all the boundary conditions. The concentration is always greater at $r = 0$ where the release initially occurred. The width of the curve increases with time, and the position of the location, $r_{1/2}$ where the concentration is 50% of the value at the origin is given by:

$$r_{1/2} = 2 \ln(2)^{1/2} (Dt)^{1/2} = 0.693 (Dt)^{1/2}$$

However, in an anisotropic medium, the diffusion equation has the form:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x} \left(D_x \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \left(D_y \frac{\partial c}{\partial y} \right) + \frac{\partial}{\partial z} \left(D_z \frac{\partial c}{\partial z} \right) \dots\dots\dots 2.33$$

where D_x, D_y, D_z , represent the values of the binary diffusion coefficients which may not necessarily be equal to one another in three directions. For an instantaneous release at the origin, the solution is given by:

$$c = \frac{Q}{(4\pi t)^{3/2} (D_x D_y D_z)^{1/2}} \cdot \exp\left(-\frac{x^2}{4D_x t} - \frac{y^2}{4D_y t} - \frac{z^2}{4D_z t}\right) \dots\dots\dots 2.34$$

When $D_x = D_y = D_z$, we may, therefore, define the quantities

$$\delta_x^2 = 2D_x t; \quad \delta_y^2 = 2D_y t; \quad \delta_z^2 = 2D_z t \dots\dots\dots 2.35$$

And the concentration is expressed as:

$$c = \frac{Q}{(2\pi)^{1/2} (\delta_x \delta_y \delta_z)^{1/2}} \cdot \exp\left(-\frac{x^2}{2\delta_x^2} - \frac{y^2}{2\delta_y^2} - \frac{z^2}{2\delta_z^2}\right) \dots\dots\dots 2.36$$

$\delta_x, \delta_y, \delta_z$ are the directional mean - square displacements, which are referred to as the dispersion coefficients.

2.5.1 Conservation of mass in atmospheric flow

The conservation of a species A is formulated by considering the process of transport and the process of production or consumption by chemical reaction as they apply to a control volume which is fixed in space, and through which the fluid moves. For a species, A, the conservation principle is expressed by the equation:

$$\iiint_V \frac{\partial \rho_A}{\partial t} dV = - \iint_S (\rho_A v_A) \cdot dS + \iiint_V r_A dV \dots\dots\dots 2.37$$

(1) (2) (3)

The term (1) represents the net rate of accumulation of species A within the control volume. Term (2) is the rate of flow of species A through the boundaries of the control surface; while term (3) indicates the total production of (A) within the control volume as a result of chemical production rate, r_A , possessing the units of $(\text{kgm}^{-3}\text{s}^{-1})$.

The surface integral, term (2), can be converted to volume integral by the use of Gauss's Theorem. Thus,

$$\iint_S (\rho_A v_A) \cdot dS = \iiint_V \nabla \cdot (\rho_A v_A) dV$$

Hence, equation (2.35) becomes:

$$\iiint_V \left[\frac{\partial \rho_A}{\partial t} + \nabla \cdot (\rho_A v_A) - r_A \right] dV = 0$$

Therefore,

$$\frac{\partial \rho_A}{\partial t} + \nabla \cdot (\rho_A v_A) = r_A \dots\dots\dots 2.38$$

Equation (2.38) is a continuity equation for species A, and expresses the change of concentration of component A at each point in space when motion and chemical reaction

are present. When the mixture consists of only two species A and B, the equation can be expressed in the following form:

$$\frac{\partial \rho_A}{\partial t} + v \cdot (\nabla \rho_A) = \nabla \cdot (D_{AB} \nabla \rho_A) + r_A \dots \dots \dots 2.39$$

In expanded form, equation (2.37) becomes:

$$\frac{\partial \rho_A}{\partial t} + u \frac{\partial \rho_A}{\partial x} + v \frac{\partial \rho_A}{\partial y} + w \frac{\partial \rho_A}{\partial z} = \frac{\partial}{\partial x} (D_{AB} \frac{\partial \rho_A}{\partial x}) + \frac{\partial}{\partial y} (D_{AB} \frac{\partial \rho_A}{\partial y}) + \frac{\partial}{\partial z} (D_{AB} \frac{\partial \rho_A}{\partial z}) + r_A \dots \dots \dots 2.40$$

In general, the molecular diffusion coefficient is a function of concentration, which is itself influenced by the presence of diffusion. When equation (2.40) is divided by molecular weight, the equation becomes expressed in molar concentration. This is advantageous since it accounts for chemical production. Thus,

$$\frac{\partial c_A}{\partial t} + u \frac{\partial c_A}{\partial x} + v \frac{\partial c_A}{\partial y} + w \frac{\partial c_A}{\partial z} = D_{AB} (\frac{\partial^2 c_A}{\partial x^2} + \frac{\partial^2 c_A}{\partial y^2} + \frac{\partial^2 c_A}{\partial z^2}) + r_A \dots \dots \dots 2.41$$

Equation (2.41) is a continuity equation, which includes Fickian diffusion and chemical reactions. It expresses the conservation of each species in a moving fluid mixture. And it balances the rate of increase of concentration as well as the rate of generation by chemical reaction. When the motion of the fluid is turbulent, there is usually a significant augmentation of mass transfer from regions of high to low mass fraction of a particular component. The influence of this mechanism, which is dominant over molecular diffusion in the lower troposphere, is referred to as turbulent dispersion.

2.6 Wind power as a consequence of atmospheric turbulence

The Harmattan season is primarily known for causing the atmosphere to be polluted. Other effects of the season include degradation of incident solar radiation, and some related effects of ill – health in humans. However, one positive aspect of the season is that of enriching the farmland with nutrients (Adetunji *et al.*, 1979). The season is also characterized with large wind power in Kano State. The speed of wind may not necessarily be as high as that during, say, the rainy season; but with the high value of mean air density, the period has been observed to be generating high wind power density, which could be

positively utilized for developmental purposes, for instance, upgrading regional electrical power supply. A similar project was carried out in Tanzania by Kainkwa and Uiso (1988).

There are several methods which can be used to estimate available wind power at a site; and they include:

Method 1.

When the average mean wind speed, \bar{u} is known at a site, passing through an area, A, the theoretical available wind power in Wm^{-2} , according to Putnam (1948) and Considine (1977), is given by:

$$P_t = 0.5\rho A\bar{u}^3 \dots\dots\dots 2.42$$

where ρ is the density of air at sea level taken as 1.22 kg m^{-3} . The quantity P_t/A is called wind power density.

Method 2

When the mean yearly wind speed, \bar{u} , (m/s) at a site is available, the wind power density can be calculated from the relation:

$$P = 0.5\rho\bar{u}^3 \dots\dots\dots 2.43$$

Method 3

When the yearly wind speed can be sub – divided into a mean value, \bar{u} , and a perturbation from the mean value, u' , such that $u = \bar{u} + u'$, then the available wind power is given by:

$$P = 0.5(\bar{u}^3 + 3\bar{u}\sigma^2) \dots\dots\dots 2.44$$

where σ is the standard deviation of the 12 mean monthly wind speed, and \bar{u} is the average or the mean wind speed.

Method 4.

Golding (1955) gave another formula for computing maximum wind power, P_m extracted by a wind turbine in a location:

$$P_m = \frac{0.593}{2} \rho A \bar{u}^3 \dots\dots\dots 2.45$$

This relation was used in estimating wind power density in the location under study.

2.7 Harmattan dust and PM10 particulate matter

Quite a number of successful researches have established significant amount of fine particles in form of PM10 particulate matter in the Sahara dust. PM10 particulate matter consists of particles with aerodynamic equivalent diameter (AED) of less than or equal to $10 \mu\text{m}$. Aerodynamic equivalent diameter is the diameter of a particle with unit density, which has the same settling speed as the particle under consideration. PM10 particle has significant resident time range in the atmosphere; hence it gets transported over long distances by winds.

When dust particles of PM₁₀ are to be studied, special sampling devices are required – they are those which allow air stream to be processed on its way to the filter so that only particles with upper size cut-off of 10 µm AED are allowed to reach the filter. Initial design of PM₁₀ inlets were based on 50% collection efficiency at 10µm (Wedding and McFarland, 1985). These inlets eliminate most of the wind speed and direction problems usually encountered within some conventional aerosol samplers. They also prevent passive loading on the filters when there is strong wind. However, the inlets operate on the principle of impaction on a plate, a situation that may lead to particle bounce-off; but such problems are corrected by coating the impaction plate with grease or using the principle of virtual impaction (Dzubay and Stevens, 1975) whereby the particles are deposited within a separate volume of air within the inlet.

2.8 The Dichotomous Air Sampler

Some requirements in atmospheric aerosols sampling (such as source identification) may necessitate aerosol collection in two separate size fractions corresponding to bimodal urban aerosols. These are fine particles fractions (<2µm AED) which consist of mainly particles from combustion sources, while larger particles (2-10µm AED) are those generated mainly by natural and mechanical processes. Thus a size cut-off of about 2µm, to some extent, separates the particles according to their origins and chemical properties (Dzubay and Stevens, 1975).

The dichotomous sampler is a device used in providing the bimodal size separations. It uses the principle of virtual impaction to separate the aerosols which are initially directed to PM₁₀ inlet (for exclusion of particles greater than 10µm) into fine and coarse particle fractions. The coarse and fine particle fractions are typically sampled at flow rates of 13.6litres/min and 0.4litres/min respectively (Dzubay and Stevens, 1975). The collection Substrate is usually a membrane filter such as Teflon, polycarbonate nuclepore and cellulose acetate filters. These provide sample compatibility with INAA and ED-XRF. The operating flow rate of all aerosol samplers, however, depends on the filtration efficiency of the filter and so must be carefully chosen to avoid clogging of the filters as the particles accumulate (Dzubay and Stevens, 1975).

2.8.1 Multi-Stage Impactor Sampler

In this type of dust samplers multiple cascade impactors are incorporated when detailed size distribution of aerosol are in the basis of the requirement for the study. The cascade impactors are used for sampling air over a wide range of flow rates. When in operation, air is drawn into the impactor through an orifice and particles of appropriate diameter in the resulting jet are impacted onto a plate. Finer particles move with the resulting air stream until they are incident on the next impacting plate with smaller orifice diameter where the jet has a higher speed resulting in deposition on the plate at this stage. The process continues until there is deposition on the plate at the final stage. In this way, an efficient division into various size classes is achieved by arranging several plates in series. Some of the impactor designs have as many as 10 stages made up of 7 regular impaction stages, 2 low pressure stages and a back up filter (Bauman et al., 1981). Ibeanu (1993) used a six-stage cascade impactor for sampling air particulate in Kano and Ile-Ife.

Generally speaking, there are two groups of dust samplers. They are used in measuring horizontal and vertical dust fluxes respectively. Those used for measuring horizontal flux by sucking in air through orifice are called hybrid samplers. These types of samplers have been described by Hall et al.(1994), Shao *et al.* (1993), Nicling and Gillies (1993), Leys and Raupach (1991), and Janseen and Jetzlaff (1991). Vertical dust flux samplers have also been described by Littman (1997), Goossen and Offer (1993), Offer, et al. (1992) Pye (1992), and Orange *et al.* (1990). Vertical dust samplers are usually passive, i.e. the air is not actively sucked into the trap.

2.8.2 Filters Used in Sampling Technique

All the different filters used in sampling techniques can be divided into two groups. These are membrane filters and fibrous filters. Membrane filters are made up of thin layer of a polymer, e. g. cellulose, ester or Teflon. A particular type of these filters, known as Nuclepore filters is composed of thin polycarbonate sheets with fine capillary pores and uniform structure and pore size distribution (Spurny *et al.*, 1965). This type of filters are more suitable for XRF analysis since X – ray absorption of the incident radiation and the generated characteristic X – rays in the filter material do not need to be considered. However, membrane filters cannot withstand high flow rate thereby leading to prolonged sampling.

Fibrous filters are made up of fibres randomly arranged and bonded together to form a mat so that particles are collected as the air flows through the fibres. Fibrous filters include cellulose filters such as Whatman 41 filters, glass fibre filters and quartz fibre filters. Generally, they have high sample collection efficiency and low pressure drop but have to be conditioned to room temperature and humidity because of its hygroscopic nature (Okunade, 2000). Glass filters are rarely used because of their high blank value, which often invalidates the samples.

2.8.3 Efficiency of Air/Dust Sampler

The measurement of dust flux flow by wind remains one of the most problematic procedures in Aeolian Geomorphology (Nickling and McKenna, 1997). Many factors are responsible for the problem, including turbulent flow of wind at the atmospheric boundary layer and, consequently the trajectory of the submerged particles. Moreover, Goosens and Offer (2000) have observed that many calibrations published in the literature of samplers are unreliable because they are mostly based on incorrect experimental procedures. Therefore, they suggested using isokinetic sampler for comparison as the only way to make a calibration of a horizontal flux sampler accurate and reliable. The isokinetic sampler is an ideal type with the instantaneous wind speed through the sampling orifice being equal to the ambient wind speed along the flow streamline. However, Belyaev and Levn (2008) pointed out that sampling isokinetically does not guarantee 100% efficiency because there may be problems with particles rebounding on the suction tube close to the orifice and the risk of spontaneous deposition of particles in the suction tube itself.

With the recent advancement in Science and Technology, improved versions of air sampling equipment are made available. Most samplers manufactured nowadays have

mechanism installed for reading off their pumping rate instantly while in operation; and at the same time the rate could be adjusted to a desired proportion.

2.9 NAA Technique for Elemental Analysis

It used to be a common assumption that several days of ultraviolet light exposure would kill off any microbes travelling in dust clouds. However, it was reported that when Harmattan dust was screened in the middle of Atlantic Ocean, as many as one billion bacterial cells were found; and among the microbial life were *pseudomonas aeruginosa* and *kocuria* which cause ear infection and mouth lesion respectively (Bjourn, 2006). In the same vein, previous studies in Korea and Trinidad, following some dust storms in 2010, have also revealed that more citizens visited the emergency units in hospitals more frequently with cases of respiratory problems (Terry, 2009). These health related problems from accumulation of dust in the atmosphere make the use of instrumental neutron activation analysis (INAA) technique in this work imperative in order to investigate (among other investigations) the possible health-effects that elemental constituents of Harmattan dust might have on humans.

Much of the detailed studies of elementary particles are made today by the use of radiation from man – made machines called research reactors. By using accelerators, particles can be accelerated to very high energies. Then they are smashed into each other or into a target, and particle detectors are used to measure and record the properties of the particles produced. Thus atomic nuclei can be explored, thereby allowing nuclear identification of new elements from the scintillation peaks produced on the counter. This technique is referred to as activation analysis. When neutrons are used as the particles for the analysis, then the technique is known as neutron activation analysis (NAA). Neutron activation analysis can detect up to 74 elements (Appendix 4) depending upon the experimental procedure.

Neutron activation analysis (NAA) is a nuclear analytical technique based on the nuclear reactions that occur in the atomic nucleus due to irradiation with neutrons. A sample is exposed to neutrons, resulting in activation of many of the constituent elements. Specific radiations emitted by the activation products are detected to determine the amount of the elements present in the sample. If NAA is conducted directly on irradiated samples it is termed Instrumental Neutron Activation Analysis (INAA).

In some cases irradiated samples are subjected to chemical separation to remove interfering species or to concentrate the radioisotope of interest. This technique is known as Radiochemical Neutron Activation Analysis (RNAA). In the technique of Instrumental Neutron Activation Analysis (INAA), gamma ray emissions are detected. Gamma ray emissions are usually distinctive enough that elements may be determined without chemical separations or special sample preparation.

2.9.1 Particles Accelerators

The particles used in bombarding the target nucleus in the Neutron Activation Analysis technique are accelerated to attain very high energies by using accelerators. All types of particle accelerators have the same three basic components: a source of elementary

particles or ions, a tube pumped to a partial vacuum in which the particles can travel freely, and some means of speeding up the particles. The charged particles are accelerated by an electrostatic field or alternating voltage, as the case may be, to very high energies. Then they are smashed into a target, and particle detectors are used to measure and record the radioactive properties of the particles produced. Thus atomic nuclei can be explored, thereby allowing nuclear identification of new elements.

The linear accelerator, or **linac**, uses alternating voltages of high magnitude to push electrons or positrons along in a straight line. They pass through a line of hollow metal tubes enclosed in an evacuated cylinder. An alternating voltage is timed so that a particle is pushed forward each time it goes through a gap between two of the metal tubes.

The cyclotron used for accelerating protons or heavier particles is somewhat like a linear accelerator wrapped into a tight spiral shape. The machine has only two hollow vacuum chambers, called **dees**, shaped like capital letter *D*s, back to back and are placed in an evacuated box (the tank) which is situated between the cylindrical pole pieces of a large magnet. When a proton is emitted at the time the second electrode (D2) is negative with respect to the first (D1), the particle will be acted on by a force given as:

$$F = qv \times \vec{B} \dots \dots \dots 2.46$$

The particle is accelerated to the right then, in an approximately circular path of radius:

$$r = \frac{Mv}{qB} \dots \dots \dots 2.47$$

The time taken by an ion to describe a semicircle within the dee-shaped chamber is:

$$t = \frac{\pi M}{Bq} \dots \dots \dots 2.48$$

And the frequency of the radio-frequency voltage accelerating the particles is given by:

$$f = \frac{Bq}{2\pi M} \dots \dots \dots 2.49$$

The maximum energy of the particle is:

$$E = \frac{1}{2} M v_m^2 = \frac{B^2 q^2 R^2}{2M} = 2\pi^2 M f^2 R^2 \dots \dots \dots 2.50$$

However, this maximum energy is limited by the relativistic effects. As the speed of the particles (*v*) tends to get closer to the velocity of light (*c*) with $\beta = \frac{v}{c}$, then the mass,

$M = \frac{M_0}{\sqrt{1-\beta^2}}$ becomes infinitely large and the radius in equation (2.47) becomes large too.

Therefore, it becomes difficult to satisfy the resonance condition required by equation (2.49). A solution to this problem led to the emergence of another two types of accelerators, the synchrocyclotron (or phasotron) and the synchrotron.

In the synchrocyclotron, the oscillator (radio-frequency generator) that accelerates the particles around the **dees** is automatically adjusted to stay in step with the accelerated particles; as the particles gain mass, the frequency of accelerations is lowered slightly to keep in step with them. They travel in circular orbits in approximately uniform and steady magnetic field. The radius of the orbit increases with energy gain, and it can be calculated from the following relations in terms of the particle kinetic energy *T* and the magnetic induction field, \vec{B} :

$$r = \frac{p}{qB} \dots\dots\dots 2.51$$

and
$$r = \frac{\sqrt{T(T+2W_0)}}{qB c} \dots\dots\dots 2.52$$

where $W_0 = M_0c^2$

The largest synchrocyclotron is the 600-cm phasotron at the Dubna Joint Institute for Nuclear Research in Russia; it accelerates protons to more than 700 MeV and has magnets weighing 6984 metric tons.

The **synchrotron** is the most recent and most powerful member of the accelerator family. As in the synchrocyclotron, the frequency of rf oscillator in the synchrotron is matched with the revolution frequency of the electron (a condition for resonance), and this is achieved by changing the magnetic field with time. The changing magnetic field through the orbit of the electrons induces an electric field along the orbit, which accelerates electrons up to about 2 MeV. The electrons revolve within a ring-shaped accelerator tube of toroidal section (doughnut) made of glass or porcelain. There is a small gap in the plating between which the rf field acts. As the electrons cross the gap, they are accelerated by the radio – frequency (rf) field along the axis of the doughnut. The frequency of the rf field is equal to the frequency of revolution of the electrons in the orbit. As the electrons gain energy, their relativistic mass increases due to which they tend to move in orbits of larger radius. The increase of the magnetic field, however, maintains the orbit radius constant. This synchrotron principle has been applied for the acceleration of protons in the GeV region, therefore the synchrotrons are the most effective accelerators for obtaining the highest energy proton beams (Ghoshal, 2007)

2.9.2 Classification of Neutrons according to Energy

Classification of neutron according to their energy is found convenient for the study of their interaction with nuclei and matter in bulk as also in the design of neutron sources and detectors. The system of classification mostly employed is:

- (a) Slow neutrons: $(0 < E < 10^3 \text{ eV})$
- (b) Intermediate neutrons: $(10^3 \text{ eV} < E < 10^5 \text{ eV})$
- (c) Fast neutrons: $(0.5 \text{ MeV} < E < 10 \text{ MeV})$
- (d) Very fast neutrons: $(10 \text{ MeV} < E < 50 \text{ MeV})$
- (e) Ultra fast neutrons: $(E > 50 \text{ MeV})$

(a) **Slow Neutrons:** The slow neutrons can be categorized as follows:

(i) **Cold neutrons:** These have energies less than $\sim 0.002 \text{ eV}$. They show very high penetrability through crystalline and polycrystalline materials.

(ii) **Thermal neutrons:** When neutrons are passing through moderators, they mostly lose energy by elastic collision with the nuclei of the moderating atoms. The process goes on till the neutron energy is comparable to the energy of the thermal agitation of the moderating atoms. They then attain thermal equilibrium and do not lose any further energy on the average. They are known as thermal neutrons under this condition. The most probable velocity of neutrons under thermal equilibrium is given by:

$$v_m = \left(\frac{2kT}{M}\right)^{\frac{1}{2}} \dots\dots\dots 2.53$$

where T is the absolute temperature of the medium, k is Boltzmann constant and M is the neutron mass. The mean velocity of the thermal neutrons is:

$$\bar{v} = \frac{2v_m}{\sqrt{\pi}} \dots\dots\dots 2.54$$

These thermal neutrons have low absorption cross sections in many materials and can diffuse through them achieving thermal equilibrium with the atoms or molecules of the medium when their velocity distribution becomes Maxwellian in character. Accordingly the number of neutrons with velocity between v and (v + dv) per unit volume can be expressed as:

$$n_v dv = Av^2 \exp\left(-\frac{Mv^2}{2kT}\right) dv \dots\dots\dots 2.55$$

where A is a constant, k is Boltzmann constant and T is the absolute temperature of the medium. M is the neutron mass.

Upon irradiation, a thermal neutron interacts with the target nucleus via a non-elastic collision, causing neutron capture. This collision forms a compound nucleus which is in an excited state. The excitation energy within the compound nucleus is formed from the binding energy of the thermal neutron with the target nucleus. This excited state is unfavourable and the compound nucleus will almost instantaneously de-excite into a more stable configuration through the emission of a prompt particle and one or more characteristic prompt gamma photons. In most cases this more stable configuration yields a radioactive nucleus. The newly formed radioactive nucleus now decays by the emission of both particles and one or more characteristic delayed gamma photons. This decay process is at a much slower rate than the initial de-excitation and is dependent on unique half-life of the radioactive nucleus. These unique half-lives are dependent upon the particular radioactive species and can range from fractions of a second to several years. Thus, once irradiated, the sample is left for a specific decay period then placed into a detector, which will measure the nuclear decay according to either the emitted particles, or more commonly the emitted gamma rays.

(iii) **Epithermal neutrons:** When neutrons of higher energy enter a material medium, they ultimately achieve thermal equilibrium with the molecules in the medium. Before this happens, there is a preponderance of relatively higher energy slow neutrons than is permitted by the Maxwell distribution law. This results from partial moderation, and it usually happens at energy greater than ~ 0.5 eV. The neutrons involved are known as epithermal neutrons. They have K. E. in the range 0.5 eV to 0.5 MeV. Activation with epithermal neutrons is known as Epithermal NAA (ENAA).

(iv) **Resonance neutrons:** Slow neutrons in the energy range 1 to 100eV are known as resonance neutrons because of the large number of very sharp resonances produced in heavier nuclei by these neutrons.

(b) **Intermediate neutrons:** The neutrons in this range suffer elastic scattering. They are produced during the slowing down of the fast neutrons in a medium.

(c) **Fast neutrons:** High kinetic energy neutrons are sometimes used for activation analysis. These neutrons are immoderated and consist of primary fission neutrons. High KE or fast neutrons have a KE >0.5 MeV and close to 1 MeV. Thus, they can have a speed up to about 14,000 km/s. Activation with fast neutrons is termed Fast NAA (FNAA). Fast neutrons are named *fast* neutrons to distinguish them from lower-energy thermal neutrons, and high-energy neutrons produced in cosmic showers or accelerators. However, fast neutrons can be made into thermal neutrons via a process called moderation.

(d) **Very fast neutrons:** Nuclear reactions involving the emission of two or more particles become possible in this region. Examples of such reactions are: (n, 2n), (n, p) etc.

(e) **Ultra fast neutrons:** These neutrons are produced in (p, n) reactions by very high energy protons accelerated in ultra high accelerators. They are also available in the cosmic rays. These neutrons, however, have rather small probability of interacting with nuclei, resulting in the partial transparency of the nuclei.

