

**STUDY ON HEAVY METAL CONTAMINATION OF SOIL AND
AIR PARTICULATE MATTER ALONG THE ROADSIDE OF
AIZAWL DISTRICT, MIZORAM**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY**

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**DEPARTMENT OF ENVIRONMENTAL SCIENCE
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**STUDY ON HEAVY METAL CONTAMINATION OF SOIL AND AIR
PARTICULATE MATTER ALONG THE ROADSIDE OF AIZAWL
DISTRICT, MIZORAM**

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Submitted
In partial fulfillment of the requirement of the Degree of Doctor of Philosophy
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CERTIFICATE

This is to certify that the thesis entitled, “Study On Heavy Metal Contamination Of Soil And Air Particulate Matter Along The Roadside Of Aizawl District, Mizoram,” is a bonafide work assigned to Gospel Lallawmzuali, Reg No. MZU/Ph.D/1324 of 01.08.2019, Department of Environmental Science for partial fulfillment of the requirement for the degree of Doctor of Philosophy under Mizoram University.

The report submitted by the candidate is her own study and carried out by her and result embodied in the thesis have not been submitted for award of degree any other elsewhere. It is recommended that this thesis be placed before examiners for the award of the degree of Doctor of Philosophy.

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DECLARATION
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I **GOSPEL LALLAWMZUALI**, hereby declare that the subject matter of this thesis is the work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anyone else, and that the thesis has not been submitted by me for any research degree in other University/Instituted.

This is being submitted to the Mizoram University for the **Degree of Doctor of Philosophy in Environmental Science**.

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Chapter 1

INTRODUCTION

1. INTRODUCTION

Heavy metal pollution of the environment has become an issue of global concern. Rapid industrialization, vehicular and other emissions, and inappropriate disposal of goods lead to environmental accumulation of hazardous heavy metals, which leads to a severe threat to ecosystems and human health. Furthermore, road transport is a significant source of heavy metals deposited in soil and atmospheric fine particles. Several investigations in several countries have found high levels of metals, such as copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), manganese (Mn) and iron (Fe), in topsoil as well as air particles around highways and urban roads (Roy et al., 2023).

Proximity to pollution sources like major roads has a great significant in shaping the concentration and speciation of heavy metals in an environmental matrix. Heavy metals in soils near roads are usually more than remote area soil, and they are directly deposited and enriched from contaminated dust. High-traffic roads exhibit elevated levels of heavy metals in fine inhalable particulates, in particular PM₁₀. They are mainly the result of vehicular exhaust and of the resuspension of road dust, what happens more often in crowded centres. The long-term exposure to these polluted atmospheres might implies the bioaccumulation of such hazardous metals, causing a range of health problems (Luhana et al., 2004).

In India, the issue of heavy metal pollution is quite serious particularly along urban roadsides because of fast increasing transport system, high number of vehicles and existence of commercial and industrial corridors in cities. Although the transition to unleaded gasoline, there are still trace amounts of metals such as Ni and Pb, which exist and are emitted from fuel combustion. In addition, non-exhaust emissions from lubricating oils, tire wear, and braking systems add to heavy metal pollution on roads. Dispersion and deposition patterns of these pollutants are also influenced by different type of components such as roadside greenbelt, distance from the traffic lane, traffic flow rate, and local meteorological. Although most research in India has concentrated on the contamination of top soils, trace metal levels of airborne particulate matter is still poorly explored in the North-Eastern region, where wet deposition via precipitation is an essential route for the introduction of environmental

contamination. The interpretation of these levels is very crucial for evaluating public health hazards and ecological effects.

The population and the number of registered vehicles in the capital of Mizoram - Aizawl has gone up significantly in the last ten years which contributed to congestion and air pollution. Additionally, the city lies on hilly land, with high humidity and heavy rainfall can be a concern for the ecology of the area. There is also very little data on account of air and soil quality monitoring from smaller cities in North-East India, including Aizawl, compromising attempts to understand the dynamics of pollution in this region. The present research was carried out to overcome this knowledge gap by providing new data in heavy metal pollution, particularly on the levels of heavy metals in airborne particulate matter and roadside soil. The information on particulate matter pollution near traffic hot spots could be useful for formulating air quality improvement policies for hill towns having comparable topographical and climatic settings. Finally, this study aims to provide an analysis of the relationship between anthropogenic activities (specifically, urban transport emissions) and ecological pollution and efforts for mitigation to suit the specific environmental context of Mizoram state.

1.1 Background

1.1.1 Source of Heavy Metals Pollution in Roadside Environment

Roadside components, such as soil, vegetation, air, surface waters, and elements of infrastructure within the vicinity of the roads, are in risk of being polluted with heavy metals decentralized in the atmosphere mainly by road transport impart (Nabizadeh et al., 2022). Hazardous metals such as Pb, Zn, Cu, Ni, Mn and Fe are released to the vicinity of road by exhaust and non-exhaust sources both (Roy et al., 2023). These metals, most of which are present in the air in particulate form, especially in PM₁₀, are known to be associated with several health and environmental risk effects due to the toxic and persistent nature of such pollutants.



Fig. 1a. Sources of Heavy metals concentration on roadside soil

1.1.1.1 Gaseous Pollutants Produced from the Exhaust of Engines

Vehicular emissions are important sources of heavy metals (Pb, Zn and Cu) in roadside soils. The metals are usually found as additives, contaminants or as remnants of lubricants or fuel. When these Equipment are burned, it allows these metals to be released in the air, mainly on two-stroke engine vehicles. These fuel-lubricant mixed engines, emit a much larger quantity of metal in exhaust, than the seven or more times cleaner four-stroke engines do, as well (Luhana et al., 2004; Al-Momani., 2022). Two-stroke engines have more tendency to burn lubricant, and thus the metals that are present in the oil escape. In contrast, metals like Cd and Ni are largely derived for fuel impurities showing how so fuel composition is important in also determining the type and level of metal emissions.

Fe is another metal more frequently enriched near roads. It is emitted as hot exhaust particles and re-suspended road dust. There are a number of studies that suggest an association between Fe loadings versus traffic intensity suggesting that Fe emissions

are dependent on the level of vehicular activity (Baranowska-Dutkiewicz., 2022; Sutherland., 2003). Iron particles, as particulates and nanoparticles, are released to the roadside environment and remain as a source of continuing metal accumulation. Further, emission control devices, such as catalytic converters. Essential for catalytic converters, these precious metals are emitted as the converters degrade, resulting in Pt, Pd, and Rh being deposited in soils and vegetation near roadsides (Yan et al., 2018). The multiple sources illustrate the vehicle exhaust heavy metal pollution, depending on the type of vehicle fuel, engine design, and emission-control devices.

1.1.1.2 Wear and tear particles from road, brake, and tire rub

Heavy metals are also significant pollutants from non-tailpipe sources, such as tire, brake and road wear. Wear of the tires results in the release of rubber particles with a relatively high content of heavy metals, notably Zn, which deposit at the roadsides and may become suspended in the air and thereby contribute to PM₁₀ levels. According to Fauser., 1999 he pointed out that Zn is a unique indicator for tire wear. Studies by Cho et al., 2019 and Werkenthin et al., 2014 report that 50% of the Zn content within 150 m to the roadsides derive mainly from tire wear particles. This is particularly the case in high traffic and studded tire areas. Metals including Cu are also released from tire wear, even though less than from exhaust emissions (Wang et al., 2024; Kaur et al., 2022).

Wear of the brakes is another significant contributor of metallic particles along roads. Metal-laden particles, including Cu, Fe, Zn, Pb, Ni and Cr, are dispersed during braking due to the contact of brake pads and rotors. High levels of these metals have been detected in soil samples taken from intersections and downgradient sites where braking activity is greater (Sanders et al., 2003; Duong and Lee., 2011). Road markings are also a possible source for contamination by heavy metals as they degrade over time and release among other substances, metals like Pb, Zn and titanium (Ti) into the roadside environment (Zereini et al., 2022). Further vehicle corrosion is involved in metal deposition. Steel auto components rust away with time, particularly in regions treated with road salts discarded Fe-rich particles that may accumulate at distances of up to 10 to 30 m from a roadside. Other

infrastructure, such as galvanized guardrails and lamp posts, also release Zn via corrosion, exacerbating the erosions of roadside metal content (Liu et al., 2009; Li et al., 2020).

1.1.1.3 Re-suspension of Road Dust and Airborne Particles

Road dust suspension, and thus atmospheric metal levels, may also be indirectly influenced by vehicular activity for roads not travelled. As vehicles drive, they stir up dust that lifts the dust into the air. This dust can then couple with PM₁₀, of which unburned fuel droplets, soot, metal particles resulting from abrasions and surrounding soil (Zhao, P., 2010) are taken into consideration. Larger particles fall to the ground faster, but those less than 2.5 µm and ultrafine particle less than 100 nm can float in the air for a long time, move a long distance, and then fall. These PM₁₀ fine and ultrafine particles are also common PM constituents with high respiratory infiltration potential that exposes residents near heavy traffic corridors to potential health risks (Kumar et al., 2013). Weather events specifically, lack of precipitation which would help control levels of dust particulates such as dry periods may cause an increase in dust resuspension.

1.1.1.4 Complexities and Implications for the Environment

Many literatures (Sanders et al., 2003; Duong and Lee., 2011; Liu et al., 2009; Li et al., 2020; Kumar et al., 2013) have demonstrated that different mechanisms relative to vehicle-related such as exhaust emissions, tyre and brake wear, corrosion, and re-suspension of dust give rise to complex patterns of heavy metal pollution in the roadside environment. Levels of contaminants from each source vary depending on various factors including volumes of traffic, road surface conditions, weather conditions and materials used in vehicles and the infrastructure. The long retention time of metals in PM₁₀ is of particular concern because of their mobilization and human health impacts, highlighting the complex task of control of heavy metal contaminants in urban areas. Reliable monitoring and source-apportionment information is necessary to derive effective mitigative measures towards abating heavy metal pollution in roadside areas and also towards improving the air quality.

