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ABSTRACTS
Airborne dust elements can seriously harm aircrafts, ground vehicles, mechanical parts, equipments, jet and piston engines, air and ground transportations, safety, performance, maintenance intervals, operational life, health and environments, and might consequently lead to partial or full fail of civil and military missions involving any of the affected machines or personnel, with all serious consequences. In this paper, three dimensional mapping of physical and chemical properties of the most severe 16 hazardous airborne dust elements, namely Al, Si, S, Zn, Cu, Ca, Ti, P, U, Sr, V, Pb, Mg, Mn, Cr, and Fe have been investigated at 4 different zones for three altitudes of 0.6m, 400m, and 800m using Unmanned Aerial Vehicle “UAV” Northern Saudi Arabia. Grain size distribution has been determined for all 16 collected samples at the investigated zones. For this purpose, a special innovative Autonomous Unmanned Aerial Vehicle with its own airborne autonomous dust collection system has been designed, manufactured and tested at the Talent and Technology Creativity Unit of the University of Tabuk, Saudi Arabia. 3D-mapping of physical and chemical properties of the hazardous airborne dust particles is planned to be used as an early warning and smart guide against various risks affecting air/ground transportations, health and environment, as well as for decision making tool to manage civil and military air and ground missions and transportation fleets. For this purpose, a decision making and management program for air/ground transportation, health, and environment is in the development phase at the present time and will be published in future work.

1. INTRODUCTION
The big differences between day and night temperatures lead to daily repeated expansion and contraction of the rock surfaces with the associated daily periodic variation in the stress and the strain of the rocks and consequently the rocks breakdown into small pieces. The wind will help in loosening these small cracked particles, force them to vibrate and saltate and the small cracked particles separate from their rocks. The cracked particles break down into smaller pieces due to their repeated strikes with the ground by the force of the wind, which carry them for variety of distances depending on their sizes. Particles in the size range of 100µm are lifting and hopping over the ground “saltation” by the force of air drag moving other particles of various sizes [1], [2]. Saltation result in ejection of small particles in the range of 100µm to the air with turbulent fluctuations [1], [2]. Small particles in the range of 20µm can remain airborne several weeks and consequently they can travel thousands of kilometers away from their sources, while airborne particles in the range of 20 to 70µm can remain airborne for short distances [3], [4]. Airborne dust particles over 70µm cannot remain airborne for long time and consequently they cannot travel away for long distances from their sources. Saltating particles, with the help of the air drag forces, can force other particles in the range over 500µm, which are normally unable to saltate due to their inertia, to slide on the ground surface ejecting dust particles of different sizes to the air [2], [4], where airborne particles in the range of 20µm remain airborne for long time, particles in the range of 20-70µm remain airborne for short time, particles in the range of 70-500 are mainly saltating, and particles in the range over 500µm are creeping. The main sources of dusts on the earth include the Northern Hemisphere, the Afro-Asian belt of deserts “dust belt” covering the Sahara desert of West and North Africa, the Arabian Peninsula, the Middle-East, southwest and central Asia including Iran, Turkmenistan, Afghanistan, Pakis-tan, Northern India, the Namib and Kalahari deserts, the Gobi desert in Mongolia and the Tarim Basin in China [5], [6], [7]. Saudi Arabia is centered among all mentioned global dust sources and therefore, it is affected by all the global dust sources by different magnitudes. Other sources of airborne particles are volcano, dust storms, and massive explosions from nuclear or uranium-enriched weapons, as well as, from the movement of armored vehicles and tanks moving in a convoy of dense pattern through deserts or dusty lands. They can lift rapidly large amount of dusts in the air to high altitudes creating enormous dust clouds. Helicopters, Vertical Takeoff and Landing “VTOL” aircrafts and ground attack fighters, might maintain prolonged operations at extreme low altitudes "Low Flights" at high speeds in dust-laden environment
initiating enormous dust clouds induced by the downwash effect of the wings and by the rotating blades, raising huge amount of dusts to the air. Fixed-wing and VTOL aircrafts as well as helicopters can create huge dust clouds during takeoff and landing in dust laden environment.

Dust clouds hinder the pilot’s ability to sense the orientation and to control the aircrafts. They create the known phenomenon of brownout, eliminate the in-flight visibility and hinder the pilots from seeing nearby objects, which provide the outside visual references necessary to control the aircraft near the ground. This will cause spatial disorientation and loss of situational awareness leading to accidents and possible crashes of the aircrafts. Intense blinding dust clouds are stirred up by the rotors and wings induce downwash of helicopters, vertical takeoff and landing “VTOL” aircrafts, as well as the downwash of fixed-wing ground attack fighters and aircrafts during low flight, takeoffs and landings. These dust clouds initiate significant flight safety risks as the collision of aircrafts with the ground obstacles, and the dynamic rollover due to sloped and uneven terrain as well as pilots sensing problems. Brownouts were the main reason for the crashes of helicopters and VTOL aircrafts in the military operations in Iraq and Afghanistan more than all other threats combined. The probability and severity of brownout are affected by soil composition, Wind speed, approach speed and angle, rotor configuration and propeller blades loading [8], [9], [10]. Blowing sands and dusts can also cause a sensory illusion of a tilted horizon leading pilots, who are not using the flight instruments for reference, to try level the aircraft with respect to a false horizon, resulting in an accident and possible crash of the aircraft. The rotors washes of the helicopters and VTOL aircrafts cause sands to blow around outside the cockpit windows, possibly leading the pilot to experience the vection illusion, where the helicopter appears to be turning when it is actually in a level hover leading the pilot to make incorrect control inputs, which can quickly result in disaster when hovering near the ground. In night landings, aircraft lighting can enhance the visual illusions by illuminating the brownout cloud. Many coalition military aircrafts were lost due to roll-overs while executing landing in dust laden environment during the Gulf War of 1990-91 reaching 230 crashed aircrafts by the year 2006 due to unsuccessful take-offs or landings. Helicopter brownout is a US$100 million per year problem for the U.S. Military in Afghanistan only and higher costs are present in Iraq [11], [12]. Severe sand rotor abrasions have been extensively observed in Afghanistan and Iraq.