2.9.3 Principles of Neutron Activation Analysis

Neutron activation analysis (NAA) is a nuclear analytical technique based on the nuclear reactions that occur in the atomic nucleus due to irradiation with neutrons. The radioactive products (usually gamma emitters) of these reactions are characterized through the radiation they emit, and quantified through different methods, allowing determination of the elements concentration in the sample. Depending on the neutron source and the energy distribution of the neutrons, different nuclear reactions may occur with the production of different radioactive isotopes. And in quantifying the radioactive products, different methods are used; the most common ones being the absolute method, the relative method, and the k_0 – standardization method.

2.10 Methods of quantifying radioactive product: The absolute (parametric) method

Another procedure known as the absolute (parametric) method was developed in the late 1950s from mathematical modeling approach for absolute standardization of the quantification of elemental concentration. Although this method which was based on nuclear data obtained from the literature, it was prone to systematic errors due to the uncertainties associated with some constants. So this “absolute” (parametric) method was not very useful because of its inherent limitations, which led to lower accuracy (Rossbach and Blaaw, 2006; Kolotov and De Corte, 2004).

2.10.1 The Relative Method

In the relative method of instrumental neutron activation analysis (INAA), both the samples and the standards are irradiated together in the whole reactor neutron spectrum under the same irradiation conditions. The standard(s) can either be pure element or a compound of known stoichiometry. They can be used separately or as a mixture. If available standard reference materials (SRMs) can also be used. SRMs are synthetic standard prepared from pure substances. A number of these SRMs are available from the National Bureau of Standards, Washington DC, USA and International Atomic Energy Agency, Vienna, Austria. A comparison of peak areas from unknown samples and a standard reference material allows the determination of the concentrations in the samples. After irradiation of samples and standards, both samples and standard materials are measured exactly under the same counting conditions on the same high purity germanium (HPGe) detector system. The use of the relative method in NAA (INAA) helps to eliminate uncertainties in nuclear parameters such as resonance integrals, epithermal neutron flux, detector efficiency and decay constants.

For the relative method of NAA (INAA), the concentrations of the unknown elements in the samples irradiated in the whole reactor neutron spectrum for cadmium channel is given by Kucera et al., (2000) and IAEA (1990) as:

$$C_{s(cd)} = \left[\frac{w}{W} \right] = \left[\frac{N_s W_{st} D_{st}}{N_s D W} \right] \dots\dots\dots 2.56$$

Where w = unknown weight of element of interest in sample

W = weight of sample irradiated

- w_{st} = weight of element in the SRM
- N_s = Net photopeak area of radionuclide of interest in sample
- N_{st} = Net photopeak area of radionuclide of interest in standard
- D = decay factor for elements in the sample
- D_{st} = decay factor for element in the SRM

In the relative method used in NAA (INAA), the elemental composition of the matrices of the SRM used should be similar to those of the actual samples analysed

2.10.2 The k_0 -Method

The k_0 -method is a parametric method that is based on the use of a nuclear compound constant k_0 , the ratio of thermal to epithermal neutron fluxes. An element is also used as a comparator and a standard. The measurement of gamma ray spectra is performed using high resolution Ge hyper pure detectors. When the signal leaves the detector, it is amplified and the pulses are sent to high speed analog digital converter (ADC). This digital information goes to a multichannel pulse height analyzer module where the spectrum is collected. Different softwares are used for data acquisition, and concentration calculations are made based on these data (Alfassi, 1990b; De Corte, 1987; IAEA, 1990).

2.10.3 The Single-Comparator Method: k_0 - Standardization

An alternative single comparator method, which combines the flexibility of the “absolute” method with the accuracy of the relative standardization method without the tedious preparation of synthetic standards from pure substances, was developed after 1974 in Budapest of Ghent. The method, termed k_0 -standardization, uses only one element as comparator and standard.

The k_0 -standardization method was intended to be an absolute technique where the uncertain nuclear data are replaced by compound nuclear constant – the k_0 -factors, which are experimentally determined with high accuracy. Basically, this determination is done as for k-factors, which are then transformed into k_0 's by lifting out the experimental parameters. k_0 -factors are thus generally applicable on condition that activation analyst recombines them with the parameters of the local irradiation and counting conditions, in this way generating ‘his’ k_0 -factors. From this point of view, the k_0 -method is a flexible single-comparator technique (De Corte, 1987).

The reaction rate R, specific activity of the elements of interest A_{sp} after irradiation with the thermal neutron flux and the weight of the element w to be determined are given by:

$$R = \sigma_{th} \Phi_{th} \dots \dots \dots 2.57$$

where σ_{th} = thermal (n, γ) cross – section, Φ_{th} = thermal neutron flux,

$$A_{sp} = \frac{N_A \cdot \theta}{M} \sigma_{th} \cdot \gamma \cdot \epsilon_p \dots \dots \dots 2.58$$

And

$$W = \frac{N_p}{S.D.C.t_m.A_{sp}} \dots\dots\dots 2.59$$

$$\therefore W = \frac{N_p}{t_m} \cdot \frac{M}{N_A \cdot \theta \cdot \sigma_{th} \cdot \gamma \cdot \epsilon_p \cdot S \cdot D \cdot C} \dots\dots\dots 2.60$$

where N_A =Avogadro's number, N_p = net peak area of the measured gamma-line (corrected for pulse losses), M = atomic mass, θ = the isotropic abundance, σ_{th} = the thermal (n, γ) cross-section, γ = the yield of the analytical gamma-line, ϵ_p = full energy peak detection efficiency for measuring E_γ , $S = 1 - \exp(-\lambda t_{irr})$ with t_{irr} = irradiation time, $D = \exp(-\lambda t_d)$ with t_d = decay time, λ = decay constant, $C = [1 - \exp(-\lambda t_m)]/\lambda t_m$ with t_m = measurement time.

By irradiating a nuclide in a neutron flux where both thermal and epithermal neutron fluxes are present. The reaction rate changes to:

$$R = R_{th} + R_{epi} = \Phi_{th} \sigma_{th} + \Phi_{epi} I_0 \dots\dots\dots 2.61$$

And the weight of the element to be determined w becomes:

$$\therefore W = \frac{N_p}{t_m} \cdot \frac{M}{N_A \cdot \theta \cdot (\sigma_{th} \Phi_{th} + I_0 \Phi_{epi}) \cdot \gamma \cdot \epsilon_p \cdot S \cdot D \cdot C} \dots\dots\dots 2.62$$

Φ_{epi} = epithermal neutron flux.

The adoption of k_0 -standardization method for routine analysis has several advantages including, elimination of problems of non-availability of suitable standards for certain elements as well as the removal of the inaccuracy caused by poorly prepared standards, (Jonah et al., 2005). Perhaps the greatest advantage of k_0 method is the flexibility it allows. The k_0 -factors are reactor- and detector-independent, and the same values are accepted and used by a growing number of NAA users all over the world. Secondly, it gives more accurate results than the absolute method since the unnecessary build-up of uncertainties in the underlying physical constants is avoided.

2.10.4 The Principle of k_0 -Standardization Method

The essence of a comparator method consists in co-irradiation of the analyzed samples with a suitable element of known mass (comparator), and combining this with the result of gamma-ray spectrometry. Various pre-calibration and nuclear data enable one to compute the concentration of any element via the comparator. The nuclear data for the comparator must be known with high accuracy. Usually gold, zirconium, or other suitable elements can be chosen.

The k_0 -factor of an analyte isotope/gamma-line relative to the gold comparator is defined by the ratio:

$$(k_0, Au)_a = \frac{M_{Au} \theta_a \sigma_{0,a} \gamma_a}{M_a \theta_{Au} \sigma_{0,a} \gamma_{Au}} \dots\dots\dots 2.63$$

where M_x , θ_x , σ_x , γ_x are the atomic mass, the isotropic abundance, the thermal (n, γ) cross-section, and the yield of the analytical gamma-line.

The formula for computing the analyte mass fraction c_a is:

$$C_a = \frac{\left(\frac{N_p/t_m}{SCDW}\right)_a}{\left(\frac{N_p/t_m}{SDCW}\right)_{Au}} \times \frac{1}{(k_{0,Au})_a} \times \frac{\epsilon_{p,Au}}{\epsilon_{p,a}} \times \frac{f_i + Q_{0,Au}(a)}{f_i + Q_{0,a}(a)} \dots\dots\dots 2.64$$

where the first term describes the result of the gamma-ray spectrometry measurements of the analytical radionuclide and the comparator, the second term is the corresponding k_0 factor, the third term is related to the full energy peak efficiency calibration of the detector, and the last term accounts for the contribution of the epithermal activation.

The list of the symbols is as follows:

N_p = net peak area of the measured gamma-line (corrected for pulse losses)

t_m = measuring time

$S = 1 - \exp(-\lambda t_{irr})$, with t_{irr} = irradiation time

$D = \exp(-\lambda t_d)$, with t_d = decay time

$C = [1 - \exp(-\lambda t_m)]/\lambda t_m$, with t_m = measurement time

W = mass of irradiated sample/ comparator

λ = decay constant

$\varepsilon_{p,x}$ = full energy peak detection efficiency for measuring E_γ

$Q_0 = I_0/\sigma_0$, with $\sigma_0(n, \gamma)$ cross-section for thermal neutrons (velocity at 2200 ms^{-1}) and

I_0 = resonance integral

α = measure of the nonideal epithermal neutron flux distribution, approximated by a $1/E^{1+a}$ behavior

The scripts “a” and “Au” refer to analyte and gold comparator respectively (Kolotov and De Corte, 2004).

The rate of production of radioactive atoms from stable atoms of interest is related to the activation rate of gold through the k_0 -constant. Generally the relative rate of production depends on the specific irradiation facilities and gamma-ray detectors used. The k_0 -constant in the 2nd term of the equation (6) represents the part of that rate that is independent of irradiation facility and detector, and plays an important part in the computation of concentration in k_0 -INAA. The other parts of this rate are the irradiation facility and detector dependent components represented by the 4th and the 3rd terms of equation (6) respectively. So knowing the k_0 -constants, each sample need to be co-irradiated with a gold comparator only, rather than with as many comparators(or standards) as there are elements to be determined in the sample. Sample and gold comparator may have different shapes, neutron and gamma characteristics. Correction procedures for these differences are parts of the k_0 -method. The k_0 -constants were therefore measured directly experimentally with high accuracy for more than 130 isotopes relative to a gold comparator and compiled into an electronic database along with other relevant nuclear data in some specialized institutes (Colotov and De Corte, 2004; k_0 -IAEA software user manual, 2005).

Nuclear research reactor, because of its high fluxes of neutrons which give the most intensive irradiations and hence produce the highest available sensitivities for nuclear investigations, is among the most suitable equipments used for activation analysis technique. Therefore, Nigeria Research Reactor-1 (NIRR-1) was used in this work, with the aim of determining the elemental constituents of the sample collected – the Harmattan dust transported to Kano State, Nigeria.

CHAPTER THREE (Methodology)

3.1 Introduction

The sampling technique used in any process of air pollution assessment allows for free choice of inlet size, and free choice of orientation of the sampling instrument – either vertical or horizontal orientation, depending on the prevailing circumstances. For instance when grit is entrained in the air flow, it is better to sample from a vertical portion of the duct as the distribution is likely to be more homogeneous than in the horizontal run. Again in the assessment of the average penetration of small particles through a high – efficiency filter, sampling may as well be carried out in a horizontal duct, though it is necessary to install a mixing device within the sampler. The mixer regulates the passage of particles in stream lines down to the filter, preventing any possible sealing leaks. Therefore, the sampling equipment used in this study was operated in a horizontal orientation since it has a provision of an in-built mixer that regulates the passage of particles directly down to the filter. The filter used is the Whattman fibrous filter which has 90% porosity and an average fibre diameter of 17µm.

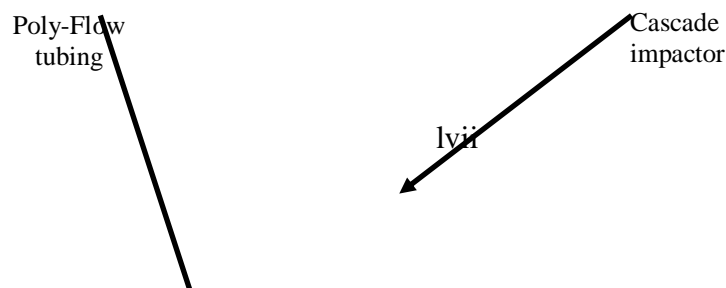
3.2 Efficiency of Air Sampler

When detailed size distributions of aerosol are in the basis of the requirement for a study, multi-stage cascade impactors are incorporated in the dust/air samplers. This allows air to be sampled over a wide range of flow rates during the exercise. However, single jet cascade impactors are also in use for air sampling studies in which size distributions of particulates are not in the basic requirements. The sampling equipment used (Plate 3.1) in this study was the F&J Specialty Products Inc., Model No.: LV-1E; Serial No.: 00695. It has a provision for a constant air-flow regulator, air-flow-meter, muffler jar and a vacuum pump connected to a single stage cascade impactor, consisting of a cylindrical housing which was coupled to a stacked filter unit (STU) that holds the filter in place. Elemental constituents of the dust samples, not size distributions, forms the most important part of the basic requirements in this analysis; thus justifying the incorporation of a single-stage cascade impactor for the sampling exercise.

When determining the efficiency of the air sampler used, the following relation was applied:

$$Efficiency = \frac{Vol. of air collected in a given time with filter installed}{Vol. of air collected in the same time without the filter} \times 100\% \dots \dots \dots (3.1)$$

Then the sampler was set for trial at a flow rate of $75.0 \times 10^{-3} \text{ m}^3 \text{ min}^{-1}$ and operated for 15 minutes with the pumping rate remaining constant.



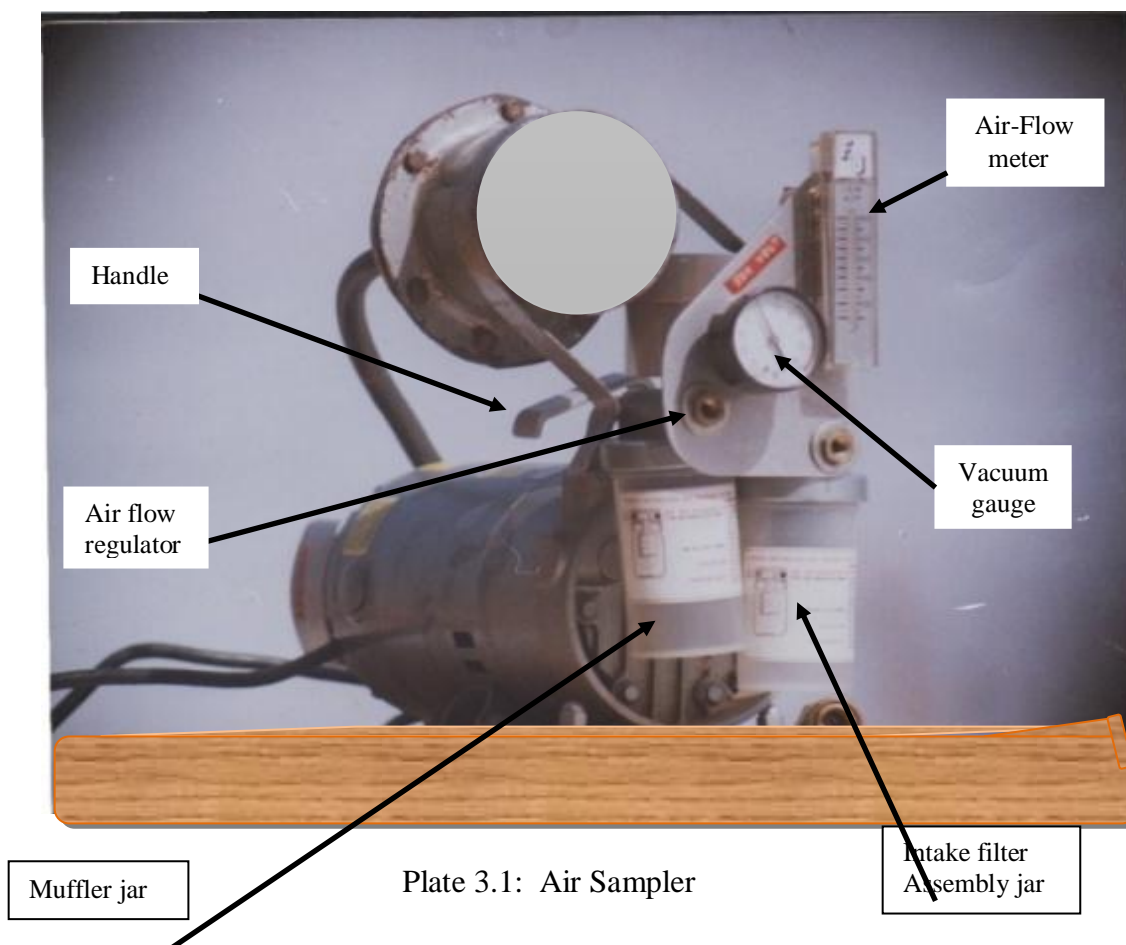


Plate 3.1: Air Sampler

The air sampler was stopped, and the fibrous Whatman-41 filter was loaded. When the machine was operated again, the flow rate was observed to fall from 75.0×10^{-3} to $52.5 \times 10^{-3} \text{ m}^3 \text{ min}^{-1}$. However, the machine was allowed to operate for another 15 minutes and this new pumping rate remained constant. Therefore, for the purpose of calibration of the equipment, the whole process was repeated for the predetermined pumping rates in the range 45.0 to $90.0 \text{ m}^3 \text{ min}^{-1}$. The corresponding fall in the flow rate, in each case, was also recorded whenever the Wattman-41 filter was loaded and the air sampler operated. Then equation (3.1) was used to evaluate the efficiency.

3.3 Zones constituted for sample collection

The dust sampling in this work was conducted in Kano State, Nigeria in 2009, from January to February. The period is characterized with much more intense Harmattan dust when compared to the early and late dates of the season, November, 2008 and March, 2009 respectively (Adetunji, 1979). When collecting the Harmattan dust, the State was divided into five zones for the exercise, with four zones in the northern, southern, eastern and western respective directions of the State Capital, Kano. Some parts of Kano Metropolis herewith referred to as “the City,” constituted the fifth zone (see Table3.1).

Therefore, in each of the first four zones mentioned, four local government areas were sampled as the sites for collecting the dust. And in the City of Kano, B. U. K. Road, Katsina Road, Zaria Road, and Bata (S/Gari) located in Gwale L. G. A., Ungogo L. G. A., Tarauni L. G. A., and Fage L. G. A. respectively were selected being the busiest areas in the State; where locally generated dust from vehicular movement might be more. Before the commencement of dust sampling in each location, a prior survey was conducted for a more convenient venue for the exercise; and a stand for supporting the sampling equipment at respective altitudes of 2.0 m and 5.0 m was erected. These positions were chosen because, in the first case, humans have direct contact with particulate matter in the air at 2.0 m above ground level. And, secondly, the height of 5.0 m above ground level is a standard for taking measurements in Meteorology (Putnam, 1948).

When collecting the Harmattan dust, the air sampler, positioned in horizontal orientation, was placed at 5.0 m and then 2.0 m above ground level in each location so as to see the effect of altitude (if any) on the dust collected. And in order to commence sample collection of the Sahara dust at the sites at the stipulated time, the places were visited as early as 6:00AM. In some instances the towns, where the sites for dust sampling were relocated, had to be visited a day before the date set for the dust sampling. Three sessions were, therefore, conducted at each site – in the morning, afternoon and evening. Each dust sampling exercise lasted for one hour. In the morning session, the dust was collected from 7:00AM to 8:00AM at the altitude of 5m, while from 9:00AM to 10:00AM it was collected at 2m. During the afternoon session, the dust was collected from 12:00 Noon to 1:00PM at the altitude of 5.0 m; and from 2:00PM to 3:00PM, it was collected at 2.0 m. From 4:00PM to 5:00PM, the dust was collected at the altitude of 5.0 m, while from 6:00PM to 7:00PM it was collected at 2.0 m. The measurements at 2.0 m and 5.0 m had to be done alternately because only one sampling-equipment was available for this work.

Table 3.1: Zones visited in Kano State for dust sampling

ZONES		LOCAL GOVERNMENT AREAS VISITED			
1.	North (N)	N1 Bichi	N2 Tsanyawa	N3 Dawakin Tofa	N4 Dambatta
2.	South (S)	S1 Dawakin Kudu	S2 Rano	S3 Bebeji	S4 Kura
3.	East (E)	E1 Wudil	E2 Gaya	E3 Albasu	E4 Warawa
4.	West (W)	W1 Gwarzo	W2 Tofa	W3 Bagwai	W4 Shanono
5.	City (C)	C1 B. U. K. Road (Gwale LGA)	C2 Katsina Road (Ungogo LGA)	C3 Zaria Road (Tarauni LGA)	C4 Bata (S/Gari) (Fage LGA)

*LGA: Local Government Area

The loading and unloading of the stacked filter cassette was done with care to avoid any source of contamination to the surface of the filter. Hence, a stainless steel of pair of tweezers was used for that purpose. Hand gloves were also used to avoid contamination. When unloaded, the filters were placed in labelled polythene containers and stored in a secured place. At the end of the exercise, they were carried to the laboratory for weighing using the Mettler balance AE240.

All observations for each sample were properly recorded in a logbook, and these included:

1. name of sampling location
2. sampling date
3. rotameter flow – rate at the beginning and ending of the sampling period
4. time at the beginning and ending of the sampling
5. any unusual event such as power failure from the national grid.

Another important preparatory measure taken for the dust sampling campaign was that of choosing the pumping rate of the sampler to be maintained during the exercise. The sampler was, therefore, set at a predetermined value of $90 \times 10^{-3} \text{ m}^3 \text{ min}^{-1}$ without the Whattman-41 fibrous filter put in place, and it was operated for 15.0 minutes, with the pumping rate remaining constant. Then the machine was stopped and the filter was installed. When operated again, the pumping rate dropped to $63 \times 10^{-3} \text{ m}^3 \text{ min}^{-1}$. This lasted for another 15 minutes without observing any change in the rate. Therefore, at this pumping rate the machine would be pumping 3,780 litres of air in one hour, the total time of dust flux collection used for each session of dust sampling. In a volume of 3,780 litres of air sucked into the cascade impactor, it was expected that sufficient Harmattan dust would be collected for the analytical investigations intended. Moreover, the sampling time chosen was such that with the rate of air flow remaining constant, there would be no filter overloading which may lead to the clogging of fibres of the filter. The rotameter was therefore continuously checked and the air – flow regulator adjusted (if necessary) to ensure that the flow rate remained constant throughout the sampling period.

3.4 Determination of Harmattan dust gravimetric concentration

When determining the mass of the dust sample collected at each sampling location, the average mass of the filter was first found by weighing thirty pieces of filters three times for accuracy; and it was determined as $1.03602 \pm 0.02\% \text{ g}$. This average value of the mass of the filter was subtracted from the mass of filter plus dust already measured.

Gravimetric concentration is defined as the mass of particulates per unit volume of air processed during the sampling exercise. Therefore, the mass of the Harmattan dust collected in each zone at 2.0 m and then 5.0 m above the ground level was divided by the total volume of air collected in one hour. The mean values of these results, represents the dust gravimetric concentration for each zone. Then the mean value for the whole State was determined by finding the average value of these results.

3.5 Absorbance of the Atmosphere

As presented by Cadle (1975), the Lambert – Beer law usually applied for the amount of light scattered by very small non – absorbing particles in the atmosphere is of the form:

$$\frac{I}{I_o} = \exp \left[- \frac{128\pi^5 r^6 (m^2 - 1)^2}{3\lambda^6 (m^2 + 1)} \cdot N\ell \right] \dots \dots \dots 3.5$$

where m is the mass of the particle, r is its radius; N is number concentration of mono-dispersal particle, and l is the characteristic length of the aerosol. The law relates the incident (I_o) and transmitted (I) intensities of beam of light passing through an aerosol to the length (l) of the aerosol as in equation (2.3). Absorbance has been defined as $\log \frac{I_o}{I}$.

Mamunu (2008) and, Sambo and Aliyu (1998) have presented monthly transmittance for atmospheric aerosol in Kano and Sokoto States, Nigeria respectively (Tables 3.2 and 3.3).

Therefore the ratios, $\frac{I_0}{I}$, were determined for the months of November, 2008 – March 2009, the period Harmattan dust prevails in these areas. The absorbance was determined from the relation $\log \frac{I_0}{I}$.