1.1.2 Characterization of Heavy Metals in Vehicular Emissions

The emissions from vehicles can introduce a variety of metallic pollutants into roadside environment, and Pb, Cu, Zn, Ni, Cd, Cr and Fe have been the most frequently reported metals accross vehicular studies around the world (Liu et al., 2009; Duong and Lee., 2011). Although some geo-genic elements such as aluminium (Al), magnesium (Mg) and calcium (Ca) are abundant in the environment due to soil content, elements like Pb and Zn show high anthropogenic contributions which can often be assigned e.g., to traffic emissions.

Lead (Pb): In the past, leaded gasoline was the major cause of bookstore Pb contamination, though Pb deposits still remain in some fuels and lubricants (Altaf et al., 2021; Skorbiłowicz et al., 2021). The contribution of Pb to the brake lining (15 % lead sulfide and oxide) is necessary for noise reduction and to improve the friction from Pb containing lining (Sanders et al., 2003). End-of-life vehicle processing as well as recycling of older vehicles, a number of which have metal Pb body parts, likewise contribute to Pb in the vicinity of automotive recycling facilities. The concentration of Pb in roadside soils is frequently associated with brake wear emissions, as evidenced by traffic flows and braking intensity (Disperati et al., 2017).

Copper (Cu): Cu is the second most concentrated TRM, is highly concentrated in roadside dust mainly due to extensive use in brake pads and its release from this source is enhanced by friction, notably during downhill braking (Hulskotte et al., 2014). Cu is also present in tire rubber, but brake wear is the main source of higher Cu content in roadside soils (Song et al., 2006; Duong & Lee., 2011). Small Cu inputs are generated by engine oils, bushings and thrust bearings.

Zinc (Zn): Tire wear is the largest sources for Zn in roadside settings, supplying more than 50% of Zn in heavily and moderately trafficked sites (Councell et al., 2004). Zn oxide is applied in tire manufacturing as a vulcanization catalyst which may justify the high concentration detected in road dust near traffic, and the high concentrations in road dust are related to traffic intensity. These studies are complemented with tenure enclosed tunnel investigations which limit the influence of soils on traffic sources where they demonstrate the Zn tire wear sources (Zotański et al., 2018) Cho

et al., (2019). Additional Zn comes from rust proof coatings of road side constructions such as guardrails and light poles, which are rust and flake off after a while (Fauser., 1999).

Nickel (Ni): It is a trace element for tire rubber, engine components but is also released from fuel residues and catalytic converters in which Ni and Cr oxide supported catalysts (Furusj et al., 2007) are present. They are also present in both tunnel and roadside dust, suggesting that the majority of these particles are derived from exhaust emissions and re-suspended dust. In addition, Ni and Cr are present in brake dust leachates, confirming their multivehicular origin (De Miguel et al., 1997).

This spectrum of metals from vehicle exhaust demonstrates the wide-reaching implications of traffic for roadside metal contamination wide range in roadside metal contamination. The insight that the source of a metal (either from fuel combustion, brake/tire wear, or corrosion) adds a layer to the challenges of controlling heavy metals in high-traffic areas, with different sources contributing differently according to traffic volume, vehicle composition, and road network.

1.1.3 Driving Force to Cause Ground and Air Pollution

The actual contents of that metals in the vicinity of roadsides are controlled by several interacting parameters of vehicles, roads, terrain characteristics, land use and meteorological conditions. These influences operate through complicated source-receptor relations dominating emission intensities, transport patterns as well as the potential depositions.

1.1.3.1 Topography/Landscape

The topography/landscape is one of the variables which plays an important role in the allocation of roadside metal concentrations is influenced. Roadside proximity to steep slopes can also enhance runoff mobilization of metals to downslope lower areas and alter deposition patterns along the road edge and in the slope (Hjortenkrans et al., 2007). Contrastingly, flat land allows for relatively little movement of metals away from the road, due to the restricted potential for drainage of contaminants from where they originate. Weeds and grass or ground cover vegetation also serve as a

metal sink within the vicinity of the stream by naturally collecting airborne particles and decreasing the chance those particles will be resuspended (Scheetz and Rimstidt., 2009). At the same time, anything in nature that serves as a barrier -- trees or rocks, can block wind-blown dispersal of metals, creating concentrated pockets adjacent to the roadside.

Vehicle factors, and road properties, weather conditions, local topography and land use are some of the multiple influences on the deposition of heavy metals along roadways. As a result of these, very complex source-receptor relationships are formed, which are determining emission rates, dispersion processes, deposition rates, and even concentration levels of heavy metals in the PM₁₀ in the air influencing the distribution of contamination along roads.

1.1.3.2 Traffic Volume

Traffic volume is a primary determinant in the emission of heavy metals. More traffic volume results in more emissions of the exhaust, tire, and brake, increasing metal concentrations on the roadsides. The Song et al., 2006 and Duong and Lee., 2011 and as a result, excessive traffic flow generates effective turbulence and resuspended road dust leading to increased metal deposition on proximal surfaces. It is repeatedly shown that the concentration of heavy metals is higher in the closest vicinity to highways and larger roads compared to narrower streets, and that traffic density, road width, and loads of heavy metals near curbs are closely related (De Miguel et al., 1997).

1.1.3.3 Variability in vehicle fleet

There are variations in metal profiles that exist on the roadside, related to vehicle types. By virtue of their engines, fuel types, and material compositions, other vehicles release different amounts of metals, such as Zn, Cu, Fe, and platinum group metals (PGMs). For instance, heavy-duty diesel trucks produce unique metal signatures compared to light-duty vehicles as found by Clarke et al., (2015). Vehicles parts, including tires, brakes and the catalytic converter, also vary in their metal concentration and vehicles. Especially, those running on leaded gasoline or equipped with Pb based solder have been found to be the major contributors to roadside Pb

levels. Electric and hybrid vehicles on the other hand usually generate lower metal emissions during operation (Hjortenkrans et al., 2007).

1.1.3.4 Local activities and road geometry

The hot-spots on the grid (interactions, stop signs) will be more subjected to buildup of metals as a function of increased wear of braking was also observed by Shakya et al., 2012. Hills also indicate higher levels of deposition from brake dust due to repetitive braking on downhill slopes (Sutherland 2003). Furthermore, tire wear is highest on tight turns where centrifugal forces create the greatest tire wear, but with some released outward. Local activities, such as open burning of metal-containing material or illegal e-waste dumping, are sporadic sources of roadside metal pollution, and result in localized spikes of metal concentrations (Ewen et al., 2009).

1.1.3.5 Roadside Environment

The concentration of metals is also higher along roadways with industrial sources, smelters or metal processing plants. Such facilities contribute metals such as Fe, Zn, Cu and Cr with atmospheric deposition, in addition to increasing the concentration of metals as a result of roadside vehicles. Construction adjacent to roads also contributes to metal pollution through the generation of metal-bearing dust, especially on unpaved road edges (Amato et al., 2011). The roadside slope vegetation serves as a sink and prevents further re-suspension of metals (Scheetz and Rimstidt., 2009).

1.1.3.6 Meteorology and Seasonality

Weather conditions and seasonality play an important role in metal concentration and distribution at the roadside. In contrast, dry periods enable increased dust resuspension which lowers air quality at roadsides, while precipitation limits the dust resuspension as well as the amount of friction from tires and brakes (Kumar et al., 2013; Hjortenkrans et al., 2007). But storm runoff in wet seasons tends to deliver metals dissolved in and particles of metal from roads to the soil or from the road area to water bodies, and result in an increased metal load at these locations (Liu et al., 2009). Continued dry periods can cause build-up of metals on roadways and rain can

lead to leach of metals into neighbouring soils. Seasonality also has an effect on the emission rate, favouring incomplete combustion or accelerating metal volatilisation (Lonati et al., 2010). In addition, de-icing salts applied in the winter facilitate the corrosion of vehicle parts, thus augmenting the metal contamination in the vicinity of roadsides (Ayaz et al., 2023).

1.1.3.7 Road Surface Characteristics

Characteristics of the road surface determine the ability of the road to retain particulate matter and release wear-related metals. Carbon soot and dust on asphalt roads are usually retained in the aging bitumen, which bleeds and collects more dust with time and can generate more wear debris than on smoother concrete roads (Ayaz et al., 2023). The surface roughness also influences the tire abrasion, because the rougher pavement surfaces cause more generation of metal particles, and smoother streets inhibit this effect (Furusio et al., 2007). Porous street surfaces work to lower surface dust accumulation over time by improving drainage, however the particles that are stored into these pores will have high metal concentrations (Disperati et al., 2017; Altaf et al., 2021).

1.1.4 Effects on Health due to Heavy Metal Exposure

Heavy metals are renowned for their stability within our environment and their bioaccumulation potential, causing toxic effects even at low dose and through long durations. This is primarily because they are non-degradable and, hence, build up within tissues and organs. Heavy metal particulate forms are generally taken into the body through the respiratory tract, while dissolved ions may be absorbed more widely, and may enter from the lungs, skin, or GI tract and deposit in specific target organs (Hong et al., 2002). According to Tchounwou et al., (2012), the distribution and toxicity of the metals are determined by various metabolic properties such as molecular weight, solubility, speciation, blood transportability, and permissibility to cells. Toxicity is also influenced by metal type and the dose and duration of exposure and general health of the exposed individual.