Only inhaled dust particles smaller than the bronchial airways size, namely particles smaller than 10µm “PM10”, can penetrate the pulmonary alveoli in the deep lung region and deposit there causing serious consequences on the health and creating inflammatory responses, the numbers of the deposited particles in this deep area of the lung are increased for particles in the range of 2-3µm and fall to zero for particles in the range of 7-10µm. The time taken by the lung to get rid of the deposited particles and to heal from their effects depend on the response of the affected cell tissues of the lung and on the chemical compositions of the deposited particles, it can take years with no assured success [13], [14], [15]. It is known that about 25% of the Saudi population are asthmatic and are adversely affected by airborne dusts [16] Airborne silica of sizes less than 3µm “PM3”, might adversely affect the health causing non occupational silicosis or desert lung syndrome [17], which is irreversible, progressive, incurable, and at later stages disabling. Some chemical dusts are toxic on some organs or systems as kidneys and livers, as well as, on blood. Systemic intoxication can be acute “rapid onset and short duration”, or chronic “long duration and slow onset”, depending on the type of chemical and on the degree of exposure. Toxic metal dusts - such as lead, cadmium, beryllium and manganese - may cause systemic intoxication, affecting blood, kidneys or the central nervous system. Some toxic dusts as pentachlorophenol crystals may enter the organism by dissolving in sweat and easily penetrate through intact skin passing to the bloodstream and causing systemic intoxication [18]. Many dust elements are carcinogens “causing cancer” for example, asbestos (particularly crocidolite), which may cause lung cancer and mesothelioma, which is a rare form of cancer that develops from cells of the mesothelium, the protective lining that covers many of the internal organs of the body[19]. Hexavalent chromium & certain chromates, arsenic (elemental and inorganic compounds), particles containing polycyclic aromatic hydrocarbons, certain nickel-bearing dusts, and certain wood dusts, have been recognized as causing nasal and lung cancer [20]. Deposited airborne radioactive particles in the lung expose it to significant doses of ionizing radiation, which may cause carcinoma of the lung tissue, or they may be transported from the lung and damage other parts of the body [18]. Airborne Fe particles in dust deposited in the lung could be detected using X-ray [18] and can indirectly dramatically impact human health by stimulating airborne toxic algal blooms deposited in the lung in coastal environments [21], [22], [23].

The most critical and severe airborne dust particles to aircrafts, ground vehicles, engines, mechanical parts and equipments are Al, Si, Ca, Mg, Cr, and Fe. They are the dominant wear material elements, which cause wind screen abrasion, erosion in the compressor blades and rotor-path components of the jet engines including the blades and the sensors, reducing their efficiencies and operating life. The wheels and mechanical parts of the trains, locomotives and vehicles, as well as their engine cylinder-heads are eroded dramatically in high rates [26]. These airborne hazardous elements may melt inside the jet engines and deposit on the rotor and stator blades changing their profiles, reducing their efficiencies, deposit on the roller bearing housed between the inner and outer ring of the jet engines of aircrafts leading to the blockage of its rotation and consequently to total failure of the jet engine and losing of its thrust, resulting in the crash of the jet aircraft or jet fighter. This was the case for some crashed jetfighters in southern Iraq during the Iraq war 1990/1991 [10], [11]. The melted hazardous dust elements might deposit on the temperature and
pressure sensors inside the jet engines resulting in incorrect readings and leading the pilots or the autopilots to control the aircrafts in wrong ways with all serious consequences [24].

Very important useful information could be acquired by correlating the predicted data of the dust physical and chemical analysis to historical, medical, transportation, environmental, or other relevant events or records. Important correlations to medical records resulted in very useful information as mentioned before [13], [14], [26]. In Iraq war 1990-1991 and 2003 and later, as well as in Afghanistan war, the American armed air and ground vehicles, tanks, equipments and troops were facing enormous dust clouds adversely affecting their safety, performance, maintenance intervals, operational ages, vision, and personal health. A study of erosion in 48 locomotive engine cylinders having cast iron or chrome plated liner materials operating in normal and in dust laden environments have been conducted at Alsabtia Diesel Workshop of the Egyptian National Railways. This study has found that the engine erosions in dust laden environment were 3 times of that in normal environment [25]. According to all previous mentioned facts, fixed-wing, VTOL aircrafts and helicopters, as well as ground armored vehicles, tanks and personnel, are extremely adversely affected by airborne dusts especially at locations of fine dust particles in the desert or in dusty lands, which might lead to catastrophic consequences and partial or total fail of the mission. These effects are drastically propagated when ground vehicles are moving in long convoys of dense patterns at high speeds in windy weather or turbulent air resulting in lifting a lot of dusts to high altitudes and creating enormous dust clouds with all mentioned negative consequences.

2. MEASUREMENTS AND INSTRUMENTATION

In this study, three dimensional mapping of the hazards from airborne dust particles to civil and military aviation, health and environment in Saudi Arabia is performed in the horizontal and vertical level by analyzing the collected airborne dust particles at 4 different zones northern Saudi Arabia at three different altitudes, namely 0.6m, 400m, and 800m. A list of tested zone names, zone numbers, GPS data, Dates of tests, for three altitudes are shown in table 1.