Table 3.2: Transmittance of the atmosphere in Kano State

	Transmittance (I/I_o) of the Atmosphere in Kano State (± 0.06%)											
Months	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
(I/I_o)	0.674	0.673	0.660	0.641	0.721	0.732	0.672	0.705	0.657	0.631	0.688	0.677

Source: Mamunu (2008)

(I_o) is the incident and (I) the transmitted intensities of beam of sunlight passing through the atmosphere

Table 3.3: Transmittance of the atmosphere in Sokoto State

	Transmittance (I/I_o) of the Atmosphere in Kano State (± 0.06%)											
Months	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
(I/I_o)	0.617	0.615	0.617	0.641	0.624	0.606	0.538	0.538	0.584	0.682	0.632	0.620

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Source: Sambo and Aliyu (1998)

(I_0) is the incident and (I) the transmitted intensities of beam of sunlight passing through the atmosphere

3.6 Turbidity of the Atmosphere in Kano State

The product $k\ell$ in the equation (2.3) has been defined as turbidity (Cadle, 1975).

By writing the equation in the following form, with turbidity $k\ell = \tau$:

$$I = I_0 \exp(-\tau) \dots \dots \dots (3.8)$$

then,
$$\frac{I_0}{I} = e^\tau \dots \dots \dots (3.9)$$

And the following relation was used in determining turbidity then:

$$\tau = \frac{\text{Log}\left(\frac{I_0}{I}\right)}{0.4343} \dots \dots \dots (3.10)$$

This derived equation, together with the data computed for absorbance (expressed as $\text{Log}\left(\frac{I_0}{I}\right)$), was used for determining turbidity in Kano; and also in Sokoto State, Nigeria, for comparison.

3.7 Air Density during Harmattan period

In measuring air density, the parameters recorded and applied in a formula include pressure, temperature, relative humidity and the atmospheric composition. And most standard laboratories have their own formulae, often significantly different from others. However, in this work, Giacomo's formula (1982) as expressed in (equation 2.4), was used for determining air density in Kano during Harmattan period.

3.8 Wind Speed during Harmattan season in Kano

The data on wind speed for Kano State, collected from NIMET Abuja, was recorded in knot at 3-hourly interval from 0 – 21 hours on Beaufort force scale, and it covered only 1998/1999 – 2002/2003 period. The Beaufort force scale is an international scale of wind speeds indicated by numbers ranging from 0 for calm to 8 or more, for hurricane. Table 3.4 is a typical format used by NIMET for recording observations on wind speed (in knot) in Kano State during the month of January, 2003. For the purpose of this work, the speed ranges have been converted to ms^{-1} using the conversion factor: $1\text{knot} = 0.514\text{ms}^{-1}$.

All the numbers recorded under the ranges of wind speed (see Table 3.4) represent the number of observations made for each range of wind speed. Then the total number of

observations made for a range of wind speed (e. g. 5.70 – 10.80) ms^{-1} in the time-interval of (0-3hours) is found as 4 + 3 = 7. The period of hurricane with the range of speed (17.50ms^{-1} or more) and the calm period were excluded from the computation because hurricanes, as specified on Beaufort force scale, were never observed in Kano State. And the calm period signifies the period of stillness for wind motion.

Therefore, when determining the mean wind speed in Kano, during Harmattan period, the mid-value for each range of the wind speed considered (e. g. 11.30 – 17.00; 5.70 – 10.80; or 0.51 – 5.10 ms^{-1} as in Table 3.5) at any specified time-interval was multiplied by the corresponding number of observations made under the respective range of wind speed. Then the results obtained for all the ranges of the wind speeds considered were added up and finally divided by the sum of the observations made within the specified time-interval. This yielded the mean wind speed during that particular time-interval as demonstrated in (Table 3.5) for January, 2003 wind speed observations. The same method was applied in computing the mean wind speed for the Harmattan period of 1998/1999 – 2002/2003.

Table 3.4: Mean observations made for ranges of wind speed in Kano State in January, 2003

BEAUFORT FORCE					
	8 or more	6 - 7	4 - 5	1 - 3	Calm
Hour	Wind Speed in knot/(ms^{-1})				
	34knot or more (17.50)m/s or more	(22 – 33) knot (11.30-17.00) m/s	(11 – 21) knot (5.70-10.80) m/s	(1 – 10) knot (0.51-5.10) m/s	0
0	0	0	4	12	15
3	0	0	3	21	7
6	0	1	1	21	3
9	0	0	21	10	0
12	0	3	17	11	0
15	0	2	14	3	2
18	0	0	3	25	3
21	0	0	1	14	16
Total	0	6	69	22	51

Source: Nigeria Metrology, NIMET, Abuja

Table 3.5: Method for computing wind speed in January, 2003

<i>January, 2003: At 0 – 3hrs</i>			
Range of Speed	Mid-Value(ms⁻¹)	No. of Observ.	Mid-value x No. of Observ.
11.30 – 17.00 (ms⁻¹)	14.15	0	0
5.70 – 10.80 (ms⁻¹)	8.25	7	57.75
0.51 – 5.10 (ms⁻¹)	2.80	33	92.40
Total		40	150.15
Mean wind speed = $150.15 \div 40 = 3.75\text{ms}^{-1}$			
<i>January, 2003: At 3 – 6hrs</i>			
11.30 – 17.00 (ms⁻¹)	14.15	1	14.15
5.70 – 10.80 (ms⁻¹)	8.25	4	33.00
0.51 – 5.10 (ms⁻¹)	2.80	22	61.6
Total		27	108.75
Mean wind speed = $108.75 \div 27 = 4.03\text{ms}^{-1}$			
<i>January, 2003: At 6 – 9hrs</i>			
11.30 – 17.00 (ms⁻¹)	14.15	1	14.15
5.70 – 10.80 (ms⁻¹)	8.25	22	181.50
0.51 – 5.10 (ms⁻¹)	2.80	31	86.80
Total		54	282.80
Mean wind speed = $282.80 \div 54 = 5.24\text{ms}^{-1}$			
<i>January, 2003: At 9 – 12hrs</i>			
11.30 – 17.00 (ms⁻¹)	14.15	3	42.45
5.70 – 10.80 (ms⁻¹)	8.25	38	313.50
0.51 – 5.10 (ms⁻¹)	2.80	21	58.8
Total	62	414.75	
Mean wind speed = $414.65 \div 62 = 6.69\text{ms}^{-1}$			
<i>January, 2003: At 12 – 15hrs</i>			
11.30 – 17.00 (ms⁻¹)	14.15	5	72.5
5.70 – 10.80 (ms⁻¹)	8.25	31	255.75
0.51 – 5.10 (ms⁻¹)	2.80	14	39.20
Total	50	367.45	
Mean wind speed = $367.45 \div 50 = 7.35\text{ms}^{-1}$			

Table 3.5: Computation of wind speed for the time ranges 0-3hrs to 18-21hrs in the month of January, 2003 (**Contd.**).

Range of Speed	Mid-Value(ms^{-1})	No. of Observ.	Mid-value x No. of Observ.
January, 2003: At 15 – 18hrs			
11.30 – 17.00 (ms^{-1})	14.15	2	29.00
5.70 – 10.80 (ms^{-1})	8.25	17	33.00
0.51 – 5.10 (ms^{-1})	2.80	28	78.40
Total		47	162.40
Mean wind speed = $162.40 \div 47 = 3.46\text{ms}^{-1}$			
January, 2003: At 18 – 21hrs			
11.30 – 17.00 (ms^{-1})	14.15	0	0.00
5.70 – 10.80 (ms^{-1})	8.25	4	33.00
0.51 – 5.10 (ms^{-1})	2.80	39	109.20
Total		43	142.20
Mean wind speed = $142.20 \div 43 = 3.31 \text{ms}^{-1}$			

- ❖ The mean wind speed in January, 2003 during Harmattan period was estimated as 4.83ms^{-1}

3.9 Viscous nature of Harmattan wind

Viscosity is an important aspect in air flow at the lowest layer of the atmosphere, the troposphere. It has the value of $1.82 \times 10^{-5} \text{Nsm}^{-2}$ on a clear day and at 15.0°C (Dorman, 2003). It is because of the existence of viscosity in a fluid that a shear flow is always established in the space between any two parallel plates, wherever one of the plates moves at constant speed while the other remains fixed. Many fluid plates exert a shear force on the moving plate. And the force (τ) varies directly as the plate velocity (U_o) and inversely as the separation distance, h (see equation 2.12). Therefore, the formula used in determining atmospheric viscosity during Harmattan period at any temperature, T ($^{\circ}\text{C}$), was equation (2.11) as given by Pruppacher and Klett (1980).

Another important parameter in air flow is kinematic viscosity, which is both a function of atmospheric pressure and temperature. Equation (2.14) which relates air viscosity and density to the parameter was, therefore, used for computation of the parameter during Harmattan period for 1998/1999 – 2002/2003 seasons.

3.9.1 Determination of Reynolds Number

The Reynolds number, Re , was used for determining the turbulent nature of Harmattan wind in this work. For wind flow to be turbulent, the value of Re has to be greater than 6000, otherwise it would result in laminar motion. Therefore, in this work the air density, ρ and absolute viscosity, μ , determined during Harmattan period for Kano State, as well as the kinematic viscosity, ν , were applied in equation (30) to determine the Reynolds number during the period. And the characteristic length used, L , for computing the number was

taken to be a horizontal distance of (0.1m) in the direction of air-flow as typified in the work of Cadle (1975). The wind velocities determined for the Harmattan seasons under review in the State, were also used in the equation.

3.9.2 The Effect of Coriolis force

Once air is forced to move by the pressure gradient force, it is immediately affected by the Coriolis or deflective force due to the earth rotation. For a given velocity, the effect of the force is highest at the poles and decreases with the sine of the latitude, becoming zero at the equator. Therefore, the Coriolis force per unit mass was determined by application of equation (2.6).

3.9.3 Wind power density during Harmattan period

The speed of wind during Harmattan period may not necessarily be as high as that during, say, the rainy season; but with the high value of consistent mean air density, the period has been observed to be generating high wind power, which could be positively utilized for development purposes: for instance upgrading regional electrical power supply.

Therefore, using the wind speeds and air density estimated for the period under study, equation (2.45) as given by Golding (1955) was used to determine wind power density in Kano State, Nigeria.

3.10 Sample Preparation for INAA Technique

The Nigeria Research Reactor-1 (NIRR-1) was used for Neutron Activation Analysis (NAA) of the dust samples collected for this work. The reactor is a Miniature Neutron Source Reactor (MNSR) with a tank-in-pool structural configuration and a nominal thermal power rating of 31 kW. It has highly enriched uranium as fuel, light water as moderator and beryllium as reflector. For full-energy efficiency curves of the gamma ray spectrometry system at different source – detector geometries, Jonah *et al.* (2005) have put in great efforts in the characterization of the neutron flux parameters in the irradiation channels of the reactor as well as in the calibration of the detector. These efforts were geared, with much success, towards optimization of the utilization of the reactor. The efficiency curves of the detector system determined in the energy range of 59.5-225.4 keV were further extended to 4000 keV by semi-empirical method (Jonah and Sadiq, 2006).

Instrumental Neutron Activation Analysis (INAA) is chosen for elemental analysis in this study because it has several important advantages over other techniques. Some of these advantages include:

1. It uses intensity of gamma rays of 'characteristic' energy, a chemical fingerprint to determine elemental concentration in samples.
2. It is suitable for precise and simultaneous multi-elemental analysis in diverse matrices,
3. There is flexibility in sample size which can be variable (typical 1mg to 1g).
4. It is nondestructive – that is valuable samples are not destroyed.
5. No chemical processing required: therefore samples are not contaminated during sample preparation.
6. The gamma ray used in spectroscopy is largely free from matrix interferences.
7. It is a sensitive and accurate tool for element analysis. Depending on the sample matrix, element concentrations can be determined at parts per million (ppm) and parts per billion (ppb) levels.
8. It is versatile – having been in use for more than half a century, it is well established and reliable.

Also the Relative-based NAA method of quantification of the radioactive products was adopted for this study for the following reasons:

1. It reduces dependence on multi-elemental standard.
2. Certified Reference Materials (CRM's) are provided by IAEA to remove the restrictions of their unavailability.
3. The Relative-based standardization INAA method does not require a prior knowledge of elements present in the sample.

Therefore, all the 36 samples of the Harmattan dust collected from the 20 sites visited for dust sampling exercise in Kano State, Nigeria were prepared and analyzed using the Instrumental Neutron Activation Analysis technique. Out of the 36 samples, 18 were collected at 2.0 m above the ground level, while the remaining 18 were collected at the altitude of 5.0 m. The filters carrying the dust samples were carefully weighed with gloves on hands to avoid contamination. Each filter was relatively molded into uniform volume, placed in a plastic wrapper and sealed; and then they were put in polyethylene vials (Plate 3.2) before placing them in the reactor core for irradiation. Certified reference material, coal fly ash, was used for determining the calibration factors for the constituent elements of the Harmattan dust samples prepared.

The sample data was recorded in the log sheet after sample preparation before irradiation and subsequently updated during irradiation, measurements and analysis. The record sheet contains data such as sample ID, weight of the sample, sample type, irradiation and counting dates and times detector geometries used, reactor pre-set neutron flux, irradiation channels used as well as the acquired spectrum filename and the name of the analyst (see appendix 6).

Then many input parameters were used in the available software for the identification of the respective elemental concentration in the samples. And these included neutron spectrum parameters, detector efficiencies, nuclear data, time parameters (irradiation, decay, counting times), sample-specification data (mass, matrix type), and spectrum-specific data (peak energies and net peak areas, dead time).

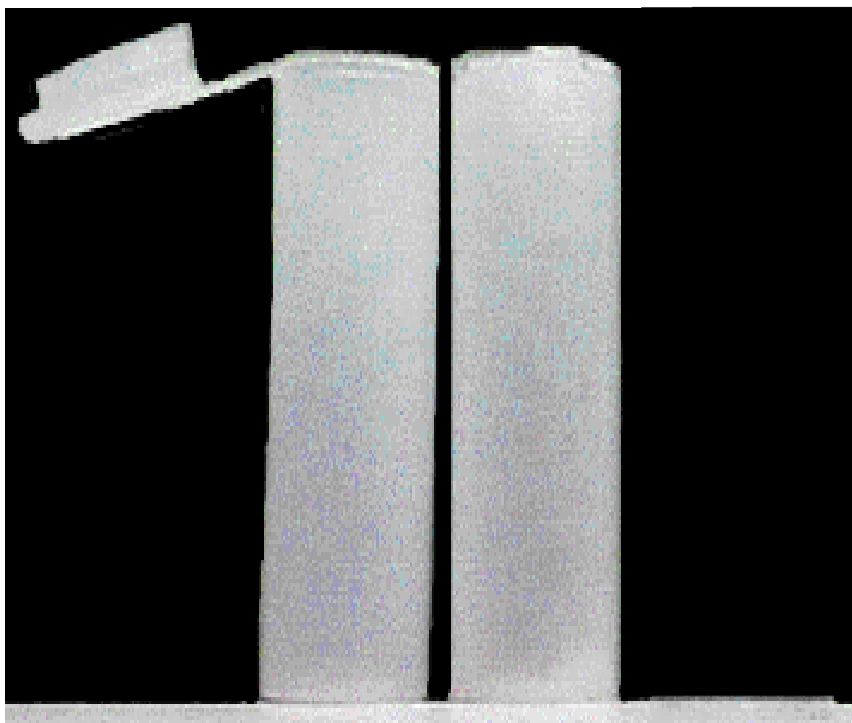


Plate 3.2: Polyethylene vials.

3.10.1 Irradiation of Harmattan dust Samples

Both the short – and long – lived irradiation schemes were applied in determining the elemental constituents of the Harmattan dust sample for this work. Therefore, 5 samples from each of the two groups of the 18 samples, making 10 samples, were selected for the long – lived irradiation analysis. The remaining 26 samples were analysed by short – lived irradiation method. Along with appropriate standards (coal fly ash) and blanks, the samples were sent near the core of the research reactor using pneumatic transfer system, and irradiated. Thus while each sample was in the reactor, it was exposed to a high neutron flux setting of $1 \times 10^{11} \text{ n.cm}^{-2}.\text{s}^{-1}$ for 10.0 minutes. The samples were pulled out of the reactor and allowed to decay in the range of time appropriate to the radioactive half-life of the indicators for the elements being determined (Table 3.6). The names of the elements are in Column 2 and their associated nuclides as Targets are in Column 3. The product nuclides and their half-lives are presented in Column 4 and Column 5 respectively, while their energy rates are presented in Column 6.

Table 3.6: Product Nuclides and their Half-lives

(Source: IAEA-TECDOC 564, 1990)

S/No.	Element	Target Isotope	Product Isotope	Half-life $T_{1/2}$	Energy (keV)
1.	Aluminium	^{27}Al	^{28}Al	2.24m	1779.0
2.	Antimony	^{121}Sb	^{122}Sb	2.70d	564.2
3.	Bromine	^{81}Br	^{82}Br	35.30h	776.5
4.	Calcium	^{48}Ca	^{49}Ca	8.72m	3084.5
5.	Chromium	^{50}Cr	^{51}Cr	27.70d	320.1
6.	Cobalt	^{59}Co	^{60}Co	5.27y	1332.5
7.	Hafnium	$^{180}\text{Hf}(\text{n}\gamma)$	^{181}Hf	42.39d	482.0
8.	Iron	^{58}Fe	^{59}Fe	44.50d	1099.3
9.	Lanthanum	^{139}La	^{140}La	40.27h	1596.0
10.	Magnesium	^{26}Mg	^{27}Mg	9.46m	1014.4
11.	Manganese	^{55}Mn	^{56}Mn	2.58h	846.8
12.	Potassium	^{41}K	^{42}K	12.36h	1524.6
13.	Samarium	^{152}Sm	^{153}Sm	46.27h	46.27h
14.	Scandium	^{45}Sc	^{46}Sc	83.81d	83.81d
15.	Sodium	^{23}Na	^{24}Na	14.96h	14.96h
16.	Tantalum	^{181}Ta	^{182}Ta	114.50d	114.50d
17.	Thorium	^{232}Th	^{233}Pa	27.00d	27.00d
18.	Titanium	^{50}Ti	^{51}Ti	5.76m	5.76m
19.	Uranium	^{238}U	^{239}Np	2.36d	2.36d
20.	Vanadium	^{51}V	^{52}V	3.75m	3.75m
21.	Zinc	^{64}Zn	^{65}Zn	243.90d	243.90d

Gamma rays are very penetrating; so as they are emitted from the nuclei of the elements in the samples, they easily reach the detector. The resulting gamma-ray spectra looks like a gas chromatograph spectra but with different "retention times." The position of each peak in the chromatograph determines the energy of the gamma ray (thus, identifying the

responsible element), and the area under the peak is proportional to its concentration. Due to the statistical nature of the technique used for the elemental analysis of the samples, all reported uncertainties were calculated mainly from counting statistics and not the normal standard deviation on replicate analysis.

3.10.2 Quality Control

Quality assurance comprises a set of experimental and statistical procedures designed to test, systematically and continually, whether a measurement process is in a state of statistical control, and consequently whether it is capable of producing data that can be used with confidence. The need for quality assurance depends on the value of the measurement data. Where lives or very large sums of money are also at stake, it is obviously important that analytical measurements be of probably high quality, and consequently it is worth the time and money required to demonstrate that quality. Again professional reputations are of great value, and worthy of being supported by reliable measurements.

Therefore, quality control procedure adopted for this work was that of including one Standard Reference Material (SRM-1633b: coal fly ash) in each batch of the samples prepared for irradiation. This made it possible to evaluate the analytical method applied (INAA) for the determination of constituent elements of the dust samples, and thus establish its accuracy provided the results obtained for the standard material agrees with the known composition – within the expected uncertainty.

CHAPTER FOUR (Results and Discussion)

4.1.1 Introduction

Dust storms are a natural phenomenon mostly linked to droughts and climate changes, but are believed to be exacerbated by human activities such as deforestation and overgrazing of pasture. The dust gravimetric concentration estimated in this work was found high, leading to serious air quality impairment. The density of air was also found above the standard value of $1.25 \times 10^{-3} \text{ g/cm}^3$ at mean sea level. The relative high wind speed during the period of Harmattan at the site for this study also has an effect on Coriolis force, the deflective force acting on the trajectory of the air passing through the dust sampling equipment. However, the detailed findings in this work are discussed in this section.

4.1.2 Efficiency of Air Sampler

As earlier explained, there was the need to calibrate the air sampler used for this work. Hence, the predetermined pumping rates of the air sampler set in the range $45.0 \times 10^{-3} - 90.0 \times 10^{-3} \text{ m}^3 \text{ min}^{-1}$, are designated as X_1 in Table 4.1. And when operated, with filter loaded, the observed fall in the rate in each case, was recorded and designated as X_2 . The mean value of the efficiency of the air sampler was established as 70.4%.

In Table 4.2, X_3 is the difference between the values (X_1) and (X_2). A graph of this difference plotted against the predetermined flow rates (X_1) yielded a straight line graph with a slope of 0.3 (fig. 4.1). Also, the ratio of the mean value of X_3 to the mean value of X_1 was found to be 0.3.

Table 4.1: Efficiency of Air sampler

	1	2	3	4	5	6	7	8	9	10	Mean Value
$X_1 (\times 10^{-3} \text{ m}^3 \text{ min}^{-1})$	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	67.5
$X_2 (\times 10^{-3} \text{ m}^3 \text{ min}^{-1})$	32.0	35.0	38.5	42.0	45.5	50.0	52.5	56.0	60.5	63.0	47.5
Efficiency (%)	71.0	70.0	70.9.0	70.0	69.2	71.4	70.6	70.0	70.5	70.0	70.4

❖ The mean value for the efficiency of the air sampler was found to be $70.4 \pm 0.3\%$.

Table 4.2: Difference in flow rate (X_3) between the predetermined values and the values obtained after installing filter

	1	2	3	4	5	6	7	8	9	10	Mean Value
$X_1(x10^{-3}m^3min^{-1})$	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	67.5
$X_2(x10^{-3}m^3min^{-1})$	32.0	35.0	38.5	42.0	45.5	50.0	52.5	56.0	60.5	63.0	47.5
$X_3(x10^{-3}m^3min^{-1})$	13.0	15.0	16.5	18.0	19.5	21.0	22.5	24.0	25.5	27.0	20.2

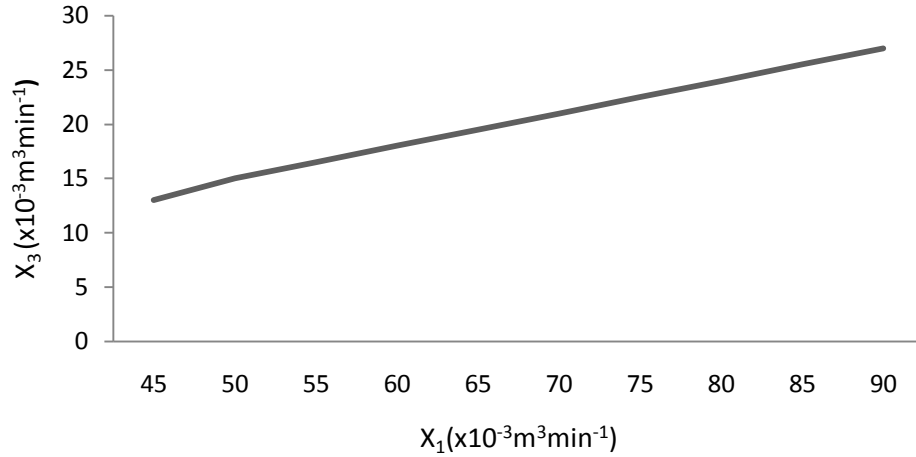


Fig. 4.1: Difference in flow rates (X₃) versus predetermined flow rate (X₁)

Therefore, if the straight line graph is considered to be a tangent to a hypothetical curve, then an expression for efficiency of a sampler, E, can be stated in the following form:

$$E = 1 - \exp\left(-\frac{x}{y}\right) \dots \dots \dots (4.1)$$

where x and y are some parameters of the air sampler to be determined such that (as applied in this case) $\exp\left(-\frac{x}{y}\right)$ equates to 0.3. Stern et al. (1960) presented an equation for computing efficiency of air sampler, E_o, from the efficiency of a single fibre, E_s, in the following form:

$$E_o = 1 - \exp\left[\frac{4}{\pi} \frac{\alpha t E_s}{D}\right] \dots \dots \dots (4.2)$$

where α is the ratio of bulk density of the filter to the density of the fibre, and t is the thickness of the filter measured parallel to the direction of flow. D is the diameter of the fibre.