Lead remains one of the most important environmental contaminations because it has been widely used by human in paint, fuel, and plumbing over generations. and, thus,

is widely distributed in soils, dust, and water. Children are at higher risk, as they absorb 50% of lead ingested whereas adults absorb less than 15% (Hong et al., 2002). Among neurodevelopmental disruptions, Pb exposure has been reported to be particularly detrimental to the developing brain, as it disrupts several functions and structures of a child's brain (Patil et al., 2003; Surkan et al., 2007; Zhang and Tooker., 2012); diminishes cognitive and intelligence quotient (IQ) levels (Needleman et al., 1990; Lanphear et al., 2005); and impairs the release and synthesis of neurotransmitters by substituting calcium ions via their transporters (Lidsky and Schneider, 2003), leading to their accumulation in calcified tissues (bones and teeth) and soft tissues (brain and kidney) (Canfield et al., 2003). High Pb can lead to serious health effects including anaemia, convulsions, retarded sexual maturation, encephalopathy, or kidney failure. In particular, lead exposure to pregnant women, infants and foetus are more susceptible because of that lead can permeate the placenta and interfere with fetal neurodevelopment (Chen et al., 1985). To ease the potential risks the U.S. Environmental Protection Agency (EPA) establishes reference doses for lead in soil, 400mg/kg and 1,200 mg/kg for play and non-play areas, respectively.

Copper, though it is needed as a cofactor for numerous enzymes, can be fatally toxic in higher doses. A daily consumption dose of 10-15 mg is usually unproblematic for a healthy adult, nevertheless, chronic exposure to doses higher than 40 mg/day is associated with damage to liver and kidney (Bremner, 1998). With poisoning at the acute level, the adverse effects include gastrointestinal disturbances, vomiting as well as hepatic and renal failure. Impaired Cu excretion in Wilson's disease leads to pathologic copper accumulation in the liver, brain, and eyes, and is responsible for progressive neurological disease, and cirrhosis (Hong et al., 2014). Workplace exposures to Cu fumes, which are encountered in welding or smelting, may cause symptoms such as headaches, cold sweats and nausea, particularly in non-tolerant individuals (Chakraborty and Roy, 2022).

Zinc, a third critical nutrient has lower level of toxicity where the daily consumption does not exceed 100-300 mg, and it has roles in numerous enzymatic and metabolic processes (Tchounwou et al., 2014). However, high doses can induce some

gastrointestinal signs -such as nausea, epigastric region discomfort-, or asthenia and diarrhoea after single doses longer than approx. 0.5 g (Zhao, 2010). When zinc is inhaled as a gas (Zn fumes), present in an industrial environment, it results in 'zinc shakes' (also referred to as metal fume fever), which is characterized by flu symptoms; shivering, fever and sore muscles. Chronic lung injury and fatal respiratory diseases can be caused by excessive inhaled airborne Zn. High Zn levels can compete with Cu for absorption and inhibit its intestinal absorption, leading to anaemia and causing harm to liver, pancreas and nervous tissues (Gandhi et al., 2018).

An essential metal for enzymatic function; high levels are neurotoxic, particularly in chronic exposure in mining, welding, or smelting industries. Chronic exposure to Mn can cause "manganism" and has symptoms that mimic Parkinson's disease such as motor-sensory impairments and cognitive dysfunctions which is caused by Mn accumulation in the brain regions with high level of dopamine that leads to the oxidative stress and neurotransmitter function disturbance (Aschner et al., 2007). Mn clearance is tightly related to liver function, and people having impairments in liver function are at greater risk (Crossgrove and Zheng, 2004). Furthermore, the pulmonary system may also be affected by inhaled Mn particles, causing respiratory problems and increased risk of infection.

Nickel, although essential in very small quantities, is a heavy metal that is toxic to humans when overexposed. Common exposure to Ni in the workplace like electroplating and welding, is responsible for a variety of respiratory conditions, such as asthma, chronic bronchitis, and an increased risk for lung and nasal cancers. Binding to cellular proteins and DNA is thought to contribute to the mutagenic and carcinogenic effects of Ni (Denkhaus and Salnikow, 2002). In addition, long-time exposure to Ni has been linked to skin allergies, for instance contact dermatitis, particularly those already sensitized to this metal (Das et al., 2008).

Iron is necessary for oxygen transport and production of cellular energy, but too much can be toxic, a condition human with a genetic disorder called hemochromatosis or due to frequent blood transfusions. However, excess Fe

saturates the body storage system causing tissue deposition in the liver, heart, and pancreas, resulting in cirrhosis, diabetes, and heart failure under certain Fe loads (Clarkson and Magos, 2006). It also enhances the formation of reactive oxygen species (ROS) that may damage DNA and proteins as well, which might increase the risk of neurodegenerative disorders including AD and PD (Gutteridge and Halliwell, 1989).

Pb: Anaemia, convulsions, retarded sexual maturation, encephalopathy, or kidney failure. Cu: Include gastrointestinal disturbances, vomiting as well as hepatic and renal failure.
Zn: Chronic lung injury and fatal respiratory diseases Ni: Asthma, chronic bronchitis, and an increased risk for lung and nasal cancers
Fe: Tissue deposition in the liver, heart, and pancreas, resulting in cirrhosis, diabetes, and heart failure Mn: Motor-sensory impairments and cognitive dysfunctions

Fig. 1b. Health effect of heavy metals on human being

1.1.5 Vehicular Growth Statistics in Aizawl District

During the past 20 years, there has been a rapid growth in economy and population in the city and district of Aizawl. This speed of sprawl has been accompanied by a rapid growth in vehicle use - two- and personal four-wheelers in particular - resulting in congestion and air pollution. Unplanned urban expansion and underdevelopment of mass transit introduced by Lallianthanga (2022) has also contributed to problem as the city depends on personal vehicles driving through ill-maintained infrastructure to accommodate the surge in traffic. Vehicle registration statistics reflect this, with Mizoram's stock of vehicles growing from around 94,000 in 2001 to over 3,49,841 in 2025, and 45-50% of the state's registered fleet being concentrated in Aizawl City (Ministry of Road Transport and Highways, 2025; Economic Survey of Mizoram, 2020-21). This rapid growth has put added pressure on the roads of Aizawl – also among the reasons why they are noisier and louder than peak hours.

Aizawl's vehicle kilometres travelled (VKT) is expected to almost double to 1,880 million km by 2031, up from an estimated 935 million km in 2021 according to business-as-usual predictions (Lallianthanga, 2022). The increasing VKT is due largely to increases in private car use which is forecasted to increase at approximately 10% pa (those are very rough figures) compared to public transport at less than half that 5% pa. It's this transition that benefits single occupancy vehicles to make congestion that much worse, and which certainly emphasises the need for infrastructure investment and to encourage people to make the switch to green forms of public transport. Also, investigation by Ramthansiana et al. (2017) that the arterial corridors of Aizawl city exceed the designed traffic capacities by 25% to 55% during peak hour resulting in longer idling, more number of jams and journey time inefficiencies.

The pollution directly next to busy roads in particular is a severe health risk to local residents, and the exposure of these populations to toxic traffic-related air pollution is even higher in urban areas. Adding to the challenge, outdated vehicles proliferate; in 2016, they constituted only 30% of commercial vehicles that complied with Bharat Stage-Level-IV standards, and many continued to be governed by older emission-related standards, further contributing to poor air quality (TERI, 2016). Furthermore, the Aizawl source-specific, estimations suggest that vehicles well contribute to the local pollution but also lead to an enhanced health risk for the people with respect to respiratory health.

To summary, the motorization in Aizawl district has grown to an unprecedented level in the past twenty years but is expected to grow even faster by 2030. Without corresponding road infrastructure expansion and traffic demand control, negative implications are anticipated with respect to deteriorating traffic conditions, emissions and inefficient use of fuel for non-free-flow traffic. This may have indirect consequences for vehicular abrasion processes and re-entrained road dust conditions that control heavy metal accumulation near roadsides.

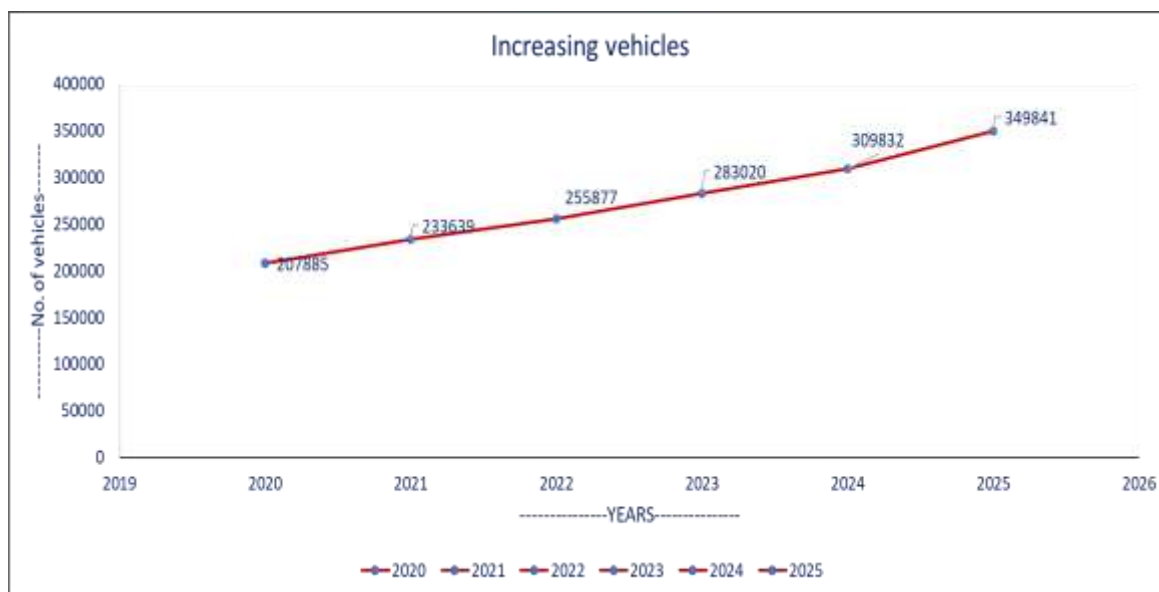


Fig. 1c. Increasing trends of vehicles from 2020 to 2025

1.1.6 Soil Properties That Favour Heavy Metal Retention

Soil physicochemical properties mediate directly heavy metal retention and bioavailability to ecological receptors after road-side accumulation in the environment. SOM, pH and other binding ligands sorb metallic contaminants by different sorption mechanisms, and therefore, the mobility and residence times are affected (Adhikari et al., 2014).