Table 1. Details of the investigated Zones; zone names, zone numbers, GPS data, and dates of tests.

<table>
<thead>
<tr>
<th>Zone No</th>
<th>Zone Name</th>
<th>Date</th>
<th>GPS Coordination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>West Tabuk, Aqaba Gulf, SA</td>
<td>02 Jul. 13</td>
<td>28°15'28.08&quot;N 44°59'33.57&quot;E</td>
</tr>
<tr>
<td>2</td>
<td>Univ. of Tabuk, Tabuk City, SA</td>
<td>01 Jul. 13</td>
<td>28°22'41.62&quot;N 36°27'53.17&quot;E</td>
</tr>
<tr>
<td>3</td>
<td>SW Aljouf, Road 85, SA</td>
<td>04 Jul. 13</td>
<td>29°22'58.15&quot;N 38°21'48.45&quot;E</td>
</tr>
<tr>
<td>4</td>
<td>N. Borders, Road 85, N. Aljouf, SA</td>
<td>06 Jul. 13</td>
<td>31°25'38.09&quot;N 39°13'53.29&quot;E</td>
</tr>
</tbody>
</table>

For this purpose a full composite Autonomous Unmanned Aerial Vehicle “AUAV” equipped with autopilot and solar cells has been designed, manufactured, and tested in the Talent and Technology Creativity Unit at the University of Tabuk, Saudi Arabia [27]. The UAV was made out of Fiberglass, Carbon Fiber and Kevlar. The Unmanned Aerial System of the UAV "UAS" has been successfully designed, installed and tested. The UAS includes an autopilot and a special autonomous dust sample collection system linked to the autopilot and to the ground station on the ground via wireless transceiver, Figure 2.

Figure 2. The Research UAV during Landing.

The airborne autonomous sample collection system "ASCs" is designed to collect airborne dusts during preprogrammed flight paths at different altitudes. The ASCS consists of a ducted fan of 80mm inlet diameter connected to a 4-port manifold with one pneumatic valve for every port. A single polycrystalline filter of 0.8 μm pore size is
connected to every pneumatic valve and the outlet air from the filters get out of the UAV fuselage after filtration from a port close to the front landing gear. The activation of any solenoid valve connected to its specific filter is achieved by connecting 12V power source to the solenoid valve forcing the air to flow from the ducted fan through the manifold to pass to the required filter and consequently to the outer air again after filtration. A special electronic circuit consisting of a preprogrammed microcontroller and 9 relays has been used to connect any electric power source to any chosen relay and consequently to any specific solenoid valve, which is necessary to open and close the way to any filter. This circuit is linked to and controlled by the autopilot and the ground station via a wireless transceiver. The first solenoid valve is activated autonomously when the AUAV climbs and reach the preprogrammed altitude of 400m and loiter with a radius of 1000m for an approximate time period from 6 am to 8 am in the morning forcing the air to pass from the ducted fan intake to the first filter, while all other solenoid valves and consequently the ways to the rest of the filters are closed. The second solenoid valve is activated autonomously for two hours in the approximate time period from 8am to 10 am, when the UAV climbs to an altitude of 800m and start loitering with 1000m radius, forcing the air to pass from the ducted fan intake to the second filter for two hours while all other solenoid valves are closed. The third solenoid valve is activated manually for two hours after landing when the UAV is standing on the ground directing the air from the ducted fan intake to the third filter, while all other solenoid valves are closed. The flight trip of the UAV and the mission of the ASCS were preprogrammed before flight using the ground station and could be reprogrammed from the ground station during the flight mission via the wireless transceiver to exchange data of the modified mission between the ASCS and the ground station (Figure 3).

![Figure 3. The Unmanned Aerial Vehicle with the autonomous control and dust sampling instrumentations.](image)

A Raman spectrum was acquired from the center of mass of each particle. Chemical identification was then achieved by spectroscopic algorithms incorporated within software, which compared and correlated the spectrums of the particles with the spectrums stored in the library. particle size distributions were then obtained. Chemical Identifications were obtained for the following 16 elements, namely Al, Si, S, Zn, Cu, Ca, Ti, P, U, Sr, V, Pb, Mg, Mn, Cr, and Fe, as well as the size distributions for the following grain-size classes; 1-10 µm, 10-22 µm, 22- 44 µm, 44- 200 µm, 200-600 µm, 600-1000 µm using G3-1D image analyzer for all 12 samples collected from 4 zones Northern Saudi Arabia at three different altitudes of 0.6m, 400m and 800m. The dust present in each filter was used in an integrated dry powder disperser which made preparing dry powder samples easy and reproducible.

3. RESULTS AND DISCUSSIONS

3.1 Physical Analysis

3.1.1 Grain Size Distribution

The % age of grain size 1-10µm had values of 6.8%, 4.6%, 3.2%, and 1.8% at the zones 4, 3, 1, and 2 respectively for the altitude of 0.6m, while at 400m, the values of 60.11%, 47%, 40.8%, and 35.6% were predicted at the zones 4, 3, 1, and 2 respectively, and at the altitude of 800m, these values were 39.2%, 32%, 31.23%, and 31.22% at the zones 4,2,1, and 3 respectively (Figure 4).
The % age of grain size 10-22μm had values of 5.35%, 4.65%, 4%, and 1.65% dry wt at the zones 3, 1, 4 and 2 respectively for the altitude of 0.6m, while at 400m, the values were 21.42%, 19.84%, 16.11%, and 12.41% were at the zones 3, 1, 4, and 2 respectively, and at the altitude of 800m, the values were 18.7%, 17.96%, 13.7%, and 13.1% at the zones of 1, 3, 2, and 4 (Figure 5).