However, in this work, whereby a single stage cascade impactor was used for the sampling processes, the parameters considered for incorporation in the proposed expression (equation 4.2) for determining efficiency were: (1) effective filtering area for dust

sampling, A, (2) filter thickness parallel to air flow, t, (3) axial distance, L, a particle has to travel in filter cascade impactor before impaction, and (4) the ratio of the bulk density of the filter to the density of the fibre, α .

The area of the filter, A, exposed for dust collection is directly proportion to the efficiency while air is being sucked in. When the area is larger, more particulates are collected then. However, the thickness of the filter, on the other hand, has an inverse relationship with the efficiency. Thick filters slow down air flow in the sampler in a given time. And this can reduce the efficiency of the sampler.

When particulates are sucked into the filter cassette constituting the cascade impactor, they acquire some kinetic energy as they travel along the length (L) of the filter cassette before getting impacted onto the filter. The longer distance they have to travel in the filter cassette before the impaction, the more kinetic energy they acquire as they get accelerated and therefore the more probable their bouncing off the filter surface after impaction. This also will have a negative effect on the efficiency of the filter. Hence, the new proposed formula for determining efficiency when a single stage cascade impactor is in use has the following form:

$$E_o = 1 - \exp \left[\frac{0.251A\alpha}{\pi Lt} \right] \dots\dots\dots(4.4)$$

α is the ratio of the bulk density of the filter to the density of the fibre and t is the thickness of the filter. The values of these parameters have been provided by the Institute of Paper Chemistry (Table 4.3).

The terms used in the numerator and the denominator of the proposed equation for efficiency (equation 4.4) have the same dimensions with those used in the Stern, et al. equation (equation 4.3) – thus, cm^2 . And when the values for the filter thickness and the ratio of the bulk density of the filter to the density of the fibre were sourced from the table of properties of fibrous filter, (Table 4.3), the value of efficiency obtained compared well with the measured value. Below is the list of values for the parameters used in the proposed equation:

$$A = 78.54 \text{ cm}^2 \quad t = 0.084\text{cm} \quad L = 8.00\text{cm} \quad \alpha = 0.129$$

Table 4.3: Physical Properties of the Institute of paper Chemistry IPC:
Fibrous Filter Mats

(Source: Cadle, 1975, p56)

Material: Viscous	
Mat Thickness	0.084cm
Average fibre diameter	17 μ m
Fiber density	1.47gcm ⁻³
Bulk density	0.189gcm ⁻³
Porosity	90%
Fibre volume	10%

The efficiency of the sampler used in this work was, therefore, estimated as 70% by applying the proposed equation, while it was determined experimentally as 70.4%, with the uncertainty of 0.03%.

4.1.3 Harmattan Dust Gravimetric Concentration

In determining the dust gravimetric concentration in the atmosphere in Kano State, Nigeria during the Harmattan period of 2009, the air sampler used for collecting dust has an estimated efficiency of 70%. The results obtained during each sampling exercise at respective heights of 2.0 m and 5.0 m in the 20 Local Government Areas of the State visited, have been presented in Tables 4.4a and Table 4.4b. When the mean value of the mass of filter used was subtracted from the results, the mass of the dust collected at each sampling site was determined and presented in Tables 4.5 – 4.9. Then the gravimetric concentration of the dust in each zone was determined by dividing the mean mass of the sampled dust in the zones by the volume of air collected (3.78 m³) in one hour, the time

used for the sampling exercise. The results obtained are presented in Tables 4.10a and 4.10b.

Table 4.4a: Harmattan dust collected in four geographical locations and the City of Kano State, Nigeria

	Day	03/01/09	14/01/09	25/02/09	17/01/09	06/01/09	01/02/09	04/02/09	21/01/09	28/01/09	11/02/09
	Location	N1	S1	E1	W1	N2	S2	E2	W2	N3	S3
Height (m)	Time	MASS OF FILTER PLUS DUST (g) \pm 0.002%									
5.0	7:00-8:00AM	1.04501	1.04677	1.04519	1.04595	1.04714	1.04692	1.04669	1.04735	1.04514	1.04803
2.0	9:00-10:00AM	1.04512	1.04551	1.04525	1.04711	1.04622	1.04620	1.04751	1.04789	1.04525	1.04748
5.0	12:00-1:00PM	1.04635	1.04552	1.04592	1.04789	1.04563	1.04509	1.04654	1.04553	1.04576	1.04586
2.0	2:00-3:00PM	1.04717	1.04456	1.04759	1.04686	1.04527	1.04548	1.04412	1.04484	1.04714	1.04651
5.0	4:00-5:00PM	1.04681	1.04527	1.04677	1.04574	1.04571	1.04562	1.04557	1.04577	1.04635	1.04612
2.0	6:00-7:00PM	1.04612	1.04564	1.04685	1.04512	1.04628	1.04552	1.04724	1.04614	1.04587	1.04620

Locations for dust sampling at 2.0 m & 5.0 m above ground level (AGL):

N1: Bichi S1: Dawakin kudu E1: Wudil W1: Gwarzo N2: Tsanyawa
 S2: Rano E2: Gaya W2: Tofa N3: Dawakin Tofa S3: Bebeji

❖ Average mass of the filter used (1.03602g \pm 0.02%)

Table 4.4b: Harmattan dust collected in four geographical locations and the City of Kano State, Nigeria (Contd.)

	Date	24/01/09	07/02/09	10/01/12	15/02/09	18/02/09	22/02/09	08/02/09	18/01/09	11/01/09	25/01/09
	Location	E3	W3	N4	S4	E4	W4	C1	C2	C3	C4
Height (m)	Time	MASS OF FILTER PLUS DUST (g) \pm 0.02%									
5.0	7:00-8:00AM	1.04505	1.04569	1.04574	1.04767	1.04562	1.04706	1.04791	1.04770	1.04895	1.04696
2.0	9:00-10:00AM	1.04526	1.04515	1.04525	1.04588	1.04749	1.04613	1.04723	1.04814	1.04925	1.04976
5.0	12:00-1:00PM	1.04523	1.04558	1.04564	1.04776	1.04717	1.04734	1.04758	1.04891	1.04884	1.04938
2.0	2:00-3:00PM	1.04581	1.04574	1.04581	1.04634	1.04728	1.04686	1.04888	1.04928	1.04887	1.04875
5.0	4:00-5:00PM	1.04578	1.04612	1.04625	1.04618	1.04775	1.04537	1.04884	1.04876	1.04978	1.04960
2.0	6:00-7:00PM	1.04582	1.04638	1.04718	1.04672	1.04783	1.04563	1.04763	1.04819	1.04789	1.04936

Locations for dust sampling at 2.0 m & 5.0 m (AGL):

E3: Albasu W3: Bagwai N4: Dambatta S4: Kura E4: Garko (Warawa)
W4: Shanono C1: B. U. K. Road C2: Katsina Road C3: Zaria Road C4: Bata (S/Gari)

Table 4.4a: Harmattan dust collected in four geographical locations and the City of Kano State, Nigeria

	Day	03/01/	14/01/	25/02/	17/01/	06/01/	01/02/	04/02/	21/01/	28/01/	11/02/
		09	09	09	09	09	09	09	09	09	09
	Location	N1	S1	E1	W1	N2	S2	E2	W2	N3	S3
Height (m)	Time	MASS OF FILTER PLUS DUST (g) \pm 0.002%									
5.0	7:00-	1.045	1.046	1.045	1.045	1.047	1.046	1.046	1.047	1.045	1.048
2.0	8:00A	01	77	19	95	14	92	69	35	14	03
	M	1.045	1.045	1.045	1.047	1.046	1.046	1.047	1.047	1.045	1.047
	9:00-	12	51	25	11	22	20	51	89	25	48
	10:00										
	AM										
5.0	12:00-	1.046	1.045	1.045	1.047	1.045	1.045	1.046	1.045	1.045	1.045
2.0	1:00P	35	52	92	89	63	09	54	53	76	86
	M	1.047	1.044	1.047	1.046	1.045	1.045	1.044	1.044	1.047	1.046
	2:00-	17	56	59	86	27	48	12	84	14	51
	3:00P										
	M										
5.0	4:00-	1.046	1.045	1.046	1.045	1.045	1.045	1.045	1.045	1.046	1.046
2.0	5:00P	81	27	77	74	71	62	57	77	35	12
	M	1.046	1.045	1.046	1.045	1.046	1.045	1.047	1.046	1.045	1.046
	6:00-	12	64	85	12	28	52	24	14	87	20
	7:00P										

	M										
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Locations for dust sampling at 2.0 m & 5.0 m above ground level (AGL):

N1: Bichi S1: Dawakin kudu E1: Wudil W1: Gwarzo N2: Tsanyawa
 S2: Rano E2: Gaya W2: Tofa N3: Dawakin Tofa S3: Bebeji

❖ Average mass of the filter used (1.03602g ± 0.02%)

Table 4.4b: Harmattan dust collected in four geographical locations and the City of Kano State, Nigeria (Contd.)

	Date	24/01/09	07/02/09	10/01/12	15/02/09	18/02/09	22/02/09	08/02/09	18/01/09	11/01/09	25/01/09
	Location	E3	W3	N4	S4	E4	W4	C1	C2	C3	C4
Height (m)	Time	MASS OF FILTER PLUS DUST (g) ± 0.02%									
5.0 2.0	7:00-8:00A M	1.04505	1.04569	1.04574	1.04767	1.04562	1.04706	1.04791	1.04770	1.04895	1.04696
	9:00-10:00 AM	1.04526	1.04515	1.04525	1.04588	1.04749	1.04613	1.04723	1.04814	1.04925	1.04976
5.0 2.0	12:00-1:00P M	1.04523	1.04558	1.04564	1.04776	1.04717	1.04734	1.04758	1.04891	1.04884	1.04938
	2:00-3:00P M	1.04581	1.04574	1.04581	1.04634	1.04728	1.04686	1.04888	1.04928	1.04887	1.04875
5.0 2.0	4:00-5:00P M	1.04578	1.04612	1.04625	1.04618	1.04775	1.04537	1.04884	1.04876	1.04978	1.04960
	6:00-7:00P M	1.04582	1.04638	1.04718	1.04672	1.04783	1.04563	1.04763	1.04819	1.04789	1.04936

Locations for dust sampling at 2.0 m & 5.0 m (AGL):

E3: Albasu W3: Bagwai N4: Dambatta S4: Kura
 E4: Garko (Warawa)

W4: Shanono
C4: Bata (S/Gari)

C1: B. U. K. Road C2: Katsina Road C3: Zaria Road

Table 4.13a: Computed average values of turbidity of the atmosphere for Kano during Harmattan period

Months		November	December	January	February	March	Average
Kano	Turbidity ($\pm 0.06\%$)	0.37	0.39	0.39	0.40	0.42	0.39

Table 4.13b: Average values of turbidity of the atmosphere for Sokoto during Harmattan period

Months		November	December	January	February	March	Average
Sokoto	Turbidity ($\pm 0.06\%$)	0.46	0.48	0.48	0.49	0.49	0.48

(Source: Sambo and Aliyu, 1998)

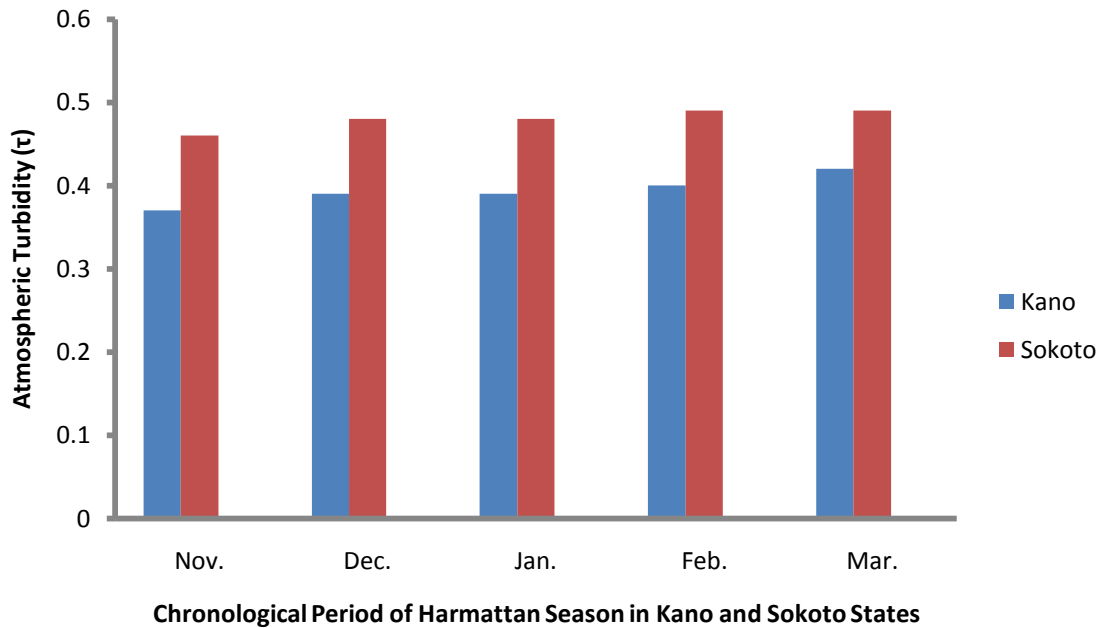


Fig. 4.4: Atmospheric Turbidity in Kano and Sokoto States

4.1.6 Wind Speed during Harmattan Period in Kano at 5.0 m height

By using the data on wind speed observations which was made at the height of 5.0 m and obtained from Nigeria Meteorology, (NIMET), Abuja, as typified in (Table 3.4), as well as the subsequent application of the methodology used for computing mean wind speed during the month of January, 2003 as demonstrated in (Table 3.5), the mean wind speed for the Harmattan period of 1998/1999 – 2002/2003, was determined and presented in (Table 4.14). The data obtained from Nigeria Metrology (NIMET), Abuja, covered only the stated period.

Table 4.14: Computed mean wind speed during Harmattan period in Kano State determined from observations on Beaufort Scale made at 5.0m height

	Nov.	Dec.	Jan.	Feb.	Mar.	Total	Average
	1998/1999						
Wind Speed (m/s) ($\pm 0.01\%$)	4.34	4.33	4.57	5.16	4.25	22.65	4.53
	1999/2000						
Wind Speed (m/s) ($\pm 0.01\%$)	4.13	4.03	4.60	4.54	4.33	21.80	4.36
	2000/2001						
Wind Speed (m/s) ($\pm 0.01\%$)	4.39	4.62	4.85	4.93	4.56	23.35	4.67
	2001/2002						
Wind Speed (m/s) ($\pm 0.01\%$)	4.71	4.91	5.65	5.97	4.91	26.15	5.23
	2002/2003						
Wind Speed (m/s) ($\pm 0.01\%$)	4.29	4.27	4.83	5.41	4.48	23.60	4.72

- ❖ The mean wind speed in Kano during Harmattan period was computed as $4.70\text{ms}^{-1} \pm 0.01\%$

4.1.7 Air Density during Harmattan Period

The mean value for air density was estimated at $3.48 \text{ kgm}^{-3} \pm 0.01\%$ at 32.8°C (see Table 4.15). Comparing with the value of 2.65 kgm^{-3} obtained at Ile – Ife, Nigeria by Adedokun et, al. (1989), shows that the value in this work is higher and this could be due to the fact that Ile – Ife is farther away from Faya Largeau, the dust source, than Kano State. Ile – Ife is 1972.6 km away, while Kano is 1324.4km. And there is an inverse proportion in the concentration of particulate matter in the atmosphere between distance of a receptive location from a source and at the source.

4.1.8 Coriolis Force

The monthly mean values of the Coriolis force acting per unit mass of air in the area of study during Harmattan period was estimated for a period of five years (1998/1999 – 2002/2003) and presented in (Table 4.16); with a mean value for the five years as $1.445 \times 10^{-4} \text{ N} \pm 0.01\%$. The force is higher during the months of February throughout the whole period of Harmattan season (1998/1999 – 2002/2003), except in 1999/2000 when the value was almost equal to that obtained in January (see fig. 4.4). However, as the force is

expressed by the relation: $f = 2\omega V \sin\theta$, where ω , v and θ are the angular velocity of the Earth, the speed of the wind (in the area of study) and the latitude of the area respectively,

Harmattan Period	R/Humidity (0.02%)	Wind Speed (0.01%)	Max. Temp. (0.02%)	P _{m.s.l.} (2.0%)	P _{station} (2.0%)	Air Density (0.01%)
	%	m/s	°C	mb	mb	kg/m ³
1998/1999	25.40	4.53	32.20	1013.00	958.80	3.48
1999/2000	29.20	4.36	33.50	1011.30	957.20	3.48
2000/2001	24.00	4.67	33.20	1012.60	958.00	3.48
2001/2002	21.40	5.23	32.20	1012.90	958.20	3.48
2002/2003	20.00	4.72	33.00	1013.00	958.10	3.48
Average	22.20	4.70	32.80	1012.60	958.10	3.48

the speed of wind is the only variable quantity in the expression. And as observed in fig 4.5, the wind speed has the highest values during the month of February when compared to the other months for the Harmattan period under study. This explains the reason for high value of Coriolis force in February.

Table 4.15: Mean Values of Air Density in Kano during Harmattan Period

Table 4.16: Mean values of Coriolis force acting on all moving objects during Harmattan period in Kano State

Months	Nov.	Dec.	Jan.	Feb.	Mar.	Total	Average
1998/1999							
Wind speed (m/s) ($\pm 0.01\%$)	4.34	4.33	4.57	5.16	4.25	22.65	4.53
Coriolis force ($\times 10^{-4} \text{N} \pm 0.01\%$)	1.30	1.25	1.27	1.39	1.33	6.54	1.31
1999/2000							
Wind speed (m/s) ($\pm 0.01\%$)	4.13	4.03	4.60	4.54	4.33	21.80	4.36
Coriolis force ($\times 10^{-4} \text{N} \pm 0.01\%$)	1.23	1.35	1.59	1.56	1.47	7.29	1.46
2000/2001							
Wind speed (m/s) ($\pm 0.01\%$)	4.39	4.62	4.85	4.93	4.56	23.35	4.67
Coriolis force ($\times 10^{-4} \text{N} \pm 0.01\%$)	1.46	1.39	1.58	1.72	1.346	7.51	1.50
2001/2002							
Wind speed (m/s) ($\pm 0.01\%$)	4.71	4.91	5.65	5.97	4.91	26.15	5.23

Coriolis force ($\times 10^{-4} \text{N} \pm 0.01\%$)	1.33	1.38	1.71	1.75	1.70	7.86	1.57
2002/2003							
Wind speed (m/s) ($\pm 0.01\%$)	4.29	4.27	5.15	5.41	4.48	23.60	4.72
Coriolis force ($\times 10^{-4} \text{N} \pm 0.01\%$)	1.30	1.33	1.46	1.47	1.35	6.91	1.38

❖ The mean value of the force over five years was found as $1.445 \times 10^{-4} \text{N} \pm 0.01\%$

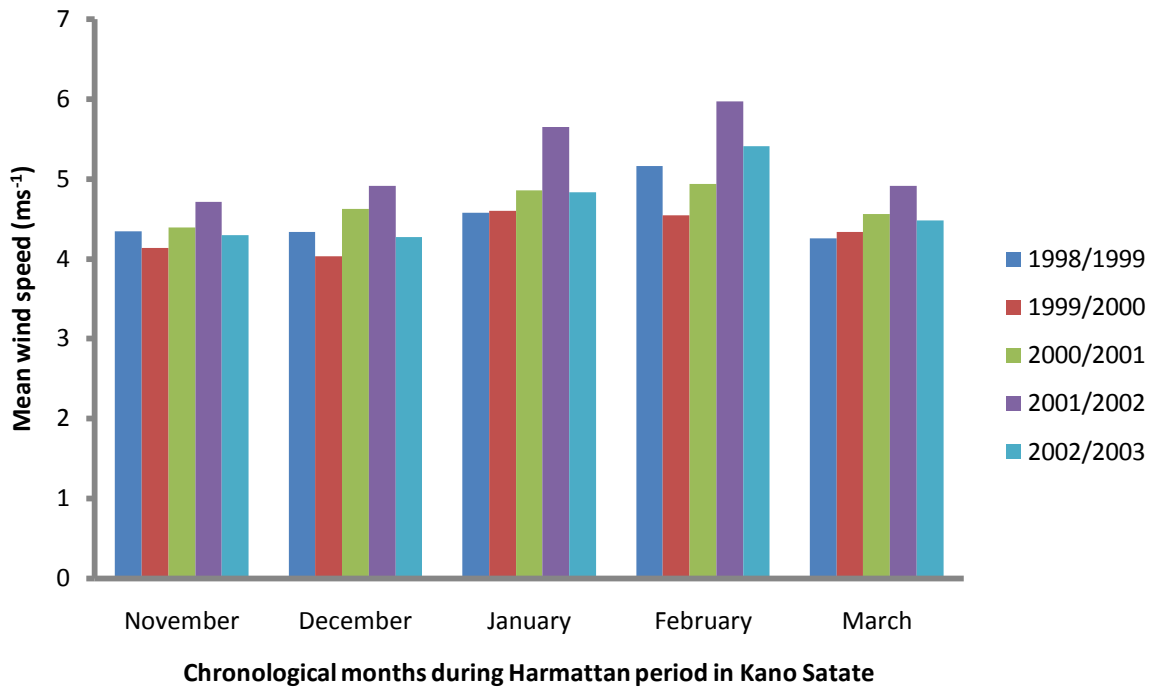


Fig. 4.5: Mean wind speed during Harmattan period in Kano State

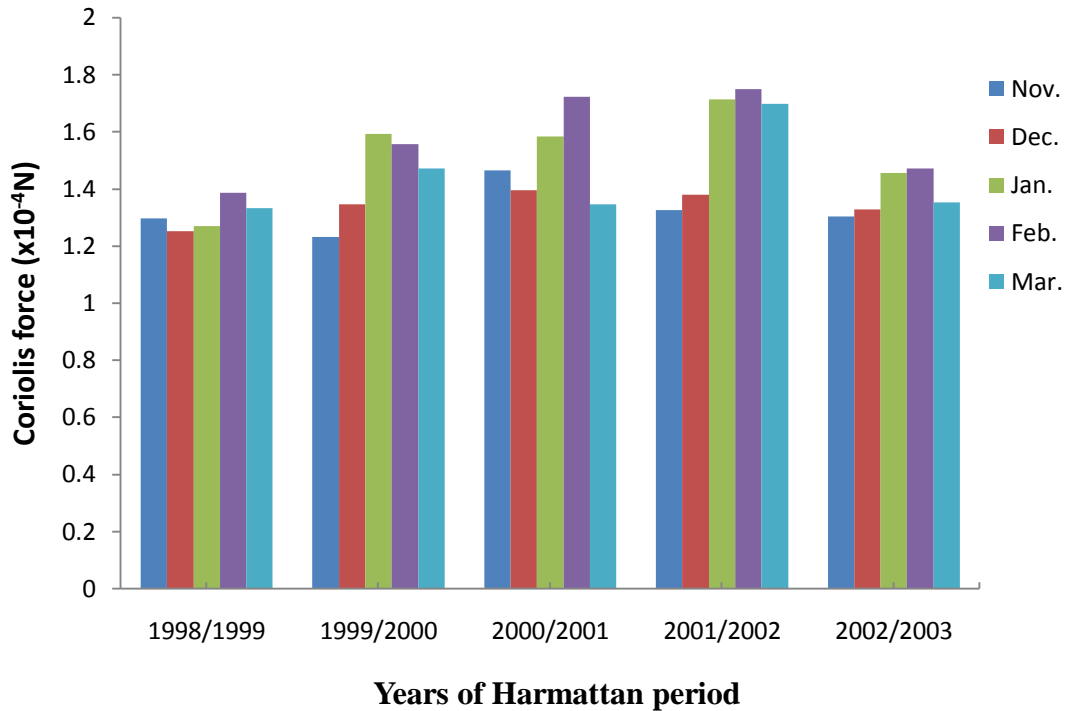


Fig. 4.6: The Coriolis force acting on unit mass of air in Kano State

4.1.9 Air Viscosity during Harmattan Period

The viscous nature of the atmosphere during Harmattan period in Kano State, when investigated, was found to have a mean value of $1.88 \times 10^{-5} \text{ Nsm}^{-2} \pm 0.04\%$ (Table 4.17) at mean maximum temperature of 32.8°C . This was done by using equation (2.11) and the subsequent application of the data on maximum temperature in the location, obtained from NIMET, Abuja (see appendix 3). And Kinematic viscosity, which has the value of $1.48 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$ when $T = 15^{\circ}\text{C}$ and sea level pressure, $P = 1013 \text{ mb}$ (Nelkon and Parker, 2005), was estimated in this work as $0.54 \times 10^{-5} \text{ m}^2 \text{ s}^{-1} \pm 0.02\%$ at $T = 32.8^{\circ}\text{C}$ and station level pressure, $P = 958.10 \text{ mb}$ (Table 4.17). The low value is due to high density of air (Table 4.15) during Harmattan period.