1.1.6.1 Role of Organic Matter

Soil organic matter (SOM) is a complex of plants and animals' residues at various stages of decomposition and products of microbial biomasses and native humus in soil. The SOM is the home of various aliphatic and aromatic functional groups (phenols, ketones, quinones, alcohols, esters, amines, amides etc.) with which the metals interact in complexation, chelation, cation exchange and surface adsorption routes (Bradl, 2004). Multidentate acidic functional groups give laminate which has high loading capacity for electropositive metals such as Pb, Cu and Cd. Elements which are oxidised and reduced on the redox-sensitive sulphur compounds include As, Cr and Hg. Increased binding of metals to soil often follows the SOM concentration but its magnitude is also a function of humus type, age, and provenance, as well as the nature of the metal.

1.1.6.2 The pH conditions

Acidic pH favours the dissolution and leaching loss of metals while alkaline pH promotes hydrolysis, carbonate precipitation, and immobilization of some metals (Petruzzelli, 1989). Consideration of lead, zinc and cadmium as the amphoteric metals which transfer easily from an exchangeable fraction to a more stable, as a hydroxide or carbonate, at high pH and thus become immobile. In the alkaline pH region (Dawodu et al., 1988, Rutkowski et al., 1996 and Soni et al., 2015), the mobility of oxyanions moves in the opposite direction. Under moderately acidic soils pH 5–7, SOM and retention mechanisms of oxides are positively correlated with the accumulation of total and bioavailable metals. Near-neutral pH is also suitable for microbially mediated metals or soil redox potential altering their speciation and retention

1.1.7 Gaps in the knowledge of Heavy Metals Pollution on the roadside and particulate Matter in the Air in Aizawl

The knowledge of heavy metals pollution on roadside exposure and particulate matter in the air is still lagging behind in the capital city of Aizawl. However, even though there are high rainfall and natural geochemical metal fluxes of the hill urban terrain of Aizawl City, especially where the study was conducted, systematic studies of the different levels, their main sources, and its effects on health by airborne and roadside heavy metal pollution are found to be noticeably deficient. Despite discrete studies which have evaluated soil quality and presence of toxic metals near the suspected industrial hot spots, there is a dearth of large-scale studies which addresses the separation of anthropogenic, vehicular and natural crustal sources of metals in the city. This extent of environmental surveillance and source profiling, which is extensively done in higher or tier-I urban centers is still lacking (Tyagi et al., 2013). In addition, no such studies focused to correlate the HM contamination with their sources to fills the partial information on their possible hazards on Aizawl inhabitants.

1.1.7.1 Limited Analysis of Multiple Elements

A brief examination of multi-element analysis: In terms of multi-element analysis of elements other than radio-nuclides, little concentration of metals has been conducted in few topsoil studies as for particular sites at Aizawl. In addition, detailed quantification of heavy metals typically associated with vehicular emissions: such as Cu, Ni, Fe, Pb and Zn across diverse road categories, has not been performed (Lallianthanga and Goswami, 2013). This is in stark contrast to Indian urban locations, where all-inclusive multi-element surveys have increasingly become the norm since the mid-2000s, as reflected in studies gathering India's environmental metal burden (across domains (Khillare et al., 2012)). However, without a detailed multi-element profile of roadside and atmospheric metals in Aizawl, assessments of urban health environment are partial and oppressive.

1.1.7.2 Source Tracking Constraints

The absence of a comprehensive source-tracking programme further hinders the identification of sources responsible for heavy metal pollutions in Aizawl. In contrast to northern and western cities, where source apportionment methods were applied to statistically allocate weightage to the traffic-related versus geogenic emissions, Aizawl (EPN-55) lacks fingerprinting studies to distinguish between vehicle and geogenic emissions. For instance, multivariate approaches applied to soil composition and elemental data enable to discern and quantify the contributions from different pollution sources thus providing a better understanding of the impact of traffic in the accumulation of heavy metals (Charlesworth and Lees, 1999; Li et al., 2013). Particulate-bound metal contamination in Aizawl may presumably be from motor vehicle tail-pipe emissions or tire/brake wear as evident among samples from other urban centers, however, this is speculative due to lack of well-defined source apportionment studies.

Monitoring of air particulate would be of great help in understanding the effect of high heavy metal pollution of the city on public health, which would in turn aid in the formulation of air quality standards and health guidelines specific for Aizawl.

This data is indispensable for preventing long-term health risks posed by heavy metal pollution in the air.

1.1.7.3 Poor Information on Airborne Heavy Metals

Despite the drastic increase of vehicular population and the unique topographical feature of Aizawl, not much comprehensive study conducted on airborne heavy metal pollution in the region. So far, there is no regular surveillance for heavy metal content in air in particular of those from the sources such as vehicle exhaust, industrial fumes, and atmospheric deposition. Unlike other cities where the studies have reported high concentrations of metals including Pb, Ni and Zn in PM₁₀ and PM_{2.5} dust (Bremner., 1998; Canfield et al., 2003), Aizawl does not have a tendency of regular air quality monitoring and analysis of particulate specific metals, where evidence on toxic metal levels in urban air might be over looked.

1.1.8. Relevance of Detailed Investigation on Heavy Metal Pollution in Aizawl

It is desirable to undertake a comprehensive study on the occurrence and the concentration of important heavy metals in the ambient air and in surface layer soil of Aizawl along the major road sides. The principle of such assays is motivated by the toxic nature of these metals, their cumulative nature in the city as a result of traffic. However, without persistent environmental surveillance in the city. As Aizawl has quickly grown motorization rate and vehicle density, taking a preventive approach towards these emissions is imperative to avoid future peril of environmental as well as public health.

1.1.8.1 Properties of Toxicity and Bioaccumulation

Nickel (Ni), lead (Pb), manganese (Mn), iron (Fe), and zinc (Zn) are also among heavy metals in which there are toxic effects to humans and environment. Such effects have been extensively reported at molecular scales, where high concentrations of the metals cause toxicity since they are redox active and can compete with essential metals in biological molecules (Bradl, 2005). Due to their persistence in the ecosystem, in addition to the capability to be biomagnified in food webs, these chronic poisonings may eventually develop into cumulative damage in organs and

elevated cancer rates over long-term exposures (Tchounwou et al., 2014). Both the toxicity of these metals and their long-term existence in the environment point to the necessity for imposing strict control measures to prevent further accumulation.

1.1.8.2 Relationships with Vehicular Emissions

International studies, as well as empirical receptor modelling and tunnel monitoring results, indicate that vehicles are major urban sources, making up 20-50% of environmental metal loads (Hjortenkrans et al., 2007; Adachi and Tainosho, 2004). In such case of Aizawl where there is no heavy large-scale industry, very dense vehicular traffic and steep road probably enhanced emission due to hilly terrain which makes vehicles as a major source of metal contamination. No such detailed studies on how much of a particular metal is emitted by vehicular traffic have been reported, emphasizing the importance of empirically validated vehicular pollution data. This information is important, particularly for the protection of people living and working alongside roads where these emissions are encountered on a regular basis.

1.1.8.3 Quantification of the Sparse Environment

Compared to other state capitals in India, which receive routine air and soil metal documentation, there is no organized data in Aizawl at these pertinent environmental samples especially from heavily trafficked roads. As per Central Pollution Control Board (CPCB, 2022), although majority of the cities are observing better air quality, generally pollution levels are often higher than the permissible limits. But Aizawl has no long term records on metals as such. The city's metal pollution levels and spatial distribution, which are necessary for form initiating successful policies, could be provided by conducting standardised measurements along the major access routes.

1.1.8.4 Worsening Emission Trajectory

It is estimated that vehicular pollution in India could further increase if not controlled effectively because of increased number of vehicles, older technology of engines and high mileage (Chakraborty and Roy, 2022). This phenomenon in Aizawl is combined with an aged vehicle population and traffic congestion and may pose the potential for

dangerous pollutant concentration in the future. Early intervention is urgently required and the quantification of the emissions amounts to the design of coordinated mitigation policies before environmental consequences become irreversible.

1.1.9. Consequences for Urban Form and Sustainable Transportation

To face challenges related to sustainable traffic and city planning, it is important to know more about how traffic-induced heavy metals are distributed and what effects they may have in urban air and soil. Results of such a work would be particularly useful in designing environment sensitive transport and downtown expansion strategy for Aizawl.

1.1.9.1 Strategies for Low-Emission mobility

Applicable abatement measures for urban road transport are only achievable if it can be specified clearly which are the pollutants and the underlying sources. The different types of pollution require specific technologies. Accurate information on this metal partitioning between exhaust and non-exhaust sources would then be used by public authorities to prioritize the measures affecting the most impact needed step for the transition to shared and clean mobility solutions with low or zero emissions (Faiz et al., 2006).

1.1.9.2 Informed Urban Planning

The incorporation of environmental consideration into land use and transportation decisions becomes paramount for sustainable urban development. One example is the lowest and highest emission zones that are established according to pollution monitoring data in a schematic map, such as the zoning policy, which could alleviate the gap of exposure among residents, especially when these are located in high population density areas near major roads (Zhao, 2010). In road construction, design and rehabilitation works it is also useful to know the path of contaminants at the inter-play of planners in road development to insert science-backed safe-guards in these urban developments.