The % age of grain size 22-44μm had values of 4.93%, 3.41%, 2.16%, and 2.03% at the zones 3, 1, 4 and 2 respectively for the altitude of 0.6m, while at 400m, the values were 13.12%, 11.22%, 10.25%, and 4.99% were at the zones 3, 1, 2, and 4 respectively, and at the altitude of 800m, the values were 9.73%, 8.76%, 8.02%, and 3.75% at the zones of 3, 2, 1, and 4 (Figure 6).

The % age of grain size 44-200μm had values of 59.83%, 54.8%, 38.36%, and 4.57% at the zones 4, 1, 2 and 3 respectively for the altitude of 0.6m, while at 400m, the values were 19.49%, 18.05%, 13.81%, and 1.22% were at the zones 2, 1, 4, and 3 respectively, and at the altitude of 800m, the values were 3.46%, 2.7%, 1.79%, and 0.16% at the zones of 2, 1, 4, and 3 (Figure 7).
The %age of grain size 200-600\(\mu\)m had values of 50.2\%, 32.73\%, 28.38\%, and 20.37\% at the zones 3, 2, 1 and 4 respectively for the altitude of 0.6m, while at 400m, the values of 16.58\%, 13.36\%, 9.35\%, and 4.71\% were at the zones 2, 3, 1, and 4 respectively, and at the altitude of 800m, the values were 2.91\%, 1.78\%, 1.41\%, and 0.6\% at the zones of 2, 3, 1, and 4 (Figure 8).

The %age of grain size 600-1000\(\mu\)m had values of 27.87\%, 22.44\%, 4.45\%, and 2.57\% at the zones 3, 2, 1 and 4 respectively for the altitude of 0.6m, while at 400m, the values of 5.7\%, 3.72\%, 0.73\%, and 0.27\% were at the zones 2, 3, 1, and 4 respectively, and at the altitude of 800m, the values were 1.46\%, 0.65\%, 0.12\%, and 0.07\% at the zones of 2, 3, 1, and 4 (Figure 9).

3.2 Chemical Analysis

3.2.1 All Elements

The analyzed dust samples for all 4 zones Northern Saudi Arabia at the altitude of 0.6m indicate that the predicted dominant elements were Si and Ca. The maximum values of the dry weight %age (dry wt %) were predicted at zones 4 and 3, while the maximum values of Ca dry wt% were predicted at zones 1, and 2 respectively. The dry wt% distribution of all 16 analyzed elements for all zones at 0.6m altitude are illustrated in Figures 10.
Figure 10: Elements dry wt % for different zones in Saudi Arabia, Altitude=0.6m

At altitude of 400m, and 800m for all zones, a dramatic decrease in the values of Si and Ca dry wt% were predicted, while the increase in Fe, Al, Zn, and V, were recorded (Figure 11,12).

Figure 11. Elements dry wt % for different zones in Saudi Arabia, Altitude=400m

Figure 12. Elements dry wt % for different zones in Saudi Arabia, Altitude=800m

3.2.2 Hazardous elements affecting air/ground vehicles, health and Environment

The Values of the most severe airborne dust elements on air/ground vehicles and their engines and mechanical parts, namely Fe, Mg, Ca, Si, Al, Cr, and the main dust elements, which are adversely affecting the health and environment, mainly Fe, Al, Si, U, Pb, Mn, Cu, V, Cr, and others, are predicted and analyzed at different zones and altitudes Northern Saudi Arabia. At altitudes of 0.6m, the predicted values of these hazardous elements indicate maximum values of Si and Ca followed by Fe and Al for all zones (figure 10), while at altitudes of 400m, and 800m the % dry wt of Si and Ca were decreased dramatically, while the values of Fe, Al, and V were increased (Figure 11, and 12).

The sum of their dry wt % values “Sum (dry wt % (Fe, Mg, Ca, Si, Al, Cr))”, at 0.6m were maximum at the zones 3 and 1, having values of 89.52%, and 89.19% respectively, while at altitude of 400m the maximum values were at the zones 1 and 3 and the predicted values were 74.0%, and 74.6% respectively, and finally at altitude of 800m, the maximum values were found at the zones 1, and 3 with values of 68.5%, and 62.6% respectively (Figure 13).
Figure 13. Variation of Sum of elements dry wt % of (Al, Si, Ca, Mg, Fe, Cr) of different zones in Saudi Arabia with the altitudes (0.6m, 400m, 800m).

Al dry wt % at altitude of 0.6m were maximum at zones 2 and 1 respectively and the values at the zones 2, 1, 3, and 4 were 6.13\%, 6.08\%, 5.14\%, and 2.16\% respectively, while at altitude of 400m, their maximum values were at the zones 3 and 1 and the values at the zones 3, 1, 2, and 4 were 27.22\%, 23.44\%, 16.34\%, and 9.21\% respectively. Their maximum values at altitude of 800m were at the zones 3 and 1 and the values at the zones 3, 1, 2, and 4 were 36.89\%, 29.59\%, 20.07\%, and 11.63\% respectively (figure 14). The predicted values of the mass concentration of Al to the total mass concentration for PM10 at Yanbu city on the red sea was predicted to be 25\% [28].

Figure 14. Variation of Al-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.