From fig. 4.6 (a & b), it is evident that both absolute and kinematic viscosities being temperature dependent have the least values in the month of January. Hence, the coldest period during Harmattan in Kano State is observed in January.

4.1.10 Reynolds number and its turbulent effect on Harmattan weather

Reynolds number (Re) whose approximate value determines whether the sheared flow in fluid is Laminar or turbulent was found to be $9.10 \times 10^4 \pm 3\%$ (Table 16). This value is

1998/1999 HARMATTAN PERIOD							
	Nov.	Dec.	Jan	Feb	Mar	Total	Av.

found to be high when compared to 6.0×10^3 , the least value required to produce turbulent flow in air. Nonetheless, this high turbulent effect could be attributed to the fact that all measurements on parameters relating to turbulence such as wind speed and air density were taken at the lower boundary of the atmosphere where the presence of mountains, hills, trees and buildings contribute in making the motion of air more turbulent.

Table 4.17: Absolute and Kinematic Viscosities of Air in Kano State

Maximum Temperature (°C)	34.10	29.80	26.50	33.50	34.00	160.96	32.20
Wind speed (m/s)	4.34	4.33	4.57	5.16	4.25	22.65	4.53
Air viscosity, η, (Nsm⁻²) (x10⁻⁵)	1.89	1.86	1.85	1.88	1.90	9.38	1.88
Kinematic viscosity, ν, (x10⁻⁵m²s⁻¹)	0.54	0.53	0.53	0.54	0.55	2.69	0.54
1999/2000							
Maximum Temperature (°C)	36.70	35.12	26.30	32.40	33.10	167.70	33.50
Wind speed (m/s)	4.13	4.03	4.60	4.54	4.33	21.80	4.36
Air viscosity, η, (Nsm⁻²) (x10⁻⁵)	1.90	1.89	1.85	1.88	1.90	9.42	1.88
Kinematic viscosity, ν, (x10⁻⁵m²s⁻¹)	0.55	0.54	0.53	0.54	0.55	2.71	0.54
2000/2001							
Maximum Temperature (°C)	32.80	31.70	27.60	36.20	32.50	165.80	33.20
Wind speed (m/s)	4.39	4.62	4.85	4.93	4.56	23.35	4.67
Air viscosity, η, (Nsm⁻²) (x10⁻⁵)	1.88	1.87	1.85	1.90	1.90	9.40	1.88
Kinematic viscosity, ν, (x10⁻⁵m²s⁻¹)	0.54	0.54	0.53	0.55	0.55	2.71	0.54
2001/2002							

Table 4.17: Absolute and Kinematic Viscosities of air in Kano State (**Contd.**)

	Nov.	Dec.	Jan	Feb	Mar	Total	Av.
Maximum Temperature (°C)	33.80	30.60	29.20	30.40	33.90	160.90	32.20
Wind speed (m/s)	4.71	4.91	5.65	5.97	5.91	26.15	5.23
Air viscosity, η, (Nsm⁻²) (x10⁻⁵)	1.88	1.87	1.86	1.87	1.90	9.38	1.88
Kinematic viscosity, ν, (x10⁻⁵m²s⁻¹)	0.54	0.54	0.53	0.54	0.55	2.70	0.54
2002/2003							
Maximum Temperature (°C)	33.70	34.90	32.50	30.50	31.60	169.20	33.80
Wind speed (m/s)	4.29	4.27	4.83	5.91	4.88	23.60	4.72
Air viscosity, η, (Nsm⁻²) (x10⁻⁵)	1.88	1.89	1.88	1.87	1.90	9.42	1.88
Kinematic viscosity, ν, (x10⁻⁵m²s⁻¹)	0.54	0.54	0.54	0.54	0.55	2.70	0.54

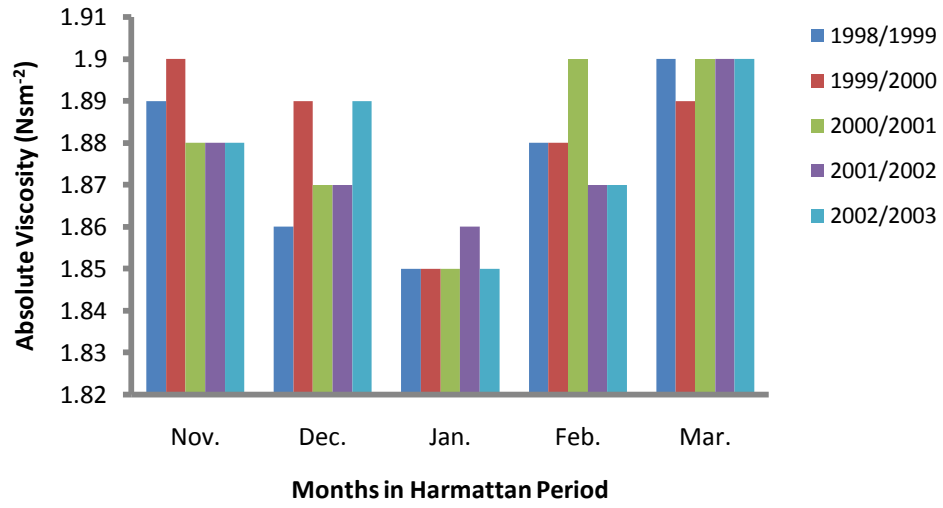


Fig. 4.7a: Air viscosity during Harmattan period in Kano State

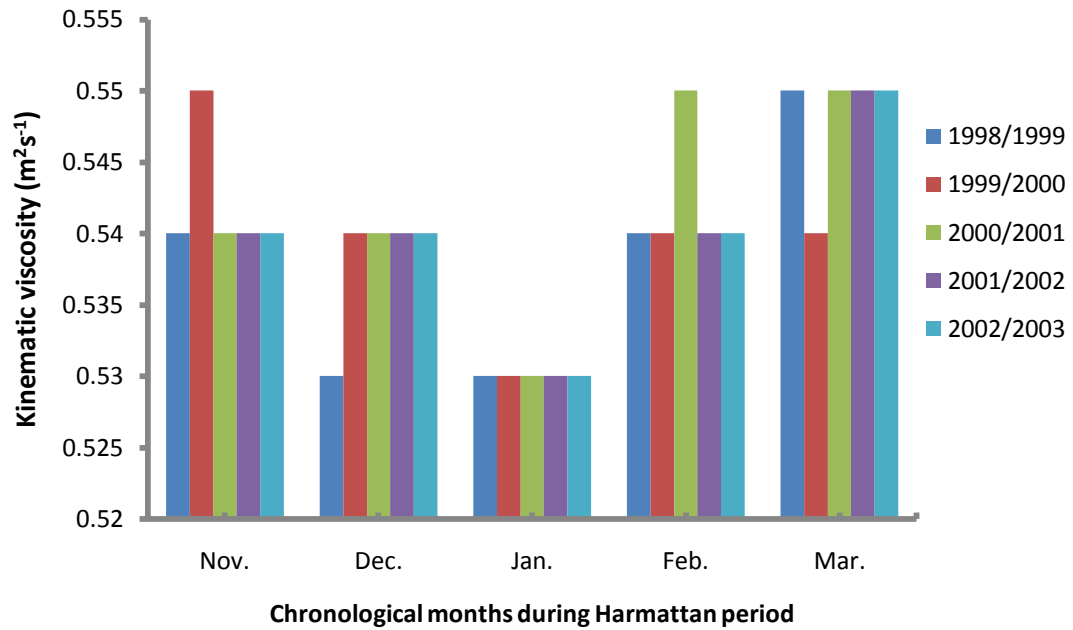


Fig. 4.7b: Kinematic viscosity during Harmattan period in Kano State

Table 4.18: Reynolds number during Harmattan period in Kano State.

The average value of Reynolds number in Kano State was found as $9.10 \times 10^4 \pm 3\%$

4.1.11 Wind power density during Harmattan period

Harmattan Period	NOV.	DEC.	JAN.	FEB.	MAR.	TOTAL	AV.
1998/1999							
Wind Speed (m/s) ($\pm 0.01\%$)	4.34	4.33	4.57	5.16	4.25	22.65	4.53
Reynolds Number (Re) ($\times 10^4$)	7.90	7.80	7.90	8.50	7.80	45.90	9.18
1999/2000							
Wind Speed (m/s) ($\pm 0.01\%$)	4.13	4.03	4.60	4.54	4.33	21.80	4.36
Reynolds Number (Re) ($\times 10^4$)	7.40	8.20	9.90	9.50	8.80	48.60	9.72
2000/2001							
Wind Speed (m/s) ($\pm 0.01\%$)	4.39	4.62	4.85	4.93	4.56	23.35	4.67
Reynolds Number (Re) ($\times 10^4$)	8.90	8.50	9.80	10.30	8.10	45.60	8.37
2001/2002							
Wind Speed (m/s) ($\pm 0.01\%$)	4.71	4.91	5.65	5.97	4.91	26.15	5.23
Reynolds Number (Re) ($\times 10^4$)	8.10	8.40	10.70	10.70	10.20	44.05	8.81
2002/2003							
Wind Speed (m/s) ($\pm 0.01\%$)	4.29	4.27	4.83	5.41	4.48	23.60	4.72
Reynolds Number (Re) ($\times 10^4$)	8.00	8.10	8.90	9.00	8.10	44.80	8.96

The mean monthly wind power density for a turbine blade of diameter 1.382m was estimated over a five-year Harmattan period (1998/1999 – 2002/2003) as $193.25 \text{ Wm}^{-2} \pm 1.0\%$ (Table 4.19) at the respective wind speed over the period. And the distribution of the wind power was found to be highest in 2001/2002, but least in 1998/1999 (Table 4.20), with a mean value of 289.98 W. However, the distribution in general, depicts some promising results in utilizing wind power positively, especially for electric power generation.

Wind power, being one of the renewable energy sources, has for long been used in several

Month	Nov.	Dec.	Jan.	Feb.	Mar.	Total	Average
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countries for electricity generation. For example, a 100, 000-kWh power plant was reported to have been built from many small wind power units (the turbines) by Denmark before the Second World War (Hill, 1980). In 1914, the largest wind turbine used for electricity generation appeared to be the 1250-kWh unit built by Morgan Smith Co. in Vermont under the direction of Palmer Putnam. The turbine had two blades of stainless steel, with a blade diameter of 57.6m. It, however, developed a maximum power of 1,400 kWh (Hill, 1980).

Table 4.19: Wind power density during Harmattan period in Kano State.

1998/1999							
Wind speed (ms^{-1}) ($\pm 0.01\%$)	3.94	3.89	4.36	5.93	5.22	24.82	4.53
	Nov.	Dec.	Jan.	Feb.	Mar.	Total	Average
Power density (Wm^{-2}) ($\pm 1.0\%$)	136.42	122.57	127.99	166.07	147.21	901.18	140.05
		1998/1999					
Wind speed (ms^{-1}) ($\pm 0.01\%$)	3.94	3.89	4.36	5.93	5.22	24.82	4.53
Wind speed (ms^{-1}) ($\pm 0.01\%$)	4.52	3.87	4.37	4.66	5.65	26.27	4.36
Wind Power (W) ($\pm 1.0\%$)	204.63	183.86	191.99	249.11	220.82	1050.41	210.08
Power density (Wm^{-2}) ($\pm 1.0\%$)	116.45	152.30	251.78	234.91	198.51	953.92	190.78
		1999/2000					
2000/2001							
Wind speed (ms^{-1}) ($\pm 0.01\%$)	4.19	5.42	4.79	4.29	4.80	22.59	4.67
Power density (Wm^{-2}) ($\pm 1.0\%$)	196.61	169.36	247.49	318.86	152.30	1084	216.92
2001/2002							
Wind speed (ms^{-1}) ($\pm 0.01\%$)	4.77	4.81	5.97	5.36	5.60	25.94	5.23
Power density (Wm^{-2}) ($\pm 1.0\%$)	145.21	163.90	313.83	334.25	305.57	1262.76	252.55
2002/2003							
Wind speed (ms^{-1}) ($\pm 0.01\%$)	4.18	4.27	5.15	5.21	4.46	22.79	4.72
Power density (Wm^{-2}) ($\pm 1.0\%$)	138.34	146.21	192.43	198.51	154.37	829.86	165.97
Mean Wind Power Density in Kano ($\pm 1.0\%$)						193.25 Wm^{-2}	

Table 4.20: Wind power during Harmattan period in Kano State.

Wind speed (ms⁻¹) (±0.01%)	4.52	3.87	4.37	4.66	5.65	26.27	4.36
Wind Power (W) (±1.0%)	174.68	228.48	377.67	352.37	297.77	1430.97	286.19
2000/2001							
Wind speed (ms⁻¹) (±0.01%)	4.19	5.42	4.79	4.29	4.80	22.59	4.67
Wind Power (W) (±1.0%)	294.92	254.04	371.24	478.29	228.45	1626.94	325.39
2001/2002							
Wind speed (ms⁻¹) (±0.01%)	4.77	4.81	5.97	5.36	5.60	25.94	5.23
Wind Power (W) (±1.0%)	217.82	245.85	470.75	501.38	458.34	1894.14	378.83
2002/2003							
Wind speed (ms⁻¹) (±0.01%)	4.18	4.27	5.15	5.21	4.46	22.79	4.72
Wind Power (W) (±1.0%)	207.51	219.32	288.65	297.77	231.56	1244.81	248.96
Mean Wind Power in Kano (±1.0%)						289.89W	

Mamunu (2009) suggested that with the estimated mean wind power density of $200 \pm 0.26 \text{ Wm}^{-2}$ in northwestern region of Nigeria, the government and other agencies in the country could come together to set a machinery in motion for exploring this energy resource in the region. Now in this work, a promising wind power density of $193.25 \text{ Wm}^{-2} \pm 1.0\%$ has been determined in Kano State.

4.2 Application of INAA for elemental analysis

The Nigerian Research Reactor-1 (NRR-1) used for elemental analysis of dust samples in this work is a Miniature Neutron Source Reactor (MNSR) with a tank-in-pool structural configuration and with a nominal thermal power of 31kW. The analysis of trace, minor and major elements has been greatly enhanced by its application at Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. In its instrumental form (INAA), neutron activation analysis has some unique features, which makes it attractive to use for routine analysis and these include multi-elemental capability, rapidity, reproducibility of results, complementarity to other methods, freedom from analytical blank, and independence of chemical state of elements (Jonah et al., 2006). The routine experimental irradiation/counting schemes by which samples can be evaluated have been developed by Jonah et al.(2006) (see appendix 5). Two irradiation regimes and four counting strategies have been adopted and applied in the procedure on the basis of the half-life of product radionuclide and the neutron spectrum parameters in the inner and outer irradiation channels of NIRR-1.

4.2.1 Quality Control of INAA Setup of NIRR-1

The Centre for Energy Research and Training, CERT, has been using well characterized internationally certified reference materials in evaluation for accuracy of the relative INAA method, currently being employed in analyzing geological and related samples at the Centre. Funtua et al., (20012) have analysed a set of geological materials of varying matrices (including coal fly ash: 1633b, the reference material used in this work) to assess fully the accuracy of NIRR-1 in neutron activation analysis (NAA). The result obtained favourably compared with the certified values of international standard. Therefore, the samples for this work were irradiated using same conditions and experimental set up.

For quality control, one standard reference material (coal fly ash: SRM-1633b) was added in each batch of seven samples of this work prepared for irradiation. The standard reference material (SRM-1633b) was irradiated in the same channel of the reactor as the samples, and counted at the same detector-sample geometry. Tables 4.21 a & b show the results of the analysis of SRM 1633b obtained for short and long-lived nuclides, using same experimental set up as applied in the analysis of the samples being investigated. Except for Mg, Eu and Co which show slight variation from the certified values, the elements detected in this work favourably compared for most of the certified elements.

Table 4.21a: Comparison of the results obtained from the analysis of the SRM Fly Ash-1633B using same experimental set up used for samples (Short-lived Nuclides)

Element	Certified Values	This work Values
Al	15.05*±0.27	15.84±0.01
Ca	1.51*±0.06	1.48±0.08
Mn	131.8±1.7	131.6±1.5
Mg	0.482*±0.008	1.21±0.18
Na	0.201*±0.003	0.20±0.10
V	295.7±3.6	294.5±0.03

Concentrations are in mg/kg unless noted by a single asterisk for mass fraction in %

Table 4.21b: Comparison of the results obtained from the analysis of the SRM Fly Ash-

1633B using same experimental set up as for samples (Long-lived nuclides)

Element	Certified Values	This work Values
Sb	(6)	4.80±0.10
As	136.2	135.8±0.02
Ba	709.0±27.0	692±1.20
Br	(2.9)	3.4±0.01
Fe	7.78*±0.23	7.64±0.01
Ti	0.791*±0.014	0.775±0.04
Cr	190.2±4.7	189.7±0.20
K	1.95*±0.03	1.93±0.16
Zn	(210)	198±0.04
La	(94)	88.26±0.01
Th	25.7±1.3	25.6±0.20
Sc	(41)	40.22±0.01
Sm	(20.0)	16.80±0.10
U	8.79±0.36	8.45±0.20
Hf	(6.8)	8.40±0.02
Ta	(1.8)	2.36±0.03
Co	(50)	48.43±0.01

Values in parenthesis are not certified and are given for information; and concentrations are in mg/kg unless noted by a single asterisk for mass fraction in %

4.2.2 Grouping of gamma rays for INAA method of Investigation

When applying instrumental neutron activation analysis (INAA) method for detecting the elements in the dust samples for this work, the Gamma rays energy used and their interferences observed are presented in Tables (4.22a – 4.22c). The data, separated into

three groups according to half-lives for the identifying isotopes, consists of those with half-lives less than 5 hours (Table 4.22a), the identifying isotopes with half-lives between 5 hours and 7 days (Table 4.22b) and the isotopes with half-lives greater than 7 days (Table 4.22c). In Column 1, the elements are listed alphabetically in each table where an isotope useful for the analysis exists. Column 2, Column 3, and Column 4 are respectively for isotopes, their half-lives and energies of the most useful gamma rays used. In Column 5, Column 6 and Column 7, the interfering isotopes, their half-lives and energies are listed respectively.

Table 4.22a: Gamma rays used for analysis of elements with half-life, $t_{1/2} < 5$ hours

Element	Isotope	Half-life	Energy (keV)	Interfering Isotope	Half-life	Energy of Interfering Isotope (keV)
Aluminium	²⁸ Al	2.24m	1779.00	-	-	-
Barium	¹³⁹ Ba	84.63m	165.8	-	-	-
Bromine	⁸⁰ Br	17.68m	616.30	-	-	-
Calcium	⁴⁹ Ca	8.72m	3084.50	-	-	-
Chlorine	³⁸ Cl	37.24m	1642.7	-	-	-
	³⁸ Cl	37.24m	2167.7	-	-	-
Copper	⁶⁶ Cu	5.10m	1039.2	-	-	-
Dysprosium	¹⁶⁵ Dy	2.33h	94.7	²³³ Th	22.3m	94.7
Indium	^{116m} In	54.15m	1097.3	-	-	-
Magnesium	²⁷ Mg	9.46m	843.80	⁵⁶ Mn	2.58h	846.8
	²⁷ Mg	9.46m	1014.40	-	-	-
Manganese	⁵⁶ Mn	2.58h	846.80	²⁷ Mg	9.46m	843.80
	⁵⁶ Mn	2.58h	1810.70	-	-	-
Titanium	⁵¹ Ti	5.76m	326.10	-	-	-
Vanadium	⁵² V	3.75m	1434.10	-	-	-

Table 4.22b: Gamma rays used for analysis of elements with half-life, $5 \text{ hrs} < t_{1/2} < 7$ days

Element	Isotope	Half-life	Energy (keV)	Interfering Isotope	Half-life	Energy of Interfering
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						Isotope (keV)
Antimony	¹²² Sb	2.70d	564.20	⁷⁶ As ¹³⁴ Cs	26.32h 2.06y	563.2 563.2
Arsenic	⁷⁶ As	26.32h	559.1	-	-	-
Bromine	⁸² Br ⁸² Br ⁸² Br	35.3h 35.3h 35.3h	554.4 619.1 776.5	- ¹⁸⁷ W ⁹⁹ Mo	- 23.9h 65.94h	- 618.3 778.0
Gallium	⁷² Ga ⁷² Ga	14.1h 14.1h	630.0 834.1	⁵⁴ Mn	312.12d	834.8
Lanthanum	⁴⁰ La ⁴⁰ La ⁴⁰ La ⁴⁰ La	40.27h 40.27h 40.27h 40.27h	328.8 487.0 815.8 1596.2	¹³¹ Ba	11.8d	486.5
Potassium	⁴² K	12.36h	1524.60	-	-	-
Sodium	²⁴ Na ²⁴ Na	14.96h 14.96h	1368.60 2754.00	¹²⁴ Sb -	60.2d -	1368.20 -
Samarium	¹⁵³ Sm ¹⁵³ Sm	46.27h 46.27h	69.70 103.20	¹⁵³ Gd ¹⁵³ Gd ²³⁹ Np	241.60d 241.60d 2.36d	69.7 103.2 103.7 X-Ray
Uranium	²³⁹ Np ²³⁹ Np ²³⁹ Np	2.36d 2.36d 2.36d	106.10 228.20 277.60	- ¹³² Te ¹⁸² Ta ²³² Th ¹⁴⁷ Nd ¹⁵² Eu	- 78.2h 114.5d 1.4E+10y 10.98d 13.33y	- 228.30 229.30 227.40 275.40 275.40

Table 4.22c: Gamma rays used for analysis of elements with half-life, $t_{1/2} > 7$ days

Element	Isotope	Half-life	Energy (keV)	Interfering Isotope	Half-life	Energy of Interfering Isotope (keV)
Cobalt	⁶⁰ Co ⁶⁰ Co	5.27y 5.27y	1173.20 1332.50	- -	- -	- -
Chromium	⁵¹ Cr	27.70d	320.10	¹⁴⁷ Nd ¹⁷⁷ Lu	10.98d 160.90d	319.4 319.0

Iron	⁵⁹ Fe	44.5d	1099.20	-	-	-
	⁵⁹ Fe	44.5d	1291.60	¹¹⁵ Cd ¹⁸² Ta	44.6d 114.5d	1290.60 1289.20
Hafnium	¹⁸¹ Hf	42.39d	133.00	¹³¹ Ba	11.8d	133.60
	¹⁸¹ Hf	42.39d	345.90	¹⁴⁴ Ce	284.9d	133.50
	¹⁸¹ Hf	42.39d	482.20	- ¹⁹⁴ Ir	- 171.0d	- 482.70
Scandium	⁴⁶ Sc	83.81d	889.31	-	-	-
	⁴⁶ Sc	83.81d	1120.60	¹⁸² Ta ²³⁸ U	114.5d 4.5E+09y	1121.30 1120.30
Tantalum	¹⁸² Ta	114.5d	67.80	-	-	-
	¹⁸² Ta	114.5d	100.10	-	-	-
	¹⁸² Ta	114.5d	1189.00	-	-	-
	¹⁸² Ta	114.5d	1221.40	-	-	-
Thorium	²³³ Pa	27.0d	300.20	¹⁶⁰ Tb ²³² Th	72.3d 1.4E+10y	298.60 300.10
	²³³ Pa	27.0d	312.00	⁴² K	12.36h	312.40
Zinc	⁶⁵ Zn	243.9d	438.6	-	-	-

4.2.3 Irradiated blank filters

For computational purposes, three blank filters were included for irradiation together with the dust samples using short-lived irradiation method, while two blank filters were included in those samples for long-lived irradiation technique. The elemental concentrations (in ppm) determined in the blank filters in each case have been presented in Tables 4.23 - 4.24. A total of 18 elements were detected in the blank filters and they included Al, Ca, Mg, Mn, Ti, Na, V, Dy, Zn, Co, Br, La, Sm, Sc, Cr, Fe, Eu, and Ta. There were some elements which were found in the blank filters with concentrations below the detection limit, such as K (in Table 4.23) and As, Rb, Sb, Ba, Eu Yb, Lu, Hf, Ta, and Th (in Table 4.24); and so the blanks are totally free of these elements.