1.1.9.3 Climate Change and Urban Resilience

The Urban Resilience Alliance and Local Governments for Sustainability networks are some among many others focused on urban resilience, which is especially important given the challenges urban areas face in a changing climate.

Vehicular emissions resulting in heavy metals, not only directly affect local air quality, but also impact the broader atmospheric radiation and regional ecosystem processes. The accumulation of these metals in soil may affect the growth of vegetation, decreasing the ability to sequester carbon, which is fundamental to the process of climate stabilization (Chen et al., 2022). The understanding of the ecological cycling and long-term impact of heavy metals accumulated in the roadside is necessary for the development of climate resilient urban landscape for ecological and the health plan of the people. When Aizawl's urban planning and urban transport planning incorporate data on metal pollution from automobiles and other human activities, the city can synchronize its policies with sustainability and resilience objectives, leading to a cleaner and healthier urban environment.

1.2. Problem Statement

Over the past two decades, Aizawl has undergone rapid urbanisation, sprouting several new townships and reliefs as its outgrowth. The number of registered vehicles in Aizawl has risen to more than 310,000 vehicles since 2001, which add a heavy burden to the road system. Personal modes of transport, especially cars and two wheelers, dominate this burgeoning fleet leading to worsened congestion and emissions.

Aizawl's story of traffic congestion, soil pollution due to lack of yard space and air pollution due to rise in motor vehicles, up-hilly capital of one of India's most 20 congested states have added to the pollutions in the environment. The region is free from big industries, and the emissions of vehicle are likely largest source of particulate and gaseous pollution which required urgent action.

Heavy metals contamination are well documented in vehicles but studies conducted on these contaminants along the roadsides in Aizawl are still scarce. Additionally, no

systematic research has yet linked a general and systematic investigation of the pollution sources of this pollutant with respect to traffic – related pollution, other human and natural sources of these metals. Since the traffic volumes is expected to further increase in the coming decades, unmanaged emissions might result in higher deposits of non-ferrous metals in the environment and residents living near congested zones may face higher exposure risks. Thus, there is a need to quantify present contamination status itself and to reveal strategies towards such a socio-economic discriminant that directly influence public health and a sustainable urban future of Aizawl.

1.3. Research Objective

The present study envisaged the following objectives:

1. To study the heavy metal contamination in roadside soil.
2. To study the heavy metal contamination in particulate matter collected at Air samplers.
3. To compare the heavy metal at different sites based upon traffic density.

The objectives focus on quantifying current heavy metal levels in soils and airborne particulates, correlate with traffic density, and to ascertain the possible sources of contaminations.

Chapter 2

Review of Literature

2. REVIEW OF LITERATURE

Heavy metal pollution has been used to define an environmental contamination with metals and metalloids with high density and high toxicity, even at low concentrations. The most common heavy metals pollutants are Cu, Fe, Mn, Ni, Pb and Zn. These metals dispersed into our surrounding by the activity of industry, vehicular emissions, agricultural usage, and geological sources. Metal pollution can be divided into soil pollution (deposition in roadside soils and in agricultural land), water pollution (release into receiving waters), and air pollution (association with particle size fractions such as for PM₁₀ and PM_{2.5}). Because heavy metals do not biodegrade and persist in the environment, they are capable of bioaccumulation in the food chain and are a serious concern for ecosystems and human health (Chen et al., 2015; Salam et al., 2011; Sadheesh et al., 2022).

The discovery of heavy metal contamination began to attract widespread attention in the mid-20th century, and in the 1970s and 1980s research became more focused when cities and industries around the world grew rapidly. The detrimental effects on human health and the ecosystems were the triggering results, because researchers found that heavy metal exposure led to severe health problems, such as neurological disorders, kidney damage, and cancer. A key driver of the global attention was the identification of elevated levels of lead in urban soils as a result of the use of leaded gasoline (Mutua et al., 2021; Yahaya et al., 2009). Studies of roadside soils became specialized fields in environmental studies, because the soils inhabit the vehicles' emissions in their porous structure and in these emissions also heavy metals such as lead, cadmium, and zinc (Leili et al., 2008; Sabourmoghaddam, 2017). In the 1990s, research like that in Europe, the U.S. and parts of Asia exposed the link between traffic density and soil contamination, which, in turn, was a concern about food safety, water contamination and an indelible concern about long-term health hazards. These observations emphasized the immediate requirement of monitoring and remediation plans to alleviate heavy metal effects on public health and ecosystem (Di Vaio et al., 2018; Sadheesh et al., 2022).

As reported by Briffa et al., (2020), Heavy metals contamination is a global problem of soils, water, and air being mainly caused by anthropogenic activities including industrial emissions, mining, smelting, agriculture, and urbanization. The key findings reveal that high concentrations of contaminants Cd, Pb, Hg, As, and Cr are commonly found in levels that surpass the permissible limits (0.003 mg/L of Cd and 0.01 mg/L) of As in water World health organisation (WHO), and 0.1 mg/m³ Pb in air Occupational Safety and Health Administration (OSHA). Soil contamination of Cd and Pb are mainly due to fertilizers, pesticides and urban leachate, whereas Hg and Cr are due to industrial effluents and mining. They continue to survive in the environment because of their resistance to degradation, bioaccumulate in the food chain and have toxic effects such as DNA damage, oxidative stress, carcinogenesis, neuro degeneration and organ damage.

Researches of Chen et al., (2015) and Hou et al., (2019) have indicated widespread heavy metal contamination in soils in mainland China, and Cd, Hg, Pb were the leading heavy metal pollutants. Chen et al., (2015) found mean Cd (0.225 mg/kg), Hg (0.087 mg/kg), and Pb levels (31.2 mg/kg) that were higher than their background values by 2.3, 1.3, and 1.2-fold/times, respectively. The majority of samples (73% for Cd, 37% for Hg and 47% for Pb) exceeded these levels. The Pollution index (PLI) ranged between 0.2 and 13.4 with average value of 1.1 that falls under moderate category of pollution levels. The values of the provinces such as Guangxi (average Cd: 59.9 mg/kg), located in the south, almost reached the contaminated level because of natural geochemical background and human activities, which included industrial, agricultural and urbanization.

In Beijing, 64 soil samples were obtained in 0-m to 21-m layers, and severe contamination of topsoil was observed, in which Hg (0.91 mg/kg), Cd (0.09 mg/kg), Cu (23.74 mg/kg), Pb (20.6 mg/kg), As (7.52 mg/kg), and Zn (54.16 mg/kg) exceeded background values, in topsoil, with a maximum of 116.88 times for Hg, 2.15 for Cd, and 1.63 for Cu. Natural (As: 63.11%, Cr: 61.67%, Ni: 70.8%), fossil fuel combustion (Hg: 97%) and traffic sources (Zn: 72.8%, Pb: 69.75%, Cu: 65.36%, Cd: 53.08%) were identified. These findings emphasized the role of industrial activities, traffic, and coal combustion in soil contamination, and they suggested that

remediation strategy should target at anthropogenic source and avoid improper treatment for natural heavy metals (Jia et al., 2023).

Soil pollution being one of the most describe environmental problems mainly due to the buildup of poisonous chemicals, heavy metals, and toxic substances as a result human activities, namely industrial activities, mining, urban runoff/sprawl, and the use of pesticides and chemicals fertilizers (Ashraf et al., 2014) The literature demonstrates heavy metals like Cd, Pb, Cr, Cu and Hg to be potential pollutants, having their soil levels as 0.01–0.7, 2–200, and 5–3000 µg/g for Cd, Pb, and Cr respectively, with the industrial sludge containing cadmium up to 1500 ppm and chromium up to 8800 ppm. They are introduced into the soil through landfill percolate, industrial discharges, and use of agricultural inputs. The ERA of the pollutants included an experimental program with bioassays and chemical analyses to assess their effects on organisms and human health. The proposed remediation approaches include bioremediation, phytoremediation and thermal in-situ technologies, which are case sensitive and stress to deal with pollution efficiently. The study also highlights the importance to take immediate actions to implement more stringent regulations on pollution control, sustainable agricultural system and to implement better waste management practices to reduce soil pollution and to mitigate the long-term ecological and human health effects of soil pollution.

Heavy metal contamination in soils is a worldwide environmental problem and it is mainly due to human actions, like industrial discharge, mining, agricultural activities, and inappropriate wastes disposal, as reported in the research made by Su, et al., (2014). The global averages showed that the mean levels of heavy metals in urban soils worldwide are Zn, 289.78 mg/kg; Cu, 49.60 mg/kg; Cr, 66.08 mg/kg; Ni, 29.14 mg/kg; Pb, 1733.94 mg/kg and Cd, 1.52 mg/kg, which frequently exceeded their corresponding regional background values. Average levels of Cr in the agricultural soils were 46.69, Cu 38.03, Pb 51.19, Zn 117.35, Ni 26.12, Cd 1.50, Hg 0.28 and As 21.19 mg/kg.

The distribution of heavy metals levels in the roadside dust of five busy traffic roads in Jos was studied by Mafuyai et al., 2015. The evaluated metals were; Cu, Pb, Ni,

Zn, Fe, Cd Mn, and Cr and their concentrations ranged as of: Cu (24.5 - 67.0 mg/kg), Pb (25.0 - 66.0 mg/kg), Ni (1.23 - 3.88 mg/kg), Zn (35.0 - 123.0 mg/kg), Fe (48.5 - 125.0 mg/kg), Cd(1.54-2.85 mg/kg), Mn (1.15-2.58 mg/kg) and Cr (1.13-2.79 mg/kg). The study found magnitude of the traffic to be a significant factor affecting metal accumulation; where metal concentrations were relatively high closer to busy roads such as Yakubu Gowon Way and Goodluck Jonathan Road. Vehicle emissions, road construction and human activities were identified the main sources for the pollution. Pollution indices (EF, CF and PLI) indicated that the levels of contamination were moderate (ABW, YGW, GJR) and low (BRR, MMW). Mean concentrations were lower than the maximum values approved by the European Union, but both metals have bioaccumulation capacity and are a risk to the urban population exposed to them, mainly the respiratory and ingestion routes, so they must be monitored and mitigation policies should be implemented.