Silica "Si", as the main constituent of sand and glass and the most dominant eroding material element, can erode the internal parts of the jet engines, piston engines and their mechanical parts and might melt "glassification" inside the jet engines or piston engines of aircrafts leading to their failure and possible crashes of the aircrafts. It erodes the engine internal parts of the trains, locomotives, and ground vehicles, as well as, all of their mechanical parts. Si dry wt % at altitude of 0.6m were maximum at the zones 4 and 3 and the values at the zones 4, 3, 2, and 1 were 58.48\%, 45.02\%, 24.17\%, and 21.72\% respectively, while at altitude of 400m, the predicted maximum values were at the zones 4 and 3 and the values at the zones 4, 3, 2, and 1 were 19.45\%, 18.64\%, 7.17\%, and 6.55\% respectively, and finally at altitude of 800m, the maximum values were identified at the zones 3 and 4 and the values at the zones 3, 4, 2, and 1 were 3.38\%, 2.95\%, 0.99\%, and 0.98\% respectively (figure 15).

Figure 15. Variation of Si-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.
The predicted dry wt % for Ca were maximum for the altitude of 0.6m at the zone 1 and 2 and the values at the zones 1, 2, 3, and 4 were 52.08%, 38.22%, 35.28%, and 11.48% respectively, while their maximum values for the altitude of 400m were at the zone 1 and 3 and the values at the zones 1, 3, 2, and 4 were 15.68%, 14.62%, 11.35%, and 3.83% respectively. Their maximum values at altitude of 800m were at the zones 2 and 3 and the values at the zones 2, 3, 1, and 4 were 1.19%, 1.08%, 1.03%, and 0.25% respectively (figure 16).

![Figure 16. Variation of Ca-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.](image)

Mg dry wt % at altitude of 0.6m were maximum at the zones 4 and 3 and the values at the zones 4, 3, 2, and 1 were 2.24%, 1.21%, 0.97%, and 0.89% respectively, while at altitude of 400m the maximum values were identified at the zones 4, and 3 and the values at the zones 4, 3, 2, and 1 were 1.78%, 0.85%, 0.81%, and 0.76% respectively, and finally increasing the altitude to 800m have changed order of the zones having the maximum values to be 4 and 3 and the values at the zone 4, 3, 1, and 2 were 2.26%, 1.06%, 0.96%, and 0.93% respectively (figure 17).

![Figure 17. Variation of Mg-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.](image)

Fe dry wt % at altitude of 0.6m were maximum, at the zones 2 and 4 and the values at the zones 2, 4, 1, and 3 were 10.47%, 7.88%, 8.23%, and 2.79%. At altitude of 400m, these values became maximum at the zones 2 and 4 and the values at the zones 2, 4, 1, and 3 were 29.43%, 29.4%, 27.76%, and 12.92% respectively, while at altitude of 800m, these values were maximum at the zones 2 and 4 and the values at the zones 4, 2, 1, and 3 were 37.17%, 36.71, 35.05%, and 19.56% respectively (figure 18). Airborne Fe in dust can indirectly impact human health by stimulating airborne toxic algal blooms in dust in coastal environments [21], [22], [23], which is the case for zone 1 having Fe dry wt% values of 8.23%, 27.76% and 35.05% at altitudes of 0.6m, 400m and 800m respectively, further investigations need to be conducted.

![Figure 18. Variation of Fe-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.](image)
The predicted maximum dry wt % of Cr at altitude of 0.6m were at the zones 1 and 3 and the values at the zones 1, 3, 4, and 2 were 0.19%, 0.08%, 0.06%, and 0.03% respectively, while at altitude of 400m, the maximum values were at the zone 1 and 3 and the values at the zones 1, 3, 4, and 2 were 0.68%, 0.38%, 0.25% and 0.09% respectively. The maximum values at altitude 800m were predicted at the zones 1 and 3 and the values at the zones 1, 3, 4, and 2 were 0.86%, 0.61%, 0.31%, and 0.14% respectively (figure 19).

![Figure 19. Variation of Cr-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.](image1)

The radioactive Uranium “U” was identified to be at its maximum values at the zones 1 and 4 for all altitudes and the values at altitude of 0.6m for the zones 1, 4, 3, and 2 were 0.41%, 0.19%, 0.12%, and 0.08% respectively, while at altitude of 400m were 0.34%, 0.18%, 0.15%, and 0.06% respectively, and for altitude of 800m, these values became 0.4%, 0.22%, 0.2% and 0.08% respectively (figure 20). The maximum values of U at zone 1 on the gulf of Aqaba at all investigated altitudes, followed by about 50% of this level at zone 4 close to the Iraqi/Jordanian border raise many questions that need additional investigations to be answered.

![Figure 20. Variation of U-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.](image2)

Manganese “Mn” as a toxic dust is investigated for all zones. It has its maximum values at the zones 1 and 4 for all altitudes and the values at zone 1, 4, 3, and 2 were 0.88%, 0.72%, 0.62%, and 0.44% respectively, while at altitude of 400m, these values at the zones 1, 4, 2, and 3 were 3.19%, 2.88%, 2.21%, and 2.19% respectively. At altitude of 800m, these values at the zones 1, 4, 3, and 2 were 4.04%, 3.63%, 3.29%, and 2.55% respectively (Figure 21). The predicted values of the mass concentration of Mn with to the total mass concentration for PM10 at Yanbu on the red sea was less than 1% [28].