Table 4.23: Mean INAA Short-lived Irradiation Results for blank filters

	Aluminum	Calcium	Magnesium	Manganese	Titanium	Sodium	Potassium	Vanadium	Dysprosium
S/No.	Al (ppm)	Ca (ppm)	Mg (ppm)	Mn (ppm)	Ti (ppm)	Na(ppm)	K (ppm)	V (ppm)	Dy (ppm)
1.	609.40± 53.63	68.10± 10.15	25.37± 4.29	4.41±2 .45	6.52± 3.24	32.25± 1.30	BDL	0.33±0 .04	0.17±2. 45
2.	501.70 ± 5.02	38.78 ± 7.29	7.41±4. 40	3.54±3 .25	BDL	33.80± 1.30	BDL	0.24±0 .03	0.17±3. 25
3.	528.20 ± 4.75	45.68 ± 8.27	14.96± 3.93	3.44±3 .05	BDL	32.20± 1.30	BDL	0.28±0 .04	BDL
Av.	546.40± 21.13	50.85 ± 8.57	15.91± 4.21	3.795± 2.95	2.17± 1.08	32.75± 1.30	BDL	0.28±0 .04	0.17±2. 85

*BDL: Below Detection Limit

Table 4.24a: Mean NAA Long-lived irradiation results for blank filters

	Arsenic	Lanthanum	Samarium	Scandium	Chromium	Iron	Zinc	Cobalt
Filter No.	As(ppm)	La (ppm)	Sm (ppm)	Sc (ppm)	Cr (ppm)	Fe (ppm)	Zn(ppm)	Co

1.	BDL	0.03±0.01	0.01±0.00	0.04±0.00	BDL	17.00±13.00	BDL	
2.	BDL	0.04±0.00	0.01±0.00	0.04±0.00	0.09±0.00	28.00±11.00	2.20±0.60	0.0
Av.	BDL	0.03±0.01	0.01±0.00	0.04±0.00	0.045±0.00	22.50±12.00	1.10±0.30	0.0

Table 4.24b: Mean Long-lived irradiation results for blank filters (**Contd.**).

S/N o.	Antim ony	Bariu m	Europi um	Luteti um	Hafni um	Tantal um	Thori um	Thori um	Urani um
	Sb (ppm)	Ba(pp m)	Eu(pp m)	Lu(pp m)	Hf(pp m)	Ta(pp m)	Th(pp m)	Th(pp m)	U (ppm)
1.	BDL	BDL	0.03±0. 01	BDL	BDL	BDL	BDL	BDL	BDL
2.	BDL	BDL	BDL	BDL	BDL	0.17±0. 02	BDL	BDL	BDL
Av.	BDL	BDL	0.02±0. 01	BDL	BDL	0.09±0. 00	BDL	BDL	BDL

***BDL**: Below Detection Limit

4.2.4a Elemental constituent and concentration of Harmattan dust

When the values for the quantities of elements (in ppm) identified in the blank filters (Tables 4.23 - 4.24 above) were subtracted from the raw results of the irradiated samples of dust on filter (Tables 4.25 a – d), the elemental constituents and concentration of the Harmattan dust collected at each sample site were determined and presented in Tables (4.26 a – d).

The results for the long-lived irradiation method applied on 10 dust samples randomly selected from 10 Local Government Areas and analyzed have been presented in Tables (4.27 a – b). Therefore, the comprehensive elemental constituents and mean concentration (in ppm) of Harmattan dust transported to Kano State, Nigeria, have been determined and presented in Table 4.28. Aluminium was found to have the highest concentration among the major elements detected (fig. 4.7), while in the case of the minor elements uranium has the least concentration (fig. 4.8). The major elements, hereby defined as those elements with concentrations greater or equal to 100ppm, have been presented in Table 4.29a, while those with concentrations less than 100ppm, defined in this work as minor elements, are presented in Table 4.29b.

Table 4.25a: INAA results of **short-lived** nuclides in Harmattan Dust Samples **plus** filter collected from northern and southern zones

	Al(ppm)	Ca(ppm)	Na (ppm)	V(ppm)	Mn(ppm)	K(ppm)
2N1	6754.00±18.00	844.00±11.00	266.00±4.40	1.63±0.37	6.24±0.10	145.00±13.00
2N2	10130.00±13.00	3364.00±23.00	656.00±6.40	4.75±0.14	21.00±0.20	345.00±13.00
2N3	8653.00±25.00	1574.00±17.00	384.00±5.50	BDL	8.70±0.10	169.00±19.00
2N4	10654.00±22.00	3186.00±22.00	293.00±4.50	2.00±0.30	8.10±0.10	244.00±16.00
	Al(ppm)	Ca(ppm)	Na (ppm)	V(ppm)	Mn(ppm)	K(ppm)
5S1	1984.00±20.00	1078.00±13.00	235.00±4.40	1.00±0.20	4.10±0.10	262.00±42.00
5S2	6973.00±44.00	2979.00±27.00	539.00±6.00	BDL	12.60±0.20	255.00±62.00
5S3	2293.00±21.00	1122.00±14.00	211.00±4.00	1.60±0.30	4.70±0.10	248.00±50.00
5S4	3977.00±36.00	2664.00±23.00	268.00±4.00	2.10±0.30	9.40±0.10	288.00±12.00

***BDL**: Below Detection Limit

Locations for dust sampling at 2.0 m & 5.0 m heights:

N1: Bichi N2: Tsanyawa N3: Dawakin Tofa N4: Dambatta
 S1: Dawakin Kudu S2: Rano S3: Bebeji S4: Kura

Table 4.25b: INAA results of **short-lived** nuclides in Harmattan dust samples **plus** filter collected from Eastern and Western zones

***BDL**: Below Detection Limit

	Al(ppm)	Ca(ppm)	Na (ppm)	V(ppm)	Mn(ppm)	K(ppm)
2E1	2712.00±43.20	1284.03±18.01	197.05±4.00	1.40±0.30	4.04±0.10	264.00±16.03
2E2	2740.00±49.20	1262.40±17.40	271.10±4.01	140.00±27.04	1.30±0.30	284.03±20.30
2E3	3169.00±38.01	1815.00±20.20	309.04±5.02	BDL	2.20±0.03	301.02±13.03
2E4	3345.00±23.00	1564.00±16.10	321.00±5.40	155.00±21.00	2.40±0.30	256.00±18.20
	Al(ppm)	Ca(ppm)	Na (ppm)	V(ppm)	Mn(ppm)	K(ppm)
5W1	1757.02±25.04	BDL	256.00±4.04	BDL	7.40±0.10	311.30±12.00
5W2	2193.00±18.00	1144.00±17.00	259.00±4.00	1.20±0.20	4.80±0.10	294.00±15.00
5W3	4062.02±23.00	2556.40±22.20	331.01±5.00	BDL	8.10±0.10	247.00±15.06
5W4	2446.00±34.05	1445.50±18.30	299.20±5.00	1.40±0.40	6.40±0.10	285.00±20.03

Locations for dust sampling at 2.0 m & 5.0 m heights:

E1: Wudil E2: Gaya E3: Albasu E4: Garko (Warawa)

W1: Gwarzo W2: Tofa W3: Bagwai W4: Shanono

Table 4.25c: INAA results of **short-lived** radionuclides in Harmattan dust samples **plus** filter

collected from City zone and some locations

	Al(ppm) Al(ppm)	Ca(ppm) Ca(ppm)	Na (ppm) Na (ppm)	V(ppm) V(ppm)	Mn(ppm) Mn(ppm)	K(ppm) K(ppm)
5C1	2207.02±20.12	961.33±21.14	266.04±14.12	1.30±0.20	4.91±0.10	265.10±10.21
5C2	2424.12±24.34	1304.00±12.01	284.37±14.16	1.61±0.20	6.02±0.10	179.22±11.34
2C3	3621.22±15.01	1560.25±21.13	321.34±15.14	1.90±0.50	9.41±0.10	206.11±14.02
2C4	3126.45±14.21	1317.36±17.11	290.43±14.16	2.62±0.30	NA	284.22±18.15

*NA: Not Analyzed

Locations for dust sampling at 2.0 m & 5.0 m heights:

C1: B. U. K. Road C2: Katsina Road C3: Zaria Road C4: Bata (S/Gari)

Table 4.25d: INAA results of **short-lived** nuclides in Harmattan dust samples **plus** filter collected from City zone and some locations

5G1	2116.05±12.42	1589.09±19.12	294.24±14.00	BDL	4.9±0.10	285.24±17.44	
5G2	2832.40±21.22	823.34±22.04	247.38±14.05	1.82±0.20	7.21±0.10	264.32±12.03	
	North	Al	Ca	Mn	Mg	Na	V
5G3	1773.35±18.21	2231.00±20.43	358.54±15.21	BDL	10.63±0.10	276.11±12.32	
2G4	3133.31±13.01	1560.32±17.21	271.37±14.04	201±0.40	8.04±0.10	245.43±11.00	
2G5	4648.00±17.21	1588.55±13.07	339.23±15.21	5.84±1.60	9.31±0.10	189.23±11.00	
2G6	3692.38±12.02	1266.38±12.14	257.41±14.00	7.82±0.10	7.82±0.10	147.06±13.12	

***BDL**: Below Detection Level

Locations for dust sampling at 2.0 m & 5.0 m heights:

G1: Bichi G2: Rano G3: Gaya G4: Bagwai G5: Bata (Sabon Gari) G6: Zaria Road

Table 4.26a: INAA results of **short-lived** nuclides in Harmattan dust samples collected from northern and southern zones.

	2N1	6716.50±19.60	3093.15±63.30	1445.56±39.0	765.25±12.11	533.25±45.21	191.36±4.55
	2N2	8583.70±76.60	2822.99±165.80	1396.21±46.20	548.14±0.16	823.25±70.44	174.48±11.65
	2N3	7870.60±37.00	2523.00±212.80	1591.63±59.0	561.75±43.10	735.24±22.87	BDL
East		Al	Ca	Mn	Mg	Na	V
	2N4	6687.74±21.60	3135.15±46.90	1435.75±166.0	733.78±9.11	976.25±16.17	203.94±4.65
Av.	2E1	7464.61±63.70	3191.76±122.20	1422.24±52.59	632.25±0.12	867.00±0.21	189.67±12.87
South		Al	Ca	Mn	Mg	Na	V
	5S1	3552.20±20.60	3026.59±73.80	1497.11±142.0	801.67±11.65	502.25±66.21	101.87±32.72
	5S2	5426.40±45.60	2928.15±239.80	1382.45±62.0	925.15±45.16	808.25±45.70	BDL
	5S3	3746.80±21.10	3071.15±174.80	1401.52±150.0	1056.45±34.11	778.25±54.67	BDL
	5S4	4430.60±28.60	2613.13±120.30	1285.61±42.0	587.37±45.11	635.25±22.65	86.83±5.76
Av.		4289.00±30.73	2909.75±127.18	1391.67±49.00	842.65±0.12	680.50±60.10	94.35±12.39

***BDL**: Below detection limit

Locations for dust sampling at 2.0 m & 5.0 m heights:

N1: Bichi N2: Tsanyawa N3: Dawakin Tofa N4: Dambatta
 S1: Dawakin Kudu S2: Rano S3: Bebeji S4: Kura

Table 4.26b: INAA results of **short-lived** nuclides in Harmattan Dust Samples collected from Eastern and Western zones.

	2E2	5193.60±35.10	5211.95±33.80	1268.12±32.30	825.63±26.12	638.00±33.27	151.05±5.65
	2E3	4893.20±29.60	3764.15±24.30	1547.15±28.64	801.45±43.11	676.25±36.00	BDL
City	2E4	5798.70±22.10	4068.15±27.30	1661.72±38.00	5193±30.41	78825±24.17	100.40±12.97
	5C1Av.	7735.235±21.75	7339104452±20809.93	811.184±20500.33	75424.75±34.13	10.69607761±75±30.41	16125452±1430
West		Al	Ca	Mn	Mg	Na	V
	5W1	3761.40±14.60	BDL	1401.61±32.54	1014.76±33.14	423.25±24.56	BDL
	5W2	4197.00±17.60	3093.15±22.50	1011.61±25.32	801.15±27.31	876.65±33.12	99.09±2.54
	5W3	6065.60±22.10	3257.03±25.32	1261.31±25.40	924.35±34.21	598.25±45.88	BDL
	5W4	4450.00±27.60	3394.15±33.34	1489.55±30.32	551.50±21.15	766.25±26.22	86.13±6.88
	Av.	4618.50±20.48	3248.11±27.05	1289.62±28.39	813.94±28.95	653.50±32.45	92.61±40.55

***BDL:** Below detection limit

Locations for dust sampling at 2.0 m & 5.0 m heights:

E1: Wudil

E2: Gaya

E3: Albasu

E4: Garko (Warawa)

W1: Gwarzo

W2: Tofa

W3: Bagwai

W4: Shanono

Table 4.26c: INAA results of **short-lived** nuclides in Harmattan Dust Samples collected from the City zone.

	5C2	6172.63±22.60	4125.32±16.13	647.19±22.72	628.92±31.16	768.66±26.12	151.31±4.31
	2C3	7040.03±43.10	4524.15±27.80	785.61±34.23	818.50±24.12	563.25±23.27	181.63±12.09
		Al(ppm)	Ca(ppm)	Mn (ppm)	Mg (ppm)	Na(ppm)	V(ppm)
	2C4	6423.53±26.48	3266.50±27.80	NA	897.79±28.76	434.48±18.17	134.01±8.53
	5G1(N1)	3447.23±23.58	3265.66±56.76	1021.25±45.55	556.34±32.10	548.66±34.22	179.91±30.54
	Av.	6842.85±28.07	3956.53±25.38	747.97±25.65	692.39±29.54	593.50±22.42	157.00±28.44
	5G2(S2)	4025.15±45.55	2986.56±74.98	1245.75±78.23	610.75±22.65	642.45±65.35	120.00±28.46

NA: Not Analyzed

Locations for dust sampling at 2.0 m & 5.0 m heights:

C1: B. U. K. Road C2: Katsina Road C3: Zaria Road C4: Bata (S/Gari)

Table 4.26d: NAA results of **short-lived** nuclides in Harmattan Dust from other samples

5G3(E3)	5822.81±32.15	4116.23±69.54	993.19± 89.60	827.49±68.54	771.43±38.54	160.44±32.64
Av.	4431.73±36.42	3456.15±68.96	1086.73±98.13	664.86±55.64	654.18±42.98	153.45±30.35
	Al(ppm)	Ca(ppm)	Mn (ppm)	Mg (ppm)	Na(ppm)	V(ppm)
2G4(W3)	7225.71±68.42	3232.77±58.25	1546.01±85.68	896.42±25.36	705.28±68.54	95.57±25.66
2G5(C4)	6056.78±65.22	4425.35±67.44	1267.56±70.33	765.34±14.22	710.35±22.45	BDL
2G6(C3)	7295.56±55.06	3256.33±43.90	1367.44±65.22	814.20±20.12	745.33±35.66	126.45±15.64
Av.	6859.35±62.60	3638.15±60.29	1393.67±80.58	825.32±23.56	720.32±54.27	111.01±20.04

***BDL**: Below detection limit

Locations for dust sampling at 2.0 m & 5.0 m heights:

G1: Bichi G2: Rano G3: Gaya
 G4: Bagwai G5: Bata (Sabon Gari) G6: Zaria Road

Table 4.27a: INAA results of **Long-lived** nuclides in Harmattan dust samples.

	Fe	Ti	Cr	Br	K	Zn	La
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5N1	1307.00±15.10	612.75±33.56	265.74±26.13	201.05±56.98	264.20±16.09	152.30±15.88	38.90±1.00
5N4	1359.04±12.26	798.40±32.87	117.04±12.43	245.42±32.84	213.12±12.54	206.45±10.55	41.35±2.51
5E1	1335.16±14.63	629.33±45.34	201.00±50.05	238.37± 24.81	335.51±25.00	122.18±10.85	39.50±1.64
5E3	1401.80±15.45	698.75±22.71	245.63±50.44	240.30±23.23	311.60±12.21	201.55±9.85	32.65±4.12
5C4	1565.32±13.22	814.80±32.57	215.00±10.61	210.15±43.21	204.42±25.12	180.64±10.00	55.70±6.58
2S2	1353.96±12.53	596.76±18.20	284.32±13.54	286.71±35.76	256.40±28.01	192.58±18.54	41.36±4.22
2S3	1465.34±11.84	698.76±22.53	208.12±25.88	274.50±65.34	199.71±10.47	188.72±9.65	38.70±2.12
2W2	1372.50±15.33	700.25±45.23	265.14±45.66	315.92±26.77	209.00±15.88	211.75±12.45	36.31±1.29
2W4	1438.43±18.21	638.90±16.28	199.86 ±23.30	268.12±14.50	244.00±22.03	201.32±9.56	29.03±5.38
2C2	1426.45±20.75	619.60±19.66	281.83±55.64	220.46±42.31	262.04±12.65	201.51±15.00	35.85±0.40
Mean Value	1402.50±15.14	680.83 ± 28.90	204.96 ± 13.00	250.10±31.61	250.00 ±18.00	185.90 ± 12.23	38.90±1.61

Locations for dust sampling at 2.0 m & 5.0 m heights:

N1: Bichi N4: Dambatta E1: Wudil E3: Shanono C4: Bata (Sabon Gari)
 S2: Rano S3: Bebeji W2: Tofa W4: Shanono C2: Katsina Road

Table 4.27b: INAA results of **Long-lived** nuclides in Harmattan dust samples

	Th	Sc	Sm	U	Hf	Ta	Sb	Co
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5N1	22.30±2.80	8.99±0.08	14.39±0.86	4.24±0.40	5.40±0.40	14.91±2.00	42.85±0.98	11.10±15.10
5N4	18.85±1.66	6.13±0.18	11.42±0.90	5.18±0.90	6.13±0.34	15.88±1.20	54.42±3.84	15.04±12.26
5E1	25.00±2.67	9.61±0.56	10.64±0.61	5.05±0.88	8.95± 1.54	13.72±0.88	43.48±2.54	33.16±14.63
5E3	20.36±0.89	8.32±0.55	9.36±0.44	4.74±0.50	3.50±0.50	19.50±2.50	40.39 ±2.23	19.80±15.45
5C4	20.47±0.49	8.05±0.21	10.64±0.44	3.04±0.20	6.14±0.34	12.50±0.88	58 .15±3.21	16.32±13.22
2S2	15.88±0.33	8.76±0.12	12.36±1.55	2.44±0.50	5.24±1.44	19.03±1.90	46.71±0.91	20.78±1.66
2S3	18.40±1.77	8.23±0.28	14.48±0.65	4.62±0.25	3.01±0.53	10.83±1.06	54.50±2.34	18.63±1.54
2W2	26.12±1.67	6.25±0.45	BDL	5.63±0.52	5.00±0.86	17.07±1.55	45.92±3.77	19.70±0.95
2W4	28.01±4.09	7.40±0.54	13.94±1.65	3.63±0.44	6.26±0.91	10.17±0.38	51.12±4.50	17.85±3.43
Locations for dust sampling at 2.0 m & 5.0 m heights.								
2C2	24.81±0.90	7.36±0.43	12.87±0.87	4.14±0.43	4.38±0. 22	15.49±2.55	42.46±2.31	18.89±4.21
Mean Value	22.00±1.37	7.91 ±0.34	10.99±0.80	4.24 ± 0.40	5.40 ± 0.40	14.91 ± 1.49	48.00±2.63	16.95±2.23

*BDL: Below
Detection Limit

N1: Bichi
N4: Dambatta

E1: Wudil E3: Shanono C4: Bata (Sabon Gari)

S2: Rano

S3: Bebeji

W2: Tofa

W4: Shanono

C2: Katsina Road

Table: 4.28: Elemental constituents of Harmattan dust transported to Kano State, Nigeria

Elements	Al	Ca	Fe	Mn	Mg	Na	Ti
Concentration (ppm)	5645.49±145.14	3547.15±128.67	1402.50±85.27	1240.20±76.10	745.09±64.42	687.25±62.11	680.83±54.12
Elements	Br	K	Cr	Zn	V	Sb	La
Concentration (ppm)	250.10±15.43	250.00±18.24	204.96±13.43	185.90±12.32	132.23±10.42	48.00±6.56	38.90±6.10
Elements	Th	Co	Ta	Sm	Sc	Hf	U
Concentration (ppm)	22.00±6.43	16.95±2.10	14.91±2.00	10.99±2.10	8.96±2.23	5.40±0.20	4.24±0.25

Table 4.29a: Major elements detected in Harmattan dust transported to Kano

	Chemical Elements						
	Al	Ca	Fe	Mn	Co	Mg	Na
Concentration (ppm)	5645.49 48.00±6.56 ±145.14	3547.15 38.90±6.1 ±128.67	1493.50 22.00±6.43 ±85.27	1240.20 16.95±2.10 ±76.10	745.09 ±64.42	14.91±2.00	687.35 ±62.11
	Sm	Sc	Hf	U			
	Ti	Br	K	Cr			
Concentration	10.99±2.10	8.96±2.23	5.40±0.20	4.24±0.25			
Concentration (ppm)	680.83 ±54.12	250.10 ±15.43	250.00 ±18.24	204.96 ±13.43	185.90 ±12.32	132.23 ±10.42	

Table 4.29b: Minor elements detected in Harmattan dust transported to Kano

(ppm)					
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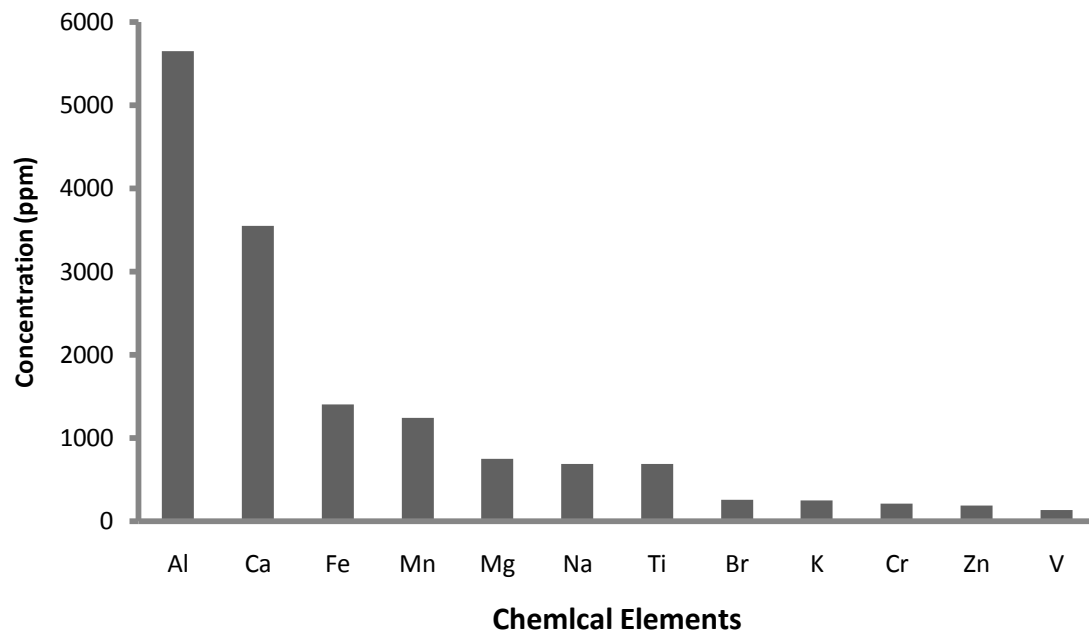


Fig. 4.8: Major elements detected in Harmattan dust transported to Kano State

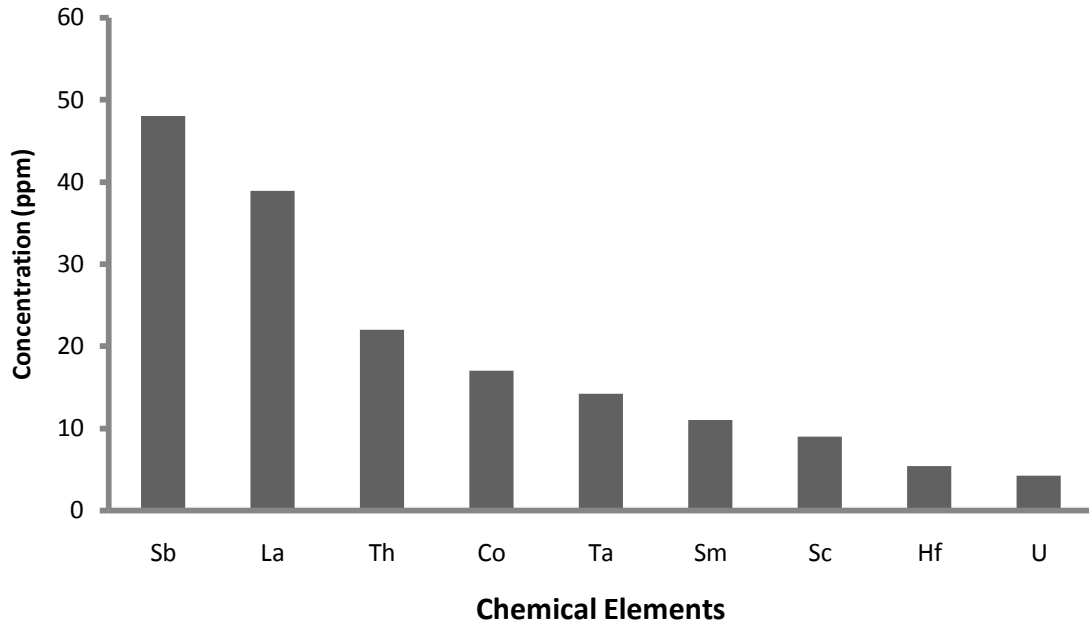


Fig. 4.9: Minor elements detected in Sahara dust transported to Kano State

Some of the elements detected, as the samples were irradiated, featured only in one sample location; that is in one Local Government Area. This indicated that they did not form components of the dust from the Sahara, but were locally generated. There were also those elements that featured in all the zones but were found to be below the detection limit (BDL). Therefore, these two groups of the elements are presented in Table 4.30.