The NERI study "Heavy Metal Emissions for Danish Road Transport" (2010) reports estimate of the heavy metal emissions from Danish road transport 2007 with the consumption of fuel, engine oil, tyre wear, brake wear and road abrasion considered as the five main sources of the heavy metal emission. A noticeable release by PM 10 of heavy metals such as arsenic (8 mg/kg) Cd (48 mg/kg), Cr (197 mg/kg), Cu (51,779 mg/kg), Mn (28 mg/kg), Ni (158 mg/kg), Pb (6,989 mg/kg), Se (33 mg/kg) and Zn (28,556 mg/kg) has been revealed in the study. Cars and vans were the largest sources, cars being responsible for above 62% of Pb and above 46% of Se emissions. Brake wear dominated Cu (100%) and Pb (96%) emissions, and tire wear act as a significant contributor of Zn emissions (39%). Road abrasion emissions were less but significant for Cr (12%) and Ni (11%). The use of analytical methods, including refining the existing Danish inventory factors, enabled accurate estimates of emissions. It highlighted that 'road LRT' contributed 95% of Cu emissions in Denmark and more than 50% of Zn and Pb, and the importance of measures to reduce these, including the use of more advanced vehicle technologies and additional regulations on non-exhaust sources of emissions.

Yassoglou et al., (1987) from Athens (Greece), were highly contaminated by Pb, Cd, Zn and Ni caused by the heavy traffic and urban them. Soil samples were taken from

170 plots between roads and at different distances and depth (0-30 cm) from roads. The amount of lead decreased exponentially as a function of distance from the road with 60 and 3520 $\mu\text{g/g}$ occurring in the topsoil (0-5 cm) and the best applicability was obtained, when the range of background values is approximately 50 m away from the road. Cd levels ranged from 1.0 to 8.0 $\mu\text{g/g}$ with enrichment in high traffic (35,000 vehicles/day) areas from air. The Zn concentration was significantly positively correlated with Cd, and decreased exponentially by six orders of magnitude with the increasing distance away from the road edge, and the Ni concentration was primarily determined by parent material and the pollution was below the criteria. Crush sequence extraction indicated that lead was bound to carbonates and crystalline oxides, which contributed 30–73% of total lead. The research identified motor vehicle activity as the source of contamination, mainly from leaded gasoline and abrasion of car parts, and stressed the health risks associated with exposure to lead enriched dust in unprotected roadside locales. The results from this study suggest that more stringent control on traffic emission and soil management should be pursued to control the pollution of heavy metals in urban environment.

As reported by Yassoglou et al. (1987), Roadside soils were investigated for heavy metal and metal concentrations in Pb, Cd, Zn and Ni in Athens, Greece/Acad Chim (Hell). In all, 280 road-deposited dust samples were collected from 170 sampling points, including total distance (up to 50 m) and profiles (0–30 cm) on both sides of the road. The results showed relatively high concentrations of lead in the 0–5 cm surface layer, varying from 60–3520 $\mu\text{g/g}$, with the contamination level decreasing exponentially with increasing distance to the pavement edge, and levelling off at approximately background concentrations (~ 110 $\mu\text{g/g}$) at 50 m, whereas concentrations of Cd (1.0–8.0 $\mu\text{g/g}$) followed the same exponential decrease, and those of Zn showed a high correlation with Cd, indicating the same sources, e.g., traffic emissions or tire wear. Sequential extraction results showed that Pb was predominantly present in carbonates and non-crystalline oxides (30–73%), and Cd and Zn were associated with vehicular and industrial activities. Nickel contamination was low and related to the geogenic parent material. The study published in on-

vehicle emission, specifically leaded gasoline and tire wear was more focused on pollution control activities and land use to mitigate health and environmental risks.

Voegborlo and Chirgawi, (2007) reported two-lane highway Tripoli–Misurata Road in Libya carries approximately 30,700 vehicles day for which heavy metals were measured in soil and vegetation. The distances to the road and soil depth showed a decay in the metal's concentration, suggesting vehicular emission as the source of the pollution. Pb concentrations in surface soils varied from 296 mg/kg at 1 m to 14 mg/kg at 50 m, Cd from 3.4 mg/kg at 1 m to 0.96 mg/kg at 50 m, and Zn from 47 mg/kg at 1 m to 17 mg/kg at 50 m. Unwashed vegetation (*Olea europaea* and *Citrus limon*) showed considerable accumulation of metals. The content of Pb in washed leaves ranged from 148 mg/kg at 1 m to 24 mg/kg at 50 m, and Cd levels from 0.7 mg/kg at 1 m to 0.5 mg/kg at 50 m. 40 % of metals applied on leaves was removed by washing, suggesting a large particulate matter component. Their study was able to prove the presence of lead-derived contamination (Pb and Zn) from gasoline for cars and tire wear as well as other metals like Ni and Cr related to car parts and lubricant.

A study on improvements of highly disturbed clay soils for highway embankments, northern Greece experimental studies shows that the stabilization of clayey soils that are problematic along the Xanthi Komotini road in northern part of Greece was studied to improve their engineering properties, for highway construction. Antonia and George (2016) Fly ash (5-25%) and lime (3-12%) were added (as admixtures) to the soil samples obtained near Nea Kessani. According to the Atterberg limits the clay exhibited a high plasticity, a LL of 62, a PI of 39, and a linear shrinkage of 12.5%, which rendered the soil as unsuitable as roadway subgrade. The research facility investigations reveal that, fly ash and lime enhanced the soil's compaction properties, lowering its maximum dry density from 1602 kg/m³ of untreated soil to 1433 kg/m³ of soil treated with 25% fly ash and 1413 kg/m³ with 12% lime, and increases OMC from 21.4% for untreated soil to 26.6% and 27.6%, respectively. Unconfined compressive firmness values reveal a remarkable increase; the improvement was more pronounced using fly ash in comparison with lime to reach 800 kPa at 90 days curing age. The strength improvement was attributed to the pozzolanic reactions, cation exchange, and flocculation of the clay particles, thus

indicating fly ash as an inexpensive and environment-friendly admixture that can be used to stabilize expansive soil for road construction.

Based on the research of Wen et al., (2022) integrated analysis of different type of heavy metal pollution in the area of five main grain-producing areas in China (such as Sanjiang Plain, Songnen Plain, Huang-Huai-Hai Plain, Sichuan Basin, Jiang-Huai Region) was carried out in relation to the data pooled from 276 articles between 2010 and 2021. Cd was found to be the most serious pollutant and its contents were found to exceed the standard in 79% of samples in some sampling stations. The content of other heavy metals has increased significantly, with the highest content observed in the Huang-Huai-Hai plain except for Cd, which showed a low contamination level. The results of the spatio-temporal analysis indicated that the level of metals concentrations such as Cd, Cu, Pb and Zn in the soil kept increasing during their observation period, and their average contents exceeded background values by the ratios of 1.73 per Cd, 1.17 per Hg, 0.43 per Zn, and 0.23 per Cu.

The work of Viard et al., (2004) extensively assessed heavy metal pollution along the A31 highway in the north of France. The study was centred on Pb, Zn and Cd and its distribution among the atmospheric deposition, roadside soil genets and active levels of snail. The highest contamination was found between 5 and 20 m, at 1–320 m from the highway, Atmospheric deposits: Zn 500 $\mu\text{g}/\text{m}^2$ per day), Pb (104 $\mu\text{g}/\text{m}^2$ per day), Cd (0.86 $\mu\text{g}/\text{m}^2$ per day), at 1 m near the highway. Lead, for example, was 110 mg/kg at the 1 m soil distance from the highway, zinc was 300 mg/kg, and Cd was 1.15 mg/kg, which exceeded Pb for background and sometimes regulatory fly limits. Plant concentrations were 2.1 mg/kg (Pb), 72 mg/kg (Zn), and 0.06 mg/kg (Cd) dry weight, and snails were significantly higher, up to 21.3 and 510.8 mg/kg and 5.7 mg/kg dry weight for Pb, Zn and Cd, respectively, 5m apart. Vehicular emissions including leaded gasoline and tire wear were found to be the source of most of the contamination, according to the study.

Maeaba et al., (2020) have quantified heavy metal in Suva City, Fiji which was studied at the 18, sampling sites which includes Albert Park, Suva Market, and Suva Bus Terminal. Results also indicated high Zn contents which average 685 mg/kg and

507 mg/kg in road dust and roadside soils, respectively, thus above the worldwide standard acceptable limit of 300 mg/kg. Pb concentrations were 71 mg/kg in dust and 59.3 mg/kg in soil, while Cd was 3.7 mg/kg in dust and 3.1 mg/kg in soil, near the standard level of 3.0 mg/kg. The adsorbents were found to be significant at 172.3 mg/kg for Cu in road dust. Emissions from vehicles, brake and tire wear, and industrial activities are the major sources of contamination.

Maeaba et al., (2020) detected Zn levels in Nausori were more with average values of 318.7 mg/kg in road dust and 250.2 mg/kg in roadside soils, which were close to the 300 mg/kg hazardous level. Pb levels of 39.9 mg/kg were observed in road dust and 68.7 mg/kg in soils and for Cd was 2.8 mg/kg in dust and 2.2 mg/kg in soils were observed and were within the permissible limits. The mean concentration value of Cu in roadside dust was 127.3 mg/kg, which suggested a moderate grade of pollution. The primary drivers were vehicle emissions, industrial discharges and tire abrasion. FASs correlated with those obtained by Carrero et al. Kreibich and Jordan (2002) also supported our trend using other published data; Arikian et al., (2013) found urban Pb levels of 80–250 mg/kg, and Charlesworth et al., (2003) reported Zn concentrations up to 500 mg/kg in European road dust.