![Figure 21. Variation of Mn-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.](image3)
Lead “Pb” as a toxic dust had its maximum values for all altitudes at the zones 2 and 1 and the values for the altitude of 0.6m at the zones 2, 1, 3, and 4 were 1.14%, 0.8%, 0.44%, and 0.14% respectively, while at altitude of 400m, these values were 3.53%, 2.51%, 1.89%, and 1.06% respectively, and at altitude of 800m, they became 4.06%, 3.16%, 2.84% and 1.33% respectively (Figure 22). Special attention should be directed toward zone 2. The predicted values of the mass concentration of Pb to the total mass concentration for PM10 at Yanbu city was predicted to be less than 1% [28].

\[ Figure \text{ 22. Variation of Pb-Element dry wt \% for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.} \]

Zn dry wt % for all altitude were maximum at the zones 4,2,3 and 1 respectively with corresponding values of 1.07%, 0.62%, 0.28%, and 0.16, their corresponding values for the altitude of 400m were 4.24%, 2.21%, 1.39%, and 0.58%. These values at the altitude of 800m became 5.36%, 2.55%, 2.12%, and 0.72% (Figure 23). The predicted values of the mass concentration of Zn to the total mass concentration for PM10 at Yanbu on the red sea was 13% [28].

\[ Figure \text{ 23. Variation of Zn-Element dry wt \% for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.} \]

Sr dry wt % at all altitudes were maximum at the zones 2 and 4 and the values at the zones 2,4,1, and 3 for the altitude of 0.6m were 6.39%, 3.58%, 3.09% and 1.68% respectively, while at altitude of 400m, these values were 5.18%, 3.35%, 2.62%, and 2.17% respectively. These values at the altitude of 800m were 5.98%, 4.25%, 3.3%, and 3.27% respectively (Figure 24). The values of the mass concentration of Sr to the total mass concentration for PM10 at Yanbu city on the red sea, was 13% [28].

\[ Figure \text{ 24. Variation of Sr-Element dry wt \% for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.} \]
**V** dry wt % maximum values were at the zones 2 and 4 for all altitudes and the values for the altitude of 0.6m at the zones 2, 4, 1, and 3 were 4.3%, 2.58%, 2.04% and 1.08% respectively, while at altitude of 400m, these values became 11.58%, 10.3%, 8.29%, and 5.38% respectively. These values at altitude of 800m, were 13.39%, 13.04%, 10.49%, and 8.08% respectively (Figure 25). The predicted values of the mass concentration of V to the total mass concentration for PM10 at Yanbu city on the red sea was 10% [18].

![Figure 25](image_url)

**Figure 25.** Variation of V-Element dry wt % for different zones in Saudi Arabia with Altitudes 0.6m, 400m, 800m.

### 3.2.3 Distribution of Metal and Nonmetal Elements

Distribution of metal and nonmetal elements at the altitudes 0.6m, 400m, and 800m have been conducted for all 4 zones. At the altitude of 0.6m the maximum values of the metal elements were predicted at the zones 1 and 2 and the values at the zones 1, 2, 3, and 4 were 75.96%, 70.82%, 49.38%, and 33.67%, while the maximum values of the nonmetal elements were at the zones 4 and 3 and the values at the zones 4, 3, 2 and 1 were 66.14%, 50.5%, 29.1% and 23.63% respectively (Figure 26).

![Figure 26](image_url)

**Figure 26.** Variation of Metal and Nonmetal elements % for different zones in Saudi Arabia at altitude of 0.6m.

At the altitude of 400m, the maximum values of the metal elements were predicted at the zones 1 and 2 and the values at the zones 1, 2, 3, and 4 were 91%, 89.6%, 72.88%, and 72.63% respectively, while for nonmetal elements these values at the zones 4, 3, 2 and 1 were 27.19%, 26.97%, 10.34% and 8.66% respectively (Figure 27).

![Figure 27](image_url)

**Figure 27.** Variation of Metal and Nonmetal elements % for different zones in Saudi Arabia at altitude of 400m.
At the altitude of 800m, the maximum values of the metal elements were predicted at the zones 2 and 1 and these values at the zones 2, 1, 4, and 3 were 95.52%, 93.13%, 87.23%, and 84.68% respectively, while nonmetal elements the maximum values were at the zone 3 and 4 and these values at the zones 3, 4, 2 and 1 were 15.12%, 12.55%, 4.4% and 3.47% respectively (Figure 28).

The distribution of the metal and nonmetal elements % at altitude of 0.6m for different zones northern Saudi Arabia indicate that the maximum average values for nonmetal elements dry wt % were about 95% for the size bands 1-10μm, 10-22μm, and 22-44μm, while for metal elements, they were 57% at size bands 44-200μm, 41.5% at 200-600μm, and 25% at 600-1000μm. The nonmetal elements were dominant at this altitude (Figure 29).

The distribution of the metal and nonmetal elements % at altitude of 400m for different zones northern Saudi Arabia indicate that the maximum metal elements % were about 90% at 44-200μm, and about 81% at 200-600μm, 10-22μm, and 44-200μm, while for nonmetal elements, they were about 27% at 22-44μm, 1-10μm and 44-200μm, and about 19% at 10-22μm, 200-600μm, and 600-1000μm. The metal elements were dominant at this altitude (Figure 30).
The distribution of the metal and nonmetal elements % at altitude of 800m for different zones northern Saudi Arabia indicate that the maximum metal elements % were about 95% at 44-200μm, and about 90% at the rest of the size bands, while for nonmetal elements, they were about 9.6% at 22-44μm, and 8% at 1-10μm. Metal elements were dominant at this altitude (Figure 31).

3D-mapping of hazardous airborne dust particles can be used as an early warning and guide against various risks affecting air/ground transportations, health and environment. For this purpose, a decision making and management
program for air/ground transportation, health, and environment is in the development phase at the present time and will be published in future work.