Table 4.30: Elements found below detection limit and those that do not form components of Harmattan dust

Element	As	Ba	Lu	Rb	Yb	Dy	Eu
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Location	2C4	5W2	5N4	5E1	5S3	2C3	2S2
Concentration	0.03±0.00	20.00±4.00	0.01±0.00	0.80±0.22	0.028±0.01	BDL	BDL

Locations visited for Harmattan dust sampling:

N1: Bichi C4: Bata (S/Gari) W2: Tofa C3: Zaria Road
S2: Rano N4: Dambatta E1: Wudil S3: Bebeji
❖ **BDL:** Below the detection limit

4.2.4b Elemental constituent and concentration of Harmattan dust (Contd.)

In an investigation on elemental composition of Harmattan dust collected in Kano State, Nigeria, Adepetu et al. (1988) presented the result with Aluminium having the highest concentration, while uranium is the least. Twenty two elements were identified in his work and they included: Al (6110 ppm), Ca (5840 ppm), Mg (4700 ppm), Fe (4310 ppm),

K (1570 ppm), Mn (825 ppm), Ba (695 ppm), Na (640 ppm), Ti (490 ppm), Zn (220 ppm), Br (195 ppm), Cr (119ppm), Rb (82.4 ppm), V (81.6 ppm), La (53.9 ppm), Sb (32.7 ppm), Ga (21.9 ppm), Co (20.9 ppm), Th(14.0 ppm), Sc (10.3 ppm), As (6.59 ppm), Sm (6.50 ppm), and U (6.28 ppm). There were four elements he found in his result which were not detected in the present work; while in the result of this same work three elements were identified, which were not detected in his work. The elements he detected which were not found in this work were Rb (82.4ppm), Ga(21.9ppm), Ba (695ppm) and As (6.59ppm), and those elements in our result which were not included in his result were Ta(14.91±2 ppm), Hf (5.40±0.40 ppm) and Ca (3547.15±128ppm).

Also, Adeyemo et al. (1989) of Obafemi Awolowo University, Ile-Ife, Nigeria, obtained a total of eight major chemical compounds in percentages as constituents of Sahara dust in Ile-Ife, Nigeria. The authors found the content of alumina relatively high and so concluded that, 'the relatively high alumina (Al_2O_3 ; 17.74%) content of the dust is reflective of its clayey nature.' Linke et al. (2006) collected dust samples in the Sahara at Cairo(2) (70km northeast), Cairo City(3), soil from Agadez (Niger), and another soil sampled from Morocco in Libya; and then used X-Ray Fluorescence analytical technique to determine optical properties and mineralogical composition of the samples. The chemical compound content of alumina (Al_2O_3) in the samples ranked second in weight %, after SiO_2 at three locations (Cairo 3, Agadez and Morocco), while CaO ranked third in these same locations. However, alumina (Al_2O_3) is an oxide of aluminium (Al), the element found with the highest concentration in this work. Therefore, the findings of both Adeyemo et al. (1989) and Linke et al. (2006) are in some way in agreement with the finding in this work relative to the element with the highest concentration in the Sahara dust – aluminium. The element aluminium, moreover, is the third most abundant element (after oxygen and silicon – another reason why alumina ranked second after SiO_2 in the work of Linke et al. (2006)). Aluminium is the most abundant metal in the Earth's crust (Shakhashiri, 2008). Therefore, this relative abundance reflects its high concentration as detected in this work.

The high concentration of aluminium detected in the dust samples (fig. 4.8) is an indication of the clayey nature of the Harmattan dust transported to Kano, and its source probably being the Bodélé area of the Chad Basin in the Sahara; the area from which the influxes of the northeast Trade Winds transport the dust to Nigeria.

When the results of elemental analysis of the dust samples for this work were considered zone by zone (North, South, East, West and the City of Kano State), it was found that the dust was again richer in aluminium content in all the zones, followed by that of Calcium Table (4.31). Also, the content of aluminium was found higher in the northern zone than those found in each of the other zones (fig.4.9). Perhaps this could be attributed to the direction of the dust influx from the Sahara into the state, as well as due to North-zone proximity to the dust source. Vanadium has the least concentration among the major elements in all the 5 zones (fig4.10). It ranks about 19th in abundance of the elements in Earth's crust; and it is never found in the pure state, but occurs in combination with various minerals throughout the world (Microsoft Encarta, 2009).

Table 4.31a: Mean concentrations of major elements in the Harmattan dust collected per zone in Kano State.

Zones	Al (ppm)	Ca (ppm)	Fe (ppm)	Mn (ppm)	Mg (ppm)	Na (ppm)	Ti (ppm)
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North	7464.61 ±148.14	3191.76 ±128.60	1486.35 ±85.27	1422.24 ±76.10	652.23 ±64.42	767.00 ±62.11	594.24 ±54.12
South	4289.00 ±139.43	2909.75 ±141.32	1524.61 ±32.76	1391.67 ±141.61	842.65 ±23.44	680.50 ±14.55	689.12 ±25.96
East	5012.75 ±177.11	4429.60 ±176.54	1369.23 ±154.96	1349.50 ±124.45	724.24 ±76.21	741.75 ±28.22	724.36 ±17.90
West	4618.50 ±206.10	3248.11 ±144.43	1487.50 ±213.21	1289.62 ±104.27	813.94 ±43.27	653.50 ±56.88	682.05 ±10.49
City	6842.85 ±187.33	3956.60 ±184.38	1144.81 ±176.99	747.97 ±155.62	692.39 ±87.31	593.50 ±33.72	714.38 ±28.61

Table 4.31b: Mean concentrations of major elements in the Harmattan dust collected per zone in Kano State

Zone	Br (ppm)	K (ppm)	Cr (ppm)	Zn (ppm)	V (ppm)
North	268.12 ±15.43	215.49 ±18.24	210.10 ±13.43	189.67 ±10.42	180.64 ±12.32
South	220.89 ±24.77	240.61 ±32.14	198.64 ±28.36	201.32 ±18.95	102.35 ±15.23

East	315.50 ±45.44	276.15 ±32.21	284.32 ±19.66	164.42 ±25.50	127.52 ±14.73
West	230.14 ±27.66	284.25 ±42.37	213.04 ±21.40	192.63 ±10.52	132.61 ±21.80
City	215.85 ±14.52	230.50 ±18.46	118.70 ±24.27	190.49 ±22.15	157.00 ±13.62

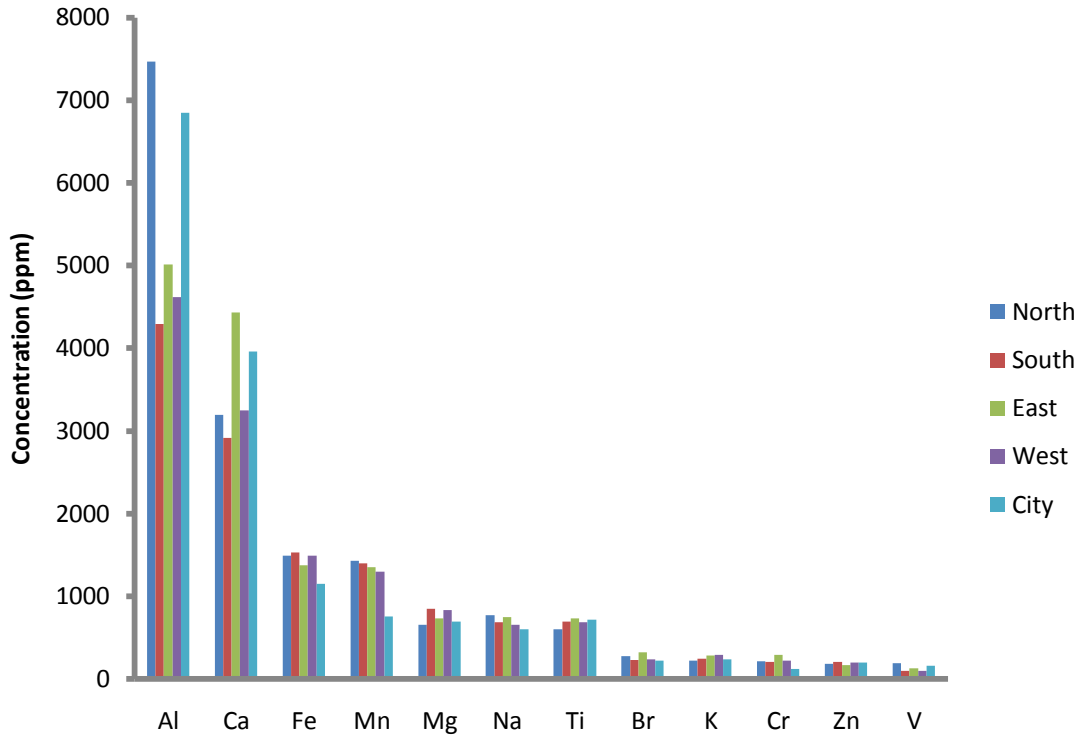


Fig. 4.10: Major elements detected in Harmattan dust per Zone

In all the minor elements detected (defined in this work as elements with concentration less than 100ppm), Lanthanum (La) and antimony (Sb) have higher concentrations with values greater than 30ppm but less than 55 ppm in all the zones (Table 4.32); and the concentration of antimony remained the highest even though it is more of a heavy metal which has specific gravity 6.7 more than that of lanthanum with specific gravity 6.5. Perhaps local contributions by anthropogenic processes could be the reason for its higher value. Cobalt (Co) and thorium (Th) have concentration less than 30ppm but greater than 10 ppm, while hafnium (Hf) and uranium (U) are the elements found with the least concentration, < 6ppm in all the zones.

Table 4.32: Mean concentrations of minor elements in the Harmattan dust collected per zone in Kano State.

Zones	Co (ppm)	Hf (ppm)	La (ppm)	Sb (ppm)	Sc (ppm)	Sm (ppm)	Ta (ppm)	Th (ppm)	U (ppm)
North	18.87 ±1.83	5.32 ±0.92	40.13 ±2.61	44.78 ±0.95	8.86 ±0.12	13.38 ±0.80	16.97 ±1.95	19.05 ±1.57	3.34 ±0.45
South	15.75 ±1.90	4.57 ±0.44	40.03 ±2.32	54.46 ±3.09	7.16 ±0.43	12.95 ±0.78	13.36 ±1.13	18.63 ±1.72	4.90 ±0.56
East	18.93 ±1.83	6.98 ±1.20	37.91 ±1.47	44.70 3.16	7.93 ±0.51	10.64 ±0.61	15.40 ±1.22	25.56 ±2.17	5.34 ±0.70
West	13.99 ±2.18	4.88 ±0.71	30.84 ±4.75	45.76 ±2.53	7.86 ±0.55	11.65 1.03	14.84 ±1.44	24.19 ±2.45	3.30 ±0.47
City	17.23 ±3.78	5.26 ±0.28	45.78 ±3.49	53.08 ±2.92	7.71 ±0.32	11.66 ±0.66	14.00 ±1.72	22.54 ±0.49	3.59 ±0.30

4.2.5 Concentration of elements in Harmattan dust with respect to height

The mean concentrations of all the 12 major elements detected in the Harmattan dust collected in Kano at respective altitudes of 2.0m and 5.0m have been presented in Tables 4.33 a & b. Six out of twelve of these elements (Mg, Na, Ti, Br, K and Cr) have

concentrations in some hundreds parts per million (ppm); Fe and Mn have concentrations just above a thousand, while Zn and V are with concentrations just above a hundred; only Al and Ca have concentrations in some thousands. However, on the overall, the analytical technique applied indicated that the concentrations of these major elements were almost uniform at the two respective altitudes of 2.0 m and 5.0 m, except in the case of aluminium and calcium. The concentrations of these two elements were found to be higher at 2.0 m above the ground level when compared to what was obtained at 5.0 m. This could be attributed to local contribution through anthropogenic processes, added to the fact that aluminium is the third most abundant element (Earnshaw, 1997) and calcium the fifth in the Earth's crust (Microsoft Encarta, 2009).

Calcium is among the most abundant minerals in the body. It is found in some foods and also in some vegetable; added to others; available as a dietary supplement; and present in some medicines (such as antacids). About 99% of the body's calcium supply is stored in the bones and teeth where it supports their structure and functions, and the remaining 1% is needed for the critical metabolic functions which include vascular contraction, muscle function, nerve transmission, intracellular signaling and hormonal secretion. But aluminum has no any known biological function in the body.

Table (4.33a): Major elements in the Harmattan dust at (2.0 m) and (5.0 m) heights

	Al (ppm)	Ca (ppm)	Fe (ppm)	Mn (ppm)	Mg (ppm)	Na (ppm)	Ti (ppm)
At 2m	6238.68 ±228.54	3810.68 ±135.43	1427.79 ±210.76	1385.87 ±118.62	688.24 ±45.49	754.38 ±21.64	659.30 ±13.55
At 5m	4453.75 ±118.32	3078.93 ±123.44	1506.06 ±132.66	1340.65 ±231.55	828.30 ±45.44	667.00 ±24.66	685.59 ±28.10
Specific Gravity	2.70	1.55	7.87	7.40	1.74	0.97	4.5

Table (4.33b): Major elements in the Harmattan dust at (2.0 m) and (5.0 m) heights

	Br (ppm)	K (ppm)	Cr (ppm)	Zn (ppm)	V (ppm)
At 2m	291.81 ±44.30	245.82 ±21.86	210.10 ±13.27	180.64 ±10.87	158.60 ±12.52
At 5m	225.52 ±32.76	262.28 ±13.5	284.32 ±34.22	127.52 ±12.66	93.48 ±14.82
Specific Gravity	3.10	0.86	7.2	7.14	6.11

The difference in concentrations of the elemental components of the dust collected at 2.0m and 5.0m above the ground level is more pronounced in the case of the minor elements (fig.4.10); the concentrations being higher for elements detected in the dust that was collected at 2.0m above the ground level. Anthropogenic sources again could be the causative factors for the higher values at the altitude. Furthermore, with the exception of scandium (Sc), all the elements are found to be heavy metals with specific gravity in the range 6.7 to 13.3 (see Table 4.34). This could be another factor contributing to their concentration being higher at the lower altitude of 2.0m. They were found to be among the heavy metals, and so they concentrate more at a lower altitude in the atmosphere as they are locally generated; this is in addition to the components of the elements already transported from the Sahara.

Table 4.34: Minor elements in the Harmattan dust at (2.0m) and (5.0m) AGL.

Element Concentration	Sb (ppm)	La (ppm)	Th (ppm)	Co (ppm)	Ta (ppm)	Sm (ppm)	Sc (ppm)	Hf (ppm)	U (ppm)
At 5m(AGL)	48.00	38.90	22.00	16.95	14.91	10.99	8.96	5.40	4.24
At 2m(AGL)	68.53	56.87	40.56	22.95	20.45	18.43	12.24	10.60	8.24
Specific gravity	6.7	6.5	11.7	8.9	11.65	7.52	2.99	13.30	11.05

AGL: Above Ground Level

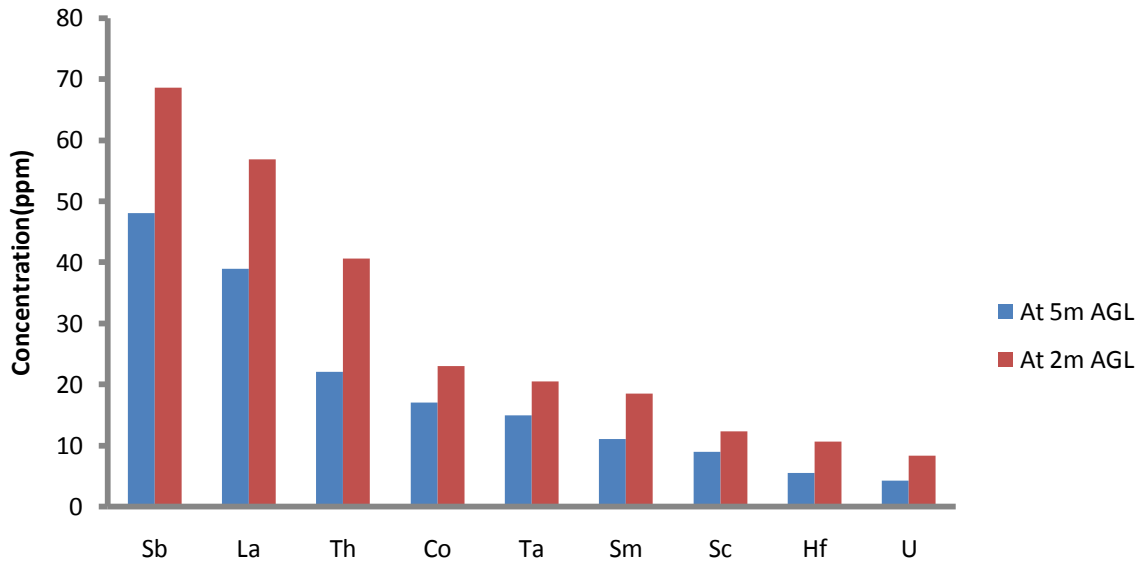


Fig. 4.11: Minor Elements in the Harmattan Dust collected at heights of 2.0 m and 5.0 m

When investigating the elemental constituents (as well as the concentration) of the Harmattan dust in the busiest areas in Kano City zone, which included Bata (S/Gari), Zaria Road, Katsina Road and B. U. K. Road (Tables 4.35 a & b), it was found that the concentration of aluminium in the dust was higher along B.U. K. Road, followed by that obtained at Zaria Road while Katsina Road was the least in concentration of the metal. Anthropogenic contributions to the air pollutants are the most likely causes of the disparity. The concentration of Calcium was also found higher (after aluminium) in the dust collected along Zaria Road, followed by that obtained in Katsina Road. These two locations, Zaria Road and Katsina Road, used to be rich in vegetations; which is another source of calcium according to Lawrence (2011). Iron ranked third in concentration among the elements detected at the City zone. In spite of all these, it is important to note that because of the prevailing abundance of the Harmattan dust in the atmosphere during the period of this study (January/February), the results of NAA obtained in this work have negligible interference from anthropogenic sources.

City		Al	Ca	Mn	Mg	Na	V
	5C1	7735.23 ±20.10	3910.15 ±29.80	811.11 ±20.00	424.35 ±34.11	607.61 ±22.12	161.54 ±21.44
	5C2	6172.63 ±22.60	4125.32 ±16.13	647.19 ±22.72	628.92 ±31.16	768.66 ±26.12	151.31 ±4.31
	2C3	7040.03 ±43.10	4524.15 ±27.80	785.61 ±34.23	818.50 ±24.12	563.25 ±23.27	181.63 ±12.09
	2C4	6423.53 ±26.48	3266.50 ±27.80	NA	897.79 ±28.76	434.48 ±18.17	134.01 ±8.53

Table 4.35a: Elements detected in Harmattan dust sampled from the City zone in Kano state, Nigeria

NA: Not Analyzed

Locations for dust sampling at 2m & 5m (AGL):

C1: B. U. K. Road C2: Katsina Road
C3: Zaria Road C4: Bata (S/Gari)

Table 4.35b: Elements detected in Harmattan dust sampled from the City zone in Kano state, Nigeria (**Contd.**)

City		Fe	Ti	Cr	Br	K	Zn
	5C1	1648.21 ±17.38	788.45 ±13.11	239.53 ±15.17	215.44 ±11.08	219.36 ±0.10	165.83 ±1.60
	5C2	1565.32 ±13.22	814.80 ±32.57	215.00 ±10.61	210.15 ±43.21	204.42 ±25.12	180.64 ±10.00
	2C3	1283.27 ±21	823.25 ±22.18	247.63 ±14.15	244.73 ±12.41	217.21 ±0.10	231.82 ±0.20
	2C4	968.45 ±20.75	619.60 ±19.66	281.83 ±55.64	220.46 ±42.31	262.04 ±12.65	201.51 ±15.00

Locations for dust sampling at 2m & 5m (AGL):

C1: B. U. K. Road C2: Katsina Road
C3: Zaria Road C4: Bata (S/Gari)

The minor elements detected in Harmattan dust collected at Bata (S/Gari) and Katsina Road (Table 4.35c) were found comparable in concentration, except in the case of antimony (Sb) and Lanthanum (La) whereby the concentrations of the two elements at Bata (S/Gari) were found relatively higher. Antimony is the 64th in natural abundance among the elements found in crustal rock and has a specific gravity of 6.70, while Lanthanum is the 28th in order of abundance of elements in Earth's crust and it has a specific gravity of 6.15. The location Bata (S/Gari) is, however, more of a crowded place which is situated by Kano State Central Market; human activities are at their peak in the area. Therefore, with much vehicular and pedestrians movements, there is much dust generated, and this increases the particulates loaded into the atmosphere at the location more than the case at Katsina Road. This could be among the reasons for having higher concentrations of the two elements at the site more than at Katsina Road.

Table 4.35c: Minor elements detected in Harmattan dust sampled from some sites of City zone in Kano state, Nigeria (**Contd.**)

	Th	Sc	Sm	U	Hf	Ta	Sb	Co	La
5C4	20.47 ±0.49	8.05 ±0.21	10.64 ±0.44	3.04 ±0.20	6.14 ±0.34	12.50 ±0.88	58.15 ±3.21	16.32 ±13.22	55.70 ±6.58
2C2	24.61 ±0.00	7.36 ±0.43	12.67 ±0.87	4.14 ±0.43	4.38 ±0.22	15.49 ±2.55	42.46 ±2.31	18.89 ±4.21	35.85 ±0.40

Locations for dust sampling at 2m & 5m (AGL):

C4: Bata (S/Gari) C2: Katsina Road

In another work in the same area of study, Ibeanu (1993) had explained how Electron Microprobe Analyzer/Scanning Electron microscope (EMPA/SEM) was used in analyzing the air particulates collected in January, 1989. The author used a sampling-equipment for 8 hours on top of a building in Kano to collect the particulates. After analysis, a total of 13 elements were detected in varying concentrations along the 6-stage cascade impactor of the air sampler used. These include Si, Ca, Al, P, Mg, S, Cl, K, Ti, Mn, Fe, Cu and Zn.

In contrast to the findings in the present work, the element calcium in Ibeanu's (1993) results has the highest mean concentration after silicon [Ca (107 279.5±7746.8µg/g)]. No reason was advanced by the author for the relative abundance of the particle in the finding. But calcium is the fifth in abundance among the elements in the Earth's crust, while aluminium is the third after oxygen and silicon (Microsoft Encarta, 2009). Thus, calcium is less in abundance in the Earth's crust when compared with aluminium, the element found with highest concentration in present work. However, it has been stated earlier that when the Sahara dust is in transportation, it interacts with the atmosphere, with the oceans, and undergoes bio-geochemical processes with adverse implications on, among others, its particulate composition. This might explain the highest concentration of calcium in Ibeanu's (1993) results obtained at that time, even though the element is less in abundance in the Earth's crust than aluminium; and it has no clayey property which is known to be among the properties of the dust source in the Sahara (in the Chad Basin) for northwestern Nigeria where Kano State is located.

4.2.6 Health Implication of Harmattan Dust

There are some chemical elements that are needed by human body in very small amounts from diet for growth, better health and protection of some vital organs from invaders. However if these elements exceed their dietary recommended allowances in the human body, they can become toxic. Major minerals (conventionally defined as those chemical elements required by the body in amounts of 100mg/day) include calcium, phosphorus, potassium, sodium, chloride, magnesium, thorium and sulfur; and minor minerals are chromium, cobalt, fluoride, zinc, selenium, boron, iron, copper, iodine, manganese, molybdenum, nickel, and silicon (Abbot, 2010). And Minor minerals (or Trace elements) are defined as those required by the body in amounts less than 100 mg/day. The concentrations of the major and trace elements required by human body but found in the Harmattan dust transported to Kano are in Table 4.36

Bala (2003) has observed that during Harmattan period in Kano State people were infected with cold viruses which affect the mucous membranes of the nose and the throat, causing such symptoms as nasal congestion and discharge, sore throat, and coughing. These symptoms, he reiterated, might not be directly linked to Harmattan dust but to the fact that people become overcrowded in places that are securely closed just in an attempt to evade the cold wind forcefully blowing during the period and then making the condition for spreading diseases by infection more conducive.