Heavy metals content of dusts collected along a major road in Kavala, Greece was collected by Christoforidis and Stamatis (2009) and Pb was found to occur at 571.3 mg/kg and 386.9 mg/kg in soils and dust which is considerably above the European safe limit of 100 mg/kg. Soil and road dust were contaminated with Zn (up to 175 mg/kg and 354.8 mg/kg, respectively) and Cd (0.2 mg/kg for each). The mean Cr was relatively high, 232.4 mg/kg for road dust and 240.3 mg/kg for soil. Automobile emissions, especially those from leaded gasoline, were the primary culprits. Metal quantification was performed by GFAAS. Comparative data from Lee et al. (2006) also found comparable Zn concentrations of 300–400 mg/kg for Korean roadside dust, and Carrero et al., (2013); the maximum value was 400 mg/kg in urban atmospheres.

Faiz et al., (2009) determined the Pb contents at 104 mg/kg in dust and 32 mg/kg in soil, and Zn contents at 116 mg/kg in dust and 91.05 mg/kg in soil for roadside dust

and soil from Islamabad in 50 samples. The levels of Cd were above safe limits, 5 mg/kg in dust and 5.95 mg/kg of the soils. Automobiles and industry the main contributors. FAAS confirmed these findings. A similar report by Ogunsola et al., (1994) had reported Pb levels of over 500 mg/kg in Nigerian cities, and Duong and Lee (2011) had found Zn levels ranging from 150 to 250 mg/kg in the road dust of Vietnam.

In Seoul, Zn concentrations ranging from 445.6 mg/kg in soils to 2665 mg/kg in road dust in excess of the safety limit of 300 mg/kg were identified by Lee et al., (2006). Pb was 214.3 and 182.1 mg/kg in dusts and soils, respectively; 4.3 mg/kg for Cd in both media. Dense traffic, brake dust and tyre abrasion were found to be the main sources. Charlesworth et al., (2003) also found the maximum levels of urban Zn of 2000 mg/kg. while Malkoc et al., (2010) showed Pb concentrations of 150–300 mg/kg in Turkish cities.

Li et al., (2013) however recorded higher heavy metal render of the urban road dusts and soils of Shanghai with Zn having concentration of 301.4 mg/kg and 294.47 mg/kg in respectively the dust and soil. For the Pb, the content was 70.69 mg/kg in soil a catchment and 55.53 mg/kg in a dust catchment, and the Cd (0.52 g/kg in soil catchment and 1.17 g/kg in dust catchment) was also detected. Industrial emissions and atmospheric deposition were major significant sources. ICP-MS analyses confirmed the results. Yadav et al., (2019) reported the same trend, describing higher concentrations of Zn (> 500 mg/kg) in industrial areas and that in the study by Zheng et al., (2020) reported 100–200 mg/kg of Pb in Chinese urban soils.

According to the study of Rossini Oliva and Fernández Espinosa (2007) in Seville (Spain) had compared heavy metal pollution in urban (Torneo and Porvenir) and rural (Castilblanco) locations. Pb, Ba, Cu, and Ni were found to be concentrated in the soil samples, and urban areas showed more contamination due to emission of vehicular source, fertilizers, and atmospheric fallout. The average concentration of Pb raised to the level of 174 mg/kg and 103 mg/kg in urban and rural soils reaching above the safety limits for residential purposes. Cu contents were as high as 80 mg/kg in urban soils (about three times that of the rural site 25.7 mg/kg), and were

associated with fertilizers and the linings of vehicle brakes. Cu concentrations in PM₁₀ were high (561 µg/kg), and were linked with those of soil and plant leaves.

According to the study by Kaur et al., (2018) near vicinity of Buddha Nullah, Ludhiana (Punjab) India, the accumulation of heavy metals in the roadside soils were investigated at different sampling stations and significant quantity of metal namely Cd, Cr, Co, Cu, Pb, Ni, Zn have been reported. The Cd was found in the range of 0.03–0.46 mg/kg and was higher than the maximum permissible limit of 0.06 mg/kg at certain sites and the amount of Cr was 104.62 mg/kg which was also higher than the safe limit of 100 mg/kg at Geeta Nagar. The concentration of Co was up to 11.43 mg/kg (exceeding 8 mg/kg), Cu was from 10.05 to 198.29 mg/kg, Pb was 69.17 mg/kg, Ni was 182.88 mg/kg, Zn was as 303.58 mg/kg. The industrial effluent, auto smoke and waste from electro-plating, cycle manufacturing and dyeing units are the main causes of pollution. Approach Pollution indices like the Index of Geoaccumulation (Igeo) indicated contamination for Cu in the ranges -1.90 to 2.40 for and a Pollution Index (PI) of 1.64 to 6.69 indicating moderate to heavy level of pollution.

A study by Khairy et al., (2011) was also carried out in Delta Region, Egypt, where the heavy metal contamination of road dust in seven sites of Nile Delta was analysed, which portrays significant contamination of Cd, Pb, Zn and Sn. The contents of these two metals ranged from 1.72 to 6.62 mg/kg (mean of 2.98 mg/kg) for Cd and were higher than the crustal reference value of 0.351 mg/kg, and from 174 to 710 mg/kg (average 307 mg/kg) for Pb and exceeded the reference value of 9.80 mg/kg. Zn reached to a high value (8153 mg/kg at the maximum and the average was 1839 mg/kg) with a background of 77.6 mg/kg, and Sn ranged from 9.38 to 18.0 mg/kg, this was significantly greater than the crustal value of 1.10 mg/kg. Traffic emissions, industrial activities, and construction work were the main sources and multivariate analysis identified vehicular emission (Pb and Ni), industrial process (Cd and Sn), and construction work (Zn).

Based on the study of El-Hasan et al., (2006) in Karak City (Jordan), three locations in the province of Karak were used to measure the percentage of cationic and anionic

metals in roadway dust: inner city (high traffic, 10,000–12,000 cars/day), suburban (moderate traffic, 6000–8000 cars/day), and control (low traffic, 100–200 cars/day). The metals Cu, Cd, Co, Fe, Mn, Ni, Pb and Zn were recorded. Pb contents varied between 31-175 mg/kg (mean, 75.33 mg/kg) in the downtown, 16-57 mg/kg (mean, 25.09 mg/kg) in the suburbs, and 14-18 mg/kg (mean, 16 mg/kg) in the control sites. Zn Concentrations reached maximum of 165 mg/kg in downtown areas, followed by means of 131, 55, and 43 mg/kg in downtown, suburb, and control areas, respectively. Cd quantities were markedly higher at all sampling sites but still limited to a mean of 2.83 mg/kg downtown, 2.36 mg/kg in the suburbs and 1.83 mg/kg at the control site. The main sources of contamination included vehicle emissions such as exhaust, brake wear, tire wear.

According to the study conducted by Malkoc et al., (2010) in Eskisehir, Turkey, the heavy metal contamination was studied in 15 sites on the roadsides of Eskisehir on the route of tramway and traffic. Concentrations of Cd ranged from 0.60 to 3.39 mg/kg (mean 1.28 mg/kg), Cr 7.54 to 226.04 mg/kg (mean 97.65 mg/kg), Cu from 9.22 to 120.93 mg/kg (mean 39.33 mg/kg), Pb from 7.92 to 101.12 mg/kg, mean 19,149.72 mg/kg), due to the composition of soil. Based on geoaccumulation index (Igeo) and enrichment factor (EF), Pb, Zn, and Cu were recognized as the most contaminated elements, while Pb and Zn Igeo were above 5 which proved extreme pollution. The pollution mainly resulted from traffic, brakes and tyre wear, industrial activities, and tramway traffic.

The Study by Mikalajūnė and Jakučionytė (2011) carried out bitumen- and cement-stabilized sand/ gravel roads was investigated and the level of heavy metal pollution was studied in soils at the edges of four gravel roads with low traffic intensity. The concentration of Ni, Pb, Cu, Zn, Mn and Cr has been studied. The maximum value of Ni was 26.5 mg/kg, higher than the background 2.2 times as well as that of Pb: 39.7 mg/kg, higher than the background 2.6 times. Cu content was higher than background values between 19.9 mg/kg and Zn achieved 40.1 mg/kg. Mn was slightly above background concentration, with highest value 248.5 mg/kg, and Cr were low, highest value 27.1 mg/kg. Traffic volume, on-road trenching, and terrain

were found to be the primary contributors to metal migration. Analytical Procedures Analgesic Consumption AAS was used.

As per the study from Wei et al., (2009), 169 road dust samples obtained from Urumqi, a metropolis of rapid urbanization in northwestern China, were used to study heavy metal contamination in road dust. Ten metals Cd, Cu, Ni, Pb, Mn, Be, Co, Zn, and U were studied and the average concentrations of Cd (1.17 mg/kg), Cr (54.28 mg/kg), Cu (94.54 mg/kg), Ni (43.28 mg/kg), Pb (53.53 mg/kg), Mn (926.6 mg/kg), Be (2.75 mg/kg), Co (10.97 mg/kg), Zn (294.47 mg/kg) and U (2.13 mg/kg) were scored to the high level of pollution which leads to the above the average background levels for these metals, in some of the samples, however, the concentration of Cd exceeded ten times their background levels. Traffic emissions (Pb, Zn, Cu), industrial activities (Ni, Be) and lithological natural sources (Mn, U, Co) contributed to contamination in both depth profiles.