4. SUMMARY AND CONCLUSION

In this paper, the physical and chemical properties of hazardous airborne dust particles that might adversely affect the ground vehicles and aircraft safety or performance, health, and environment have been investigated at 4 different zones in northern Saudi Arabia at the altitudes of 0.6m, 400m, and 800m. This investigation aims, in the first step, to acquire a complete 3D map of these hazards in the airspace of Saudi Arabia at different altitudes for the whole area of Saudi Arabia. For this purpose, a special Autonomous Unmanned Aerial Vehicle has been designed, manufactured, and tested [27] to carry the airborne dust collection system to different altitudes, where dust samples were planned to be collected. A special autonomous airborne dust collection system was designed, manufactured, tested to collect airborne dust samples autonomously when reaching altitudes of 400m and 800m and loitering at these altitudes for two hours while collecting the dust samples. Acquiring samples at 0.6m is conducted after landing while the UAV is on the ground.

The physical analysis of the dust particles samples collected at 0.6m indicated that the % age of grain size 1-10μm had maximum values at the zones 4 and 3 and the values were 6.8% and 4.6% respectively for the altitude of 0.6m, while at 400m they were 60.11% and 47% for the zones 4 and 3 respectively, and at the altitude of 800m, they were 39.2% and 32% at the zones 4 and 2 (Figure 4). The % age of grain size 10-22μm had maximum values of 5.35% and 4.65% at the zones 3 and 1 respectively for the altitude of 0.6m, while at 400m, they were 21.42% and 19.84% at the zones 3 and 1, and at the altitude of 800m, they were 18.7% and 17.96% at the zones 1 and 3 respectively (Figure 5). The % age of grain size 22-44μm had their highest values of 4.93% and 3.41% at the zones 3 and 1 respectively for the altitude of 0.6m, while at 400m, they were 13.12% and 11.22% at the zones 3 and 1 respectively, and at the altitude of 800m, they were 9.73% and 8.76% at the zones 3 and 2 (Figure 6). The % age of grain size 44-200μm had their highest values of 59.83% and 54.8% at the zones 4 and 1 respectively for the altitude of 0.6m, while at 400m, these values were 19.49% and 18.05% at the zones 2 and 1 respectively, and at the altitude of 800m, they were 3.46% and 2.7% at the zones 2 and 1 (Figure 7). The % age of grain size 200-600μm had maximum values of 50.2% and 32.73% at the zones 3 and 2 respectively for the altitude of 0.6m, while at 400m, they were 16.58% and 13.36% at the zones 2 and 3 respectively, and at the altitude of 800m, they were 2.91% and 1.78% at the zones 2 and 3 respectively (Figure 8). The % age of grain size 600-1000μm had highest values of 27.87% and 22.44% at the zones 3 and 2 respectively for the altitude of 0.6m, while at 400m, these values were 5.7% and 3.72% for the zones 2 and 3 respectively, and at the altitude of 800m, they were 1.46% and 0.65% at the zones 2 and 3 respectively (Figure 9).

The chemical distribution of the dust particles sampled northern Saudi Arabia for the hazardous elements adversely affecting aircrafts and ground vehicles as Fe, Mg, Ca, Si, Al, Cr and human health and environment as Fe, Al, Si, U, Pb, Mn, Cu, V, Cr, and others are investigated and their dry wt % distribution in the airborne dust particles were determined at all four investigated zones. The distribution of the dry wt % of airborne dust elements at altitude of 0.6m indicated maximum values for Si and Ca followed by Fe and Al (figure 10), while at altitudes of 400m, and 800m the % dry wt of Si and Ca are decreased dramatically, while Fe, and Al were increased followed by V (Figure 11, and 12). The sum of their dry wt % “Sum(Fe, Mg, Ca, Si, Al, Cr)” dry wt % at an altitude of 0.6m were maximum at zone 3 followed by zone 1, with values of 89.52%, and 89.19% respectively, while at altitude of 400m they were at the zones 1 and 3 respectively having values of 74.0% and 74.6% and finally at the altitude of 800m, they were at zone 1 and 3 with predicted values of 68.5%, and 62.6% (figure 13).