Table 4.36: Major and trace elements required by human body but detected in Harmattan dust

Chemical Elements					
Ca	Fe	Mn	Mg	Na	Br
3547.15 ±128.67	1402.50 ±85.27	1240.20 ±76.10	745.09 ±64.42	687.25 ±62.11	250.10 ±15.43
K	Cr	Zn	Th	Co	
250.00 ±18.24	204.96 ±13.43	185.90 ±12.32	22.00 ±6.43	16.95 ±2.10	

The Recommended Dietary Allowances (RDA) and Upper Limits (UL) as well as the functions of some of the elements in human body have been presented by National Academies (2001) (see Appendix 7). These elements have also been detected in the Harmattan dust in its ubiquitous form in the area under study.

Some heavy metals (chemical elements with specific gravity at least 5 times that of water) when they enter into the human body and accumulate in the soft tissues without getting metabolised, they become toxic – i.e. poisonous. Murphy et al., (2007) asserted that Particulate Matter acts as a vehicle for the atmospheric transport and inhalation of toxic substances such as heavy metals. And Glanze (1999) listed 23 of these elements, which include antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc. And iron, manganese, and chromium are among the elements detected in the Sahara dust samples of this work with concentration above 100 ppm; and so are defined as major elements.

Considering the period under review, January and February, which is of intense Sahara dust in the entire northwestern Nigeria where Kano State is located, it could be stated that the results of INAA presented in this work are for the Sahara dust. The contribution from anthropogenic sources could be considered negligible due to the fact that it is only at this period that flights are cancelled due to the thick haze resulting from the Sahara dust that besieged the State.

From the results of the investigations carried out on Harmattan dust in this work, seven of the elements listed by Galanze (1999) as toxic, were found among the elemental constituents of the Harmattan dust, and they have been presented in Table 4.37 with their respective concentrations. With the exception of cobalt and uranium, all the other five

Element	Co	Cr	Fe	Mn	U	V	Zn
Concentration (ppm)	16.95 ±2.01	204.96 ±13.11	1402.50 ±85.23	1240.20 ±76.30	4.24 ±0.40	132.23 ±10.12	185.90 ±12.07

elements have concentrations greater than 100 ppm; and for this reason, we define (in this work) elements detected in the samples and with concentrations greater or equal to 100 ppm as major elements, while those with concentrations less than 100 ppm are defined as minor elements.

Table 4.37: Some toxic elements found among the constituents of Harmattan dust

ALUMINUM, the most abundant elements detected in Harmattan dust transported to Kano State has its health effects on humans and these include: production of mental status changes, Learning disabilities, speech disturbances, and coarse tremors. It fosters bone disorders, including fractures; causes a microcytic hypoproliferative anaemia; it is a toxic agent in the etiology of Alzheimer's disease; and it kills liver cells. It causes blood to clot at 3–4 ppm, causing strokes and heart attacks (<http://customers.hbci.com>). Banks and Kastin (1989), Linda (2011), Jann (2006), Pfeiffer (2008), Helmboldt (2007) and Institute of Medicine, Washington DC (2001) have indicated the toxic effects of some elements (see Appendix 8). The elements are, however, found among the constituents of the Harmattan dust transported to Kano State.

CHAPTER 5

Summary, Conclusion and Recommendations

5.1 Summary

The Harmattan dust collected at elevations of 2.0 and 5.0 metres above the ground level in each of the 20 sampling sites from twenty local government areas of Kano State, Nigeria, was found to have a mean gravimetric concentration of $2.268 \text{ mgm}^{-3} \pm 0.04\%$. Faya Largeau in the Sahara desert was considered as the source of the dust. The value was considered high when compared to 1.6 mgm^{-3} , 1.7 mgm^{-3} , and 1.4 mgm^{-3} obtained by Utah et al., (2005) for Jos, Bauchi and Makurdi respectively with Libya considered as the dust source.

The mean gravimetric concentration of $2.788 \text{ mgm}^{-3} \pm 0.04\%$ determined in the City zone was found to be higher than $2.120 \text{ mgm}^{-3} \pm 0.04\%$, $2.181 \text{ mgm}^{-3} \pm 0.04\%$, $2.189 \text{ mgm}^{-3} \pm 0.04\%$, and $2.155 \text{ mgm}^{-3} \pm 0.04\%$, obtained for North, South, East, and South zones of around Kano respectively. The high value of the concentration in the City could be attributed to much anthropogenic contribution.

The absorbance of atmosphere, a parameter often used in designing some instruments that measure aerosol concentration by light extinction, was determined as $16.981 \times 10^{-2} \pm 0.02\%$ in Kano State. That obtained for Sokoto ($20.746 \times 10^{-2} \pm 0.06\%$) State by Sambo and Aliyu (1998) was higher because of the proximity of the State to the Sahara dust source in Niger Republic.

Atmospheric turbidity in Kano State was determined as $0.39 \pm 0.02\%$, and the mean value of air density was found to be $3.48 \text{ kg m}^{-3} \pm 0.14\%$ at 32.8°C during the Harmattan period. However, there is an inverse proportion between the concentration of particulate matter in the atmosphere (an indicative factor for turbidity) at any location and the distance of the location from the source (Adeyemo, 1989).

Absolute viscosity of air, which is temperature dependent, was evaluated at mean value of $1.88 \times 10^{-5} \text{ Nsm}^{-2} \pm 1.06\%$ at 32.8°C during Harmattan period in this work. Its minimum value of $1.85 \times 10^{-5} \text{ Nsm}^{-2} \pm 1.06\%$ was determined during the month of January.

The Coriolis force that originates due to the rotation of the Earth and is acting on all moving objects, including mass of air, was found to have a value of $1.439 \times 10^{-4} \text{ N} \pm 0.28\%$. The force was found to be larger in January and February, the period found with the wind blowing forcefully.

The average wind speeds computed during the Harmattan period of (1998/1999 – 2002/2003) in Kano State was 4.70 ms^{-1} . And the Reynolds number used for expressing the turbulent nature of wind flow was established as $9.10 \times 10^4 \pm 3\%$. Then the resulting average wind power density during the season was determined at $193.26 \text{ Wm}^{-2} \pm 1.0\%$.

When neutron activation analysis (NAA) technique was used in analyzing the elemental constituent of Harmattan dust for this work, 21 elements were detected with Aluminum, Calcium, Iron and Manganese dominating with concentrations above 1000ppm. However, in earlier research works in the same location by Adepetu *et al.* (1988) and Ibeanu (1993), the elements that featured prominently with concentrations above 1000ppm were Aluminium, Calcium, and Iron. Some elements detected with health implications because of their toxic nature include cobalt, chromium, iron, manganese, uranium, vanadium and zinc. Uranium and cobalt were the only elements found with concentration less than 100 ppm.

5.2 Conclusion

The impact of the Harmattan wind around Kano is conspicuously felt in every house as a result of the ubiquitous deposition of its in-borne dust which covers tables, windows, beds, plates, including our bodies; with our faces turned grey by the eminent colour of the dust. Therefore, the importance of addressing questions concerning the quantity, the origin, and the impact of the dust on the surroundings cannot be overemphasized. In particular, for a proper understanding and quantification of the impact of the Harmattan dust at any location, a detailed knowledge on the dust physical, elemental and chemical characteristics is necessary. And this is the main aim of this work when conducted around Kano, Nigeria.

Therefore, some of the parameters of the Harmattan dust (or Saharan dust) as it reaches Kano State, which have been established for the first time in the area include air density, air turbidity, air viscosity, atmospheric absorbance, wind speed, wind power, wind power density, the Coriolis force, and the Reynolds number which expresses air turbulence. Then Neutron Activation Analysis was applied in investigating the elemental constituent of the dust collected around the area. During the analysis, 21 elements were detected in the dust. It has been established in this work that there is an added advantage of collecting and analyzing air particulates at several sites in a location, as particulates that do not form components in an intended sample can easily be identified and sorted out.

5.3 Recommendations

1. Frequent monitoring of air pollution, particularly dust concentration in the atmosphere, is recommended for densely populated areas like Kano State.
2. People, especially children, should be wearing thick clothes to avoid falling sick during Harmattan period; and as much as possible they should avoid getting crowded in poorly ventilated places as such a situation makes it easier to get infected with cold viruses.
3. It is also recommended that Medical personnel and other researchers should be working together regularly in investigating the health effects of air pollutants in this country. This will help greatly in reducing the hazards associated with air pollution.
4. Sampling exercise of air pollutants from a distant source should be carried out at several receptive sites rather than one. Local contributions could easily be traced and identified then.

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Appendix 1: Mean concentration of air particulates in Kano (Ibeanu, 1993)

		Mean Concentration of Particulates in the Atmosphere ($\mu\text{g/g}$) Along Different Impactor Stages					
	1	2	3	4	5	6	Total
Al	184.2	2253.7	2679.9	1513.7	834.1	1779.1	9244.7
Si	5565.5	28116.9	50118.7	23254.7	23844.6	16127.2	147027.6
P	*	*	*	*	1545.4	1953.5	3498.9
S		7278.8	14691.5	5957	5561.1	6968.1	40456.5
Cl	1050.7	1668.7	2051.9	667.5	1854.1	*	7292.9
K	12490. 9	43267.6	63124.4	29582.3	34348.4	2261.3	185074.9
Ca	33833. 6	14289.2	22392.6	88100.4	95942.8	58980.5	313539.1
Ti	*	2.2	6.1	3.4	2.5	*	14.2
Mn		*	11.5	14.2	*	11	36.7
Fe	2149	9129.3	14579.3	6823.9	7806.3	4836.2	45324
Cu	1	1.2	0.9	1.1	1.1	1.1	6.4
Zn	36.8	16.7	*	*	24.4	22.6	100.5

*Not Available

Gases	Concentration	Residence Time
N₂	0.780 84	4x10 ⁸ yr for cycling through sediment
O₂	0.20 946	6x10 ³ yr for cycling through sediment
Ar	9.34 x 10 ⁻³	Largely accumulating
CO₂	0.346 x 10 ⁻³	10yr, for cycling through biosphere
H₂O	(4 - 0.004) x10 ⁻²	-
Ne	1.818 x 10 ⁻⁵	Largely accumulating
He	5.24 x 10 ⁻⁶	2 x 10 ⁻⁶ yr for escape
N₂O	3.3 x 10 ⁻⁷	5-50 yr.
Xe	8.7 x 10 ⁻⁸	Largely accumulating
O₃ (Ozone)	(3-1) x 10 ⁻⁸	-
CH₂O(formaldelyde)	<1 x 10 ⁻⁸	-
NH₃ (Ammonia)	(20-6) x 10 ⁻⁹	About 1 day
SO₂	(4 -1) x 10 ⁻⁹	Hours to weeks
NO + NO₂	1 x 10 ⁻⁹	> 1 month
CH₃Cl (methylchloride)	5 x 10 ⁻¹⁰	-
CCl₄ (carbontetrachloride)	(2.5-1) x 10 ⁻¹⁰	-
CF₂Cl₂ (Freon 12)	2.3 x 10 ⁻¹⁰	45-68 yr.

Appendix 2: Composition of the Atmosphere and concentration (by volume) of its components.

H₂S	5.2×10^{-10}	<1 day
CFCL₃ (Freon 11)	1.3×10^{-10}	45-68 yr
Co	$(2-0.6) \times 10^{-7}$	0.5 yr.

(Source: Cadle, 1975)

Appendix 3a: Some Meteorological data on Harmattan weather in Kano State, Nigeria (1998/1999 Season)

	Nov. 1998	Dec. 1998	Jan. 1999	Feb. 1999	Mar. 1999	Total	Average
Relative Humidity (%) ($\pm 0.02\%$)	25.30	25.20	21.40	24.10	16.00	12.00	22.40
Wind Direction ($^{\circ}$) ($\pm 0.03\%$)	13.20	13.80	14.80	15.30	11.80	68.90	13.80
Max. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	34.10	29.80	26.5	23.50	37.00	160.90	32.20
Min. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	16.20	12.90	15.4	17.80	16.50	79.10	15.80
Pressure at m.s.l. (mb) ($\pm 2.0\%$)	1011.10	1014.30	1014.30	1013.70	1011.80	5065.20	1013.00
Station Level Pressure (mb)($\pm 2.0\%$)	957.10	959.20	959.50	959.80	958.20	4793.80	958.80

Appendix 3b: Some Meteorological data on Harmattan weather in Kano State, Nigeria (1999/2000 Season) (**Contd.**)

	Nov. 1999	Dec. 1999	Jan. 2000	Feb. 2000	Mar. 2000	Total	Average
Relative Humidity (%) ($\pm 0.02\%$)	19.60	23.00	21.60	18.90	17.90	101.00	20.20
Wind Direction ($^{\circ}$) ($\pm 0.03\%$)	12.40	13.20	15.80	14.80	13.10	69.30	13.90
Max. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	36.70	35.20	26.30	32.40	37.10	167.70	33.50
Min. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	19.50	17.30	12.70	16.20	21.80	87.50	17.50
Pressure at m.s.l. (mb) ($\pm 2.0\%$)	1011.40	1013.80	1013.50	1010.60	1007.30	5056.60	1011.30
Station Level Pressure (mb)($\pm 2.0\%$)	957.70	959.20	958.10	956.80	954.30	4786.1	957.20

Appendix 3c: Some Meteorological data on Harmattan weather in Kano State, Nigeria (2000/2001 Season) (Contd.)

	Nov. 2000	Dec. 2000	Jan. 2001	Feb. 2001	Mar. 2001	Total	Average
Relative Humidity (%) ($\pm 0.02\%$)	26.70	23.00	25.00	28.30	17.00	120.00	24.00
Wind Direction ($^{\circ}$) ($\pm 0.03\%$)	11.80	13.00	11.20	11.10	13.90	61.00	12.20
Max. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	32.80	31.70	27.60	36.20	37.50	165.80	33.20
Min. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	16.90	15.80	15.40	16.20	16.60	80.90	16.20
Pressure at m.s.l. (mb) ($\pm 2.0\%$)	1012.00	1014.10	1012.00	1014.90	1009.80	5062.80	1012.60
Station Level Pressure (mb) ($\pm 2.0\%$)	958.20	959.30	957.50	959.90	956.20	4791.10	958.20

Appendix 3d: Some Meteorological data on Harmattan weather in Kano State, Nigeria (2001/2002 Season) (**Contd.**)

	Nov. 2001	Dec. 2001	Jan. 2002	Feb. 2002	Mar. 2002	Total	Average
Relative Humidity (%) ($\pm 0.02\%$)	21.50	23.40	20.80	22.00	18.60	106.90	21.40
Wind Direction ($^{\circ}$) ($\pm 0.03\%$)	12.60	11.40	14.60	13.40	12.30	64.30	12.90
Max. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	33.80	30.60	29.20	30.40	36.90	160.90	32.20
Min. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	14.10	11.10	10.60	12.60	16.50	64.90	13.00
Pressure at m.s.l. (mb) ($\pm 2.0\%$)	1013.80	1012.30	1012.60	1013.00	1012.80	5064.50	1012.90
Station Level Pressure (mb)($\pm 2.0\%$)	958.10	957.20	958.50	959.80	957.20	4790.80	958.20

Appendix 3e: Some Meteorological data on Harmattan weather in Kano State, Nigeria (2002/2003 Season) (**Contd.**)

	Nov. 2002	Dec. 2002	Jan. 2003	Feb. 2003	Mar. 2003	Total	Average
Relative Humidity (%) ($\pm 0.02\%$)	28.80	20.40	20.00	15.80	15.10	100.10	20.00
Wind Direction ($^{\circ}$) ($\pm 0.03\%$)	7.90	8.90	14.60	9.90	7.40	48.70	9.70
Max. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	33.70	34.90	32.50	30.50	37.60	169.20	33.00
Min. Temp. ($^{\circ}\text{C}$) ($\pm 0.02\%$)	14.60	12.80	11.70	13.90	20.00	73.00	14.60
Pressure at m.s.l. (mb) ($\pm 2.0\%$)	1013.40	1013.50	1013.70	1012.80	1011.50	5064.90	1013.00
Station Level Pressure (mb) ($\pm 2.0\%$)	958.70	959.40	959.10	955.80	957.30	4790.30	958.10

APPENDIX 4: Seventy four elements detected in samples, using INAA Technique

With minimum detection limits ranging from 0.1 to 1×10^6 mg g⁻¹, INAA can detect up to 74 elements depending upon the experimental procedure, and depending on elements under investigation. Heavier elements have larger nuclei; therefore they have a larger neutron capture cross-section and are more likely to be activated. Some nuclei can capture a number of neutrons and remain relatively stable, not undergoing transmutation or decay for many months or even years.

Estimated Detection limits for INAA using decay gamma rays (assuming irradiation in a reactor neutron flux of 1×10^{13} n cm ⁻² s ⁻¹)	
Sensitivity (picograms)	Elements detected
1	Dy, Eu
1–10	In, Lu, Mn
10–100	Au, Ho, Ir, Re, Sm, W
100–1000	Ag, Ar, As, Br, Cl, Co, Cs, Cu, Er, Ga, Hf, I, La, Sb, Sc, Se, Ta, Tb, Th, Tm, U, V, Yb
1000–10	Al, Ba, Cd, Ce, Cr, Hg, Kr, Gd, Ge, Mo, Na, Nd, Ni, Os, Pd, Rb, Rh, Ru, Sr, Te, Zn, Zr
10^4 – 10^5	Bi, Ca, K, Mg, P, Pt, Si, Sn, Ti, Tl, Xe, Y
10^5 – 10^6	F, Fe, Nb, Ne
10^7	Pb, S

(Source: http://archaeometry.missouri.edu/naa_overview.html)

Appendix 5: Routine Irradiation and measuring regime developed for NIRR-1 Facilities

Neutron flux/irradiation channel	Procedure	T_{irr}	T_d	T_m	Activation products
IRRADIATION (Long / Short)			GAMMA-RAY COUNTING (1 st / 2 nd)		

1x10 ¹¹ n/cm ² s/ outer irradiation channels (B4, A2)	S1	2min	2.15min	10min	²⁸ Al, ²⁷ Mg, ¹⁸ Cl, ⁴⁹ Ca, ⁶⁶ Cu, ⁵¹ Ti, ⁵² V, ¹¹⁶ In,
	S2	2min	3.4h	10min	²⁴ Na, ¹⁶⁵ Dy, ⁵⁶ Mn, ¹⁵² Eu,
5x10 ¹¹ n/cm ² s/ inner irradiation channels (B1, B2, B3, and A1)	L1	6h	4.5d	30min	²⁴ Na, ⁴² K, ⁷⁶ As, ⁸² Br, ¹⁴⁰ La, ¹⁵¹ Sm, ¹⁹⁸ Au, ²³⁹ Np(U), ⁷² Ga, ¹²² Sb,
	L2	6h	10.15d	60min	⁴⁶ Sc, ¹⁴¹ Ce, ⁶⁰ Co, ⁶¹ Cr, ¹³¹ Cs, ¹⁵² Eu, ¹⁷⁷ Lu, ¹⁰ Ba, ⁸⁶ Rb, ¹⁸² Ta, ¹⁶⁰ Tb, ¹⁷⁵ Yb, ²¹¹ Pa (Th), ⁶⁵ Zn, ⁵⁹ Fe, ¹⁸¹ Hf.

(Source: Jonah et al., 2006)

T_{irr} = irradiation time, T_d = decay time, T_m = measurement time.

S: Short irradiation scheme

L: Long irradiation scheme

S1, S2, L1 and L2 represent irradiation and counting schemes adopted for the respective elements

Appendix: 6

NIRR-1 RECORD SHEET FOR IRRADIATION AND COUNTING No: NIRR1/DS/ /
Control Console Neutron Flux Setting: Irradiation Channel:

Sample ID	Weight	Date	T _{irr}	T _{in}	T _{end}	Date	T _{begin}	T _{cool}	T _{live}	T _{real}	Geom	File Name

NAME OF ANALYST:

SIGNATURE:

DATE:

Appendix 7: Toxic effects of some elements

S/No.	Elements	Adequate Intake Level (AI) Functions in the Body	Upper Intake Level (UL)	Possible Toxic Effects
1.	Al (nontoxic)	500 grams for 80 kg person ⁵ .	NA	Neurotoxicity ¹ , gastrointestinal problems, extreme nervousness, anaemia, headaches, decreased liver and kidney function, memory loss, speech problems ² . Causes blood to clot at 3–4 ppm, causing strokes and heart attacks ³ .
2.	Ca	Men & Women: 19-50y: 10 ³ mg/d; >50y: 1.2x10 ³ mg/d	UL: 2.5x10 ³ mg/d.	Calcium toxicity symptoms may include fatigue, depression, defensiveness, muscle weakness, pain, arteriosclerosis, arthritis, kidney stones and gallstones ⁴ .
3.	Fe	RDA [Men]: 8mg/d. RDA [Women]: 18mg/d.	UL: 45mg/d.	Non-heme iron absorption is lower for those consuming vegetarian diets than for those eating non-vegetarian diets
4.	Mn	RDA [Men]: 2.3 mg/d. RDA [Women]: 1.8 mg/d	UL: 11mg/d.	Emotional disturbances, sleepiness, weakness, spastic gait, paralysis, languor ³ .
5.	Mg	RDA[Men & Women]: 19-30y: 310mg/d. >30y: 320mg/d.	UL: 350mg/d	There is no evidence of adverse effects from the consumption of naturally occurring magnesium in foods.
6.	Ti	NA	NA	Relatively non-toxic. But can cause skin and eye irritation, respiratory irritation, gastrointestinal effects, and neurological problems in humans.
7.	Zn	9-13yrs: 8mg/d for men & women. 14-18yrs: 11mg/d for men & 9mg/d for women. 19+yrs: 11mg/d for men & 8mg/d for women	UL for men and women: 9-13yrs: 23mg/d 14-18yr: 34mg/d 19+yrs: 40mg/d	Acute adverse effects of high zinc intake include nausea, vomiting, loss of appetite, abdominal cramps, diarrhea, and headaches ⁶

¹Banks and Kastin (1989); ²Linda, (2011); ³Jann (2006); ⁴Pfeiffer (2008); ⁵Helmboldt (2007); Institute of Medicine⁶ (2001)

Appendix 8: Dietary allowances of some trace elements

1.	Ca	Calcium is needed for bone and tooth formation, blood clotting, muscle contraction, and nerve transmission.	RDA [Men]: 19-50y: 10^3 mg/day; >50y: 1.2×10^3 mg/day. RDA [Women]: 19-50y: 10^3 mg/day; >50y: 1.2×10^3 mg/day. UL: 2500mg/day
2.	Fe	Iron is mainly needed for transporting oxygen to cells, tissues and vital organs by attaching to proteins called hemoglobin and myoglobin in the blood. It is also needed for cell growth, including growth of white blood cells, which protect the body from foreign invaders.	RDA [Men]: 8mg/d. RDA [Women]: 18mg/d. UL: 45mg/d. Sources: Meat, seafood and poultry.
3.	Mn	Manganese protects cells by minimizing oxidation, thus decreasing damage to cells. It activates enzymes that are important for metabolism.	RDA [Men]: 2.3 mg/d. RDA [Women]: 1.8 mg/d UL: 11mg/d. Sources: pineapples, nuts, beans, sweet potatoes and brown rice.
4.	Mg	Cofactor for enzyme systems.	RDA [Men & Women]: 19-30y: 310mg/d. >30y: 320mg/d. UL: 350mg/d
5.	K	Potassium is essential in co-regulating ATP with sodium.	Dietary sources include legumes, potato skin, tomatoes, and bananas.
6.	Cr	Chromium helps the hormone insulin work more efficiently, allowing cells to pick up glucose in the blood.	RDA [Men]: $35 \mu\text{g/d}$. RDA [Women]: $25 \mu\text{g/d}$ Source: grapes, garlic, potatoes and beef.
7.	Zn	Zinc helps the immune system work at its best, especially during sudden illness. It also aids in wound healing and helps cells divide. Men should get but women need only. Sources include	RDA [Men]: 11 mg/d. RDA [Women]: 8mg/d UL: 40mg/d Source: Oysters, beef, beans, yogurt and cashews.

Source: Institute of Medicine (2010), *The National Academies, DRI reports*.