*Al* dry wt % at altitude of 0.6m were maximum at the zones 2 and 1 respectively, while at altitudes of 400m, and 800m, the highest values were predicted at the zones 3 and 1 having values of 27.22% and 23.44% respectively at altitude of 400m, and of 36.89% and 29.59% respectively at altitude of 800m (figure 14). Silica "Si", as the most dominant eroding material element and due to its melting "glassification" inside the jet or piston engines, beside its adverse effects on the lung and health, is considered as one of the most dangerous elements seriously harming air/ground vehicles, trains, as well as, health. The predicted dry wt % values of the Si at altitude of 0.6m were maximum at the zones 4 and 3 having values of 58.48% and 45.02% respectively, while at altitude of 400m, the maximum values were at the zones 4 and 3 respectively having values of 19.45% and 18.64% respectively, finally at altitude of 800m, the highest values were at the zones 3 and 4 having values of 3.38% and 2.95% (figure 15). The predicted dry wt % for *Ca* were maximum mainly for the altitude of 0.6m at the zones 1 and 2 having values of 52.08% and 38.22% and were at the zones 1 and 3 at altitude of 400m having values of 15.68% 14.62% respectively, while at altitude of 800m, these values became at the zones 2 and 3 respectively having values of 1.19% and 1.08% respectively (figure 16). *Mg* dry wt % at altitude of 0.6m were maximum at the zones 4 and 3 respectively having values of 2.24% and 1.21% respectively, while at altitude of 400m the highest values of 1.78% and 0.85% dry wt % were predicted at the zones 4 and 3 respectively and finally increasing the altitude to 800m changed their maximum values to be at the zones 4 and 3 having values of 2.26% and 1.06% respectively (figure 17). *Fe* dry wt % at altitude of 0.6m were maximum, at the zones 2 and 4 having values of 10.47% and 7.88% respectively. At altitude of 400m, these values became maximum at the zones 2 and 4 having values of 29.43% and 29.4% respectively, while at altitude of 800m, these values were...
maximaums at the zones 4 and 2 having values of 37.17% and 36.71 respectively (figure 18). As the airborne Fe in dust can indirectly impact human health by stimulating airborne toxic algal blooms in airborne dust in coastal environments [21], [22], [23]. This was the case of zone 1 having Fe dry wt% of 8.23%, 27.76% and 35.05% at altitudes of 0.6m, 400m and 800m respectively, further investigations need to be conducted. The highest values of Cr dry wt% at altitude of 0.6m were at the zones 1 and 3 respectively having values of 0.19% and 0.08% respectively, while at altitude of 400m, they were at the zones 1 and 3 having values of 0.68% and 0.38% respectively. Their maximum values at altitude of 800m, were predicted at the zones 1 and 3 having values of 0.86% and 0.61% respectively (figure 19). The radioactive Uranium “U” were identified to be at its maximum values at zone 1, and 4 for all altitudes having values of 0.41% and 0.19% respectively for altitude of 0.6m, while at altitude of 400m changed to 0.34% and 0.18% respectively, and for altitude of 800m, these values became 0.4% and 0.22% respectively (figure 20). From these results, it is clear that the maximum values of U are at zone 1 on the gulf of Aqaba at all investigated altitudes, followed by about 50% of this level at zone 4 close to the Iraqi/Jordanian border raising many questions, which need additional investigations to be answered. Manganese “Mn” as a toxic dust is investigated for all zones. It has its maximum values mainly at zones 1 and 4 having values of 0.88% and 0.72% respectively at altitude of 0.6m. At altitude of 400m, their maximum values have been predicted at the zones 1 and 4 with values of 3.19% and 2.88% respectively, while at altitude of 800m, their maximum values were at the zones 1 and 4 having values of 4.04% and 3.63% respectively (Figure 21). Sr dry wt % at all altitudes were maximum at the zones 2 and 4 having values of 6.39% and 3.58% respectively for the altitudes of 0.6m, while at altitude of 400m, these values were 5.18% and 3.35% respectively, and the values at the altitude of 800m were 5.98% and 4.25% respectively (Figure 24). V dry wt % values at all altitudes were maximum at the zones 2 and 4 having values of 4.3%, and 2.58% respectively at altitude of 0.6m, while at altitude of 400m, these values became 11.58% and 10.3% respectively and at altitude of 800m, they were 13.39% and 13.04% respectively (Figure 25). Lead “Pb” as a toxic dust had its maximum values for all altitudes at the zones 2 and 1 having values of 1.14% and 0.8% respectively, while at altitude of 400m, the values were 3.53% and 2.51% respectively, and at altitude of 800m, they became 4.06% and 3.16% respectively (Figure 22). Zn dry wt % for all altitudes were maximum at the zones 4 and 2 having values of 7.6% and 1.07% respectively, these values at the altitude of 400m were 4.24% and 2.21% respectively and changed to 5.36% and 2.55% respectively for altitudes of 800m (Figure 23).

**Distribution of metal and nonmetal elements** at the altitudes 0.6m, 400m, and 800m are conducted for all 4 zones. At an altitude of 0.6m the maximum values of the metal elements were predicted at the zones 1, and 2 having values of 75.96% and 70.82% respectively, while maximum values of nonmetal elements were at the zones 4, and 3 with values of 66.14% and 50.5% respectively (Figure 26). At an altitude of 400m, the maximum values of the metal elements were predicted at the zones 1 and 2 with values of 91% and 89.6%, respectively, while those of the nonmetal elements were at the zones 4 and 3 having values of 27.19% and 26.97% respectively (Figure 27). At an altitude of 800m, the maximum values of the metal elements were predicted at the zones 1 and 2 with values of 93.13% and 95.52%, while those of the nonmetal elements were at the zones 3 and 4 having values of 15.12% and 12.55% respectively (Figure 28). The distribution of the metal and nonmetal elements % at altitude of 0.6m for different zones northern Saudi Arabia indicate that the predicted metal average values for nonmetal dust dry wt % were about 95% for the size bands 1-10µm, 10-22µm, and 22-44µm, while for metal elements, they were 57% at size bands 44-200µm, 41.5% at 200-600µm, and 25% at 600-1000 µm. The nonmetal elements were dominant at this altitude (Figure 29). The distribution of the metal and nonmetal elements % at altitude of 400m for different zones in Saudi Arabia indicate that the maximum metal elements % were about 90% for 44-200µm, and about 81% for 200-600µm, 10-22µm, and 44-200µm, while for nonmetal elements, they were about 27% for 22-44µm, and 1-10µm, 44-200µm and about 19% for 10-22µm, 200-600µm, and 600-1000µm. The metal elements were dominant at this altitude (Figure 30). The distribution of the metal and nonmetal elements % at altitude of 800m for different zones in Saudi Arabia indicate that the maximum metal elements % were about 95% at 44-200µm, and about 90% at the rest of the size bands, while for nonmetal elements, they were about 9.6% at 22-44µm, and 8% at 1-10µm. Metal elements were dominant at this altitude (Figure 31). The metal elements % for different grain size bands at altitudes 0.6m, 400m, 800m are shown in Fig 32. The nonmetal elements % for different grain size bands at altitudes 0.6m, 400m, and 800m (Figure 33). 3D-mapping of hazardous airborne dust particles can be used as an early warning and guide against various risks affecting air/ground transportations, health and environment. For this purpose, a decision making and management program for air/gound transportation, health, and environment is in the development phase at the present time and will be published in future work.

**References**


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