Bi et al., (2020) found that heavy metal concentrations were determined in urban soils in Haikou, the capital of the Hainan Province nearly without any industrial development, China-industry undeveloped city in Southern China where different metals were analysed. The contents of the elements were in the following ranges: Cd 0.01–1.34 mg/kg (mean 0.25 mg/kg), Cr 8.1–376 mg/kg (mean 89.5 mg/kg), Cu 0.61–98.7 mg/kg (mean 19.1 mg/kg), Ni 1.46–190 mg/kg (mean 50.0 mg/kg), Pb 1.47–69.4 mg/kg (mean 29.2 mg/kg), and Zn 13.8–208 mg/kg (mean 84.7 mg/kg). They were, in general, lower compared with other major Chinese cities because of the lower industrial development in Haikou. Based on principal component analysis (PCA) and lead isotopic compositions, it was true that the primary point where of heavy metals were found are in natural parent materials, coal combustion, and traffic emissions, with the proportions of 5.3 –82.4 % (mean 39.7 %), 0–85.7 % (mean 25.5 %), and 1.9 – 64% (mean 34.8 %), respectively. Pb was primarily being the most metals being accumulated as the effect of higher and heavier traffic while Cd and Ni levels were markedly rise in the suburbs, due to their basaltic parent material.

As reported in the study of Zhang et al., (2012) The investigation was carried out to evaluate heavy metal contamination in farmland soil in mountainous areas along the

Trishuli Highway, Nepal. The levels of Cu, Zn, Cd and Pb were discussed and compared with state allowable limits, with most values below the tolerable limits, but with isolated maximum levels of Zn, Cd and Pb surpassing the maximum tolerable limits, suggesting the presence of pollution one points. The high-level Zn value was 250 mg/kg, and the Cd and Pb values peaked at 0.8 mg/kg and 70 mg/kg, more than the soil background. Tree preservation had a significant role in decreasing the concentrations of Cu and Pb. The distribution was affected by roadside distance, geography and the elevation.

According to Skorbilowicz et al., (2021) on the road no Białystok-Budzisko in northeastern Poland, “the concentrations of heavy metals: Cd, Zn, Pb and Cr were examined, along the 160 km section of the trunk road.” Mean Cd was 1.2 mg/kg, Zn 140 mg/kg and Pb 90 mg/kg with all averaging local GCB values. Igeo indices showed low to moderate contamination of Zn and Pb and strong contamination of Cd. Tire- and brake-wear during road transportation constituted the major part of contamination.

There are heavy metal contaminations on a global scale, that mostly came from industrialization process, vehicle emission and dish out unclear waste. According to Cook's (1977) observations. Metal toxicants like Cd, Pb, Hg have been enlisted as priority pollutants because of their toxic nature and environmental persistence. Concentrations of Cd in estuarine sediments were up to 500 times background, Pb levels in industrial waste were 100 times the background.

As reported by Sithole et al., (1993) Harare (Zimbabwe) Roadside soil and vegetation was assessed along three of the main routes in Harare; Simon Mazorodze, Hatfield and Mutare Roads in Harare for the negative influence of Pb on the environment. Soil Pb concentrations, which averaged 446.6 µg/g, were greatest with Simon Mazorodze Road with maximum at 1480 µg/g near the road edge and declining rapidly away from the road to a roughly constant level of Pb from greater than 20 meters onwards at 160 µg/g. Pb levels were also high at the Hatfield Road site (608 µg/g at the edge to 25 m where it was 160 µg/g) and its Mutare Road followed (the latter with maximum values of 404 µg/g at 50 m to 22 µg/g

penultimate to the road edge). Vehicle age, leaded fuel and traffic volume were found to be major contributors.

The influence of traffic volume has also been the focus of research on the contamination of street dust by Pb in a city in Az Zarqa City, Jordan, by Kamal Ayoub Momani (2006). Pb levels were dominated in the carbonate fraction (50%) then Fe-Mn oxides (25%), followed by the (WHO standard $0.005 \mu\text{g}/\text{m}^3$) was also above the WHO guideline value., Cr also exceeded the acceptable limit, reaching its max at $0.9827 \mu\text{g}/\text{m}^3$ compared to the Texas Commission on Environmental Quality (TCEQ) accepted level set at $0.01 \mu\text{g}/\text{m}^3$. Ni followed for moderate pollution values translated by values within $0.0847 \mu\text{g}/\text{m}^3$. "The high-level heavy metals were closely related to industrial emission, traffic-associated source and approaching to the factories using the heavy metals in timber and semi-conductor production".

Liu et al. (2019) reported heavy metals deposition in Changji, Xinjiang, in China. It was $3.70 \text{ mg}/\text{m}^2$ (Ni), $4.81 \text{ mg}/\text{m}^2$ (Cu), $0.53 \text{ mg}/\text{m}^2$ (Cd) and $22.74 \text{ mg}/\text{m}^2$ (Pb) for dry and much lower for the wet deposition ($0.77 \text{ mg}/\text{m}^2$ (Ni), $3.25 \text{ mg}/\text{m}^2$ (Cu), $0.04 \text{ mg}/\text{m}^2$ (Cd) and $0.11 \text{ mg}/\text{m}^2$ (Pb)). The proportion of the total deposition by dry deposition were 82.79% (Ni), 59.67% (Cu), 92.33% (Cd) and 99.52% (Pb) and dry deposition appears to be the major contributor of atmospheric deposition in arid environment with relatively very small wet deposition due to low precipitation. During the heating period, fluxes were increased as a result of combustion of coal, with the maximum deposition fluxes of Pb and Cd to be $12.48 \text{ mg}/\text{m}^2$ and $0.28 \text{ mg}/\text{m}^2$, respectively. Based on the research, the main sources of the heavy metals included the emissions of vehicles, combusting of coal and industrial operations.

Such a relationship was reported in the research by Salam et al., (2011) measured air pollution in Dhaka, Noakhali, Chittagong, Faridpur and Kushtia. Maximum TSPM concentration in Chittagong ($671.65 \mu\text{g}/\text{m}^3$) and minimum in Faridpur ($184.09 \mu\text{g}/\text{m}^3$) was found which was notably higher (WHO limit = $150 \mu\text{g}/\text{m}^3$). For heavy metals the highest value reached $11.42 \text{ ng}/\text{m}^3$ in Chittagong so far higher than the WHO guideline limit ($5 \text{ ng}/\text{m}^3$). Pb in Dhaka was $485 \text{ ng}/\text{m}^3$, which is close to the WHO air quality standard $500 \text{ ng}/\text{m}^3$ and, respectively, Cd, Cu and Zn concentration

were high in Chittagong at 801.26 ng/m³ and 1,721.60 ng/m³. Vehicular pollutions, industrial waste, and construction activities were found to be the major sources, according to the research. Analytical methods were AAS for metals determination, where industrial and vehicular emissions should be controlled promptly.

Jin et al., (2019) studied Mn, Cu, Cd, Pd, and Ni at 4 seasons. The concentrations of PM₁₀ in winter (263.7 µg/m³) and summer (89.3 µg/m³) were observed to be given the highest and lowest values where both are higher than 70 µg/m³ respectively. Pb levels were 56 µg/m³, Cd 6 µg/m³, and Mn 48 µg/m³, where enrichment factors (EF) for Pb, Cd were recorded over 100, showing high anthropogenic source. Large emissions from steel and coal combustion were the main sources.

According to Farahmandkia et al., (2010) assessed wet precipitation and PM₁₀ heavy metal deposition in Zanzan, Iran. Pb concentrations in wet were from 5.8 to 22.2 µg/L, Zn from 29.26 to 70 µg/L, Cd from 0.25 to 1.2 µg/L and Cr from 1.4 to 4 µg/L, with the highest values during industrial peak hour. Pb (approximately 840 ng/m³), Zn (about 16233 ng/m³), Cd (around 54.8 ng/m³), and Cr, (about 32 ng/m³) exceeded the WHO guidelines for air quality. Emission sources were the lead and zinc mining, the smelting process, and coal burning.

According to Kumari et al., (2021), Dhanbad (India, coal mining area) air quality was evaluated as well. Average PM₁₀ were 229.54 µg/m³ and PM_{2.5} were 129.73 µg/m³, which have elevated standard than the national ambient air quality standard of 100 µg/m³ and 60 µg/m³, respectively. Pb concentration was 84.3 mg/kg and Cd concentration was 12.6 mg/kg in road dust, which indicate that Pb and Cd are above limits, 50 mg/kg for Pb and 3 mg/kg for Cd. Zn and Ni contamination in road dust were 293 mg/kg and 62 mg/kg. Traffic exhaust was the major local source, and the situation was worsened by coal traffic.

According to Fikri et al., (2024) heavy metals was studied at six indoor and outdoor locations at an energy nuclear agency. Fe concentrations up to 31.65 %, Cu 27.3 %, and Ni 14.2 % have been recorded in the dust with values that are clearly over the background levels. Greatest levels in dust collected from the Environmental Safety

Laboratory can be attributed to industrial discharges and radiological material handling.

According to Di Vaio et al., (2018), in Acerra (Italy), PM₁₀ daily average levels for all seasons was 43.7 µg/m³ and detected values above the daily threshold value of 50 µg/m³ were observed in summer (54.3 µg/m³) and spring (51.2 µg/m³). Trace metals represented 8% of the PM₁₀ mass, as shown by Cd (0.15 µg/m³), Pb (0.28 µg/m³), and Zn (1.82 µg/m³) all with high enrichment factors (EF > 10). Based on the health risk assessment, the non-carcinogenic risk was higher for children (THQ = 0.65) than for adults (0.45). Oil burning and emissions from vehicle combustion were identified as the major sources by use of ICP-MS and PCA. These results underscore the importance using emission control measures, especially during the months with highest PM₁₀ levels when season is warmer.

Mutua et al., (2021), in Nairobi City, Kenya, in industrial areas, PM₁₀ was found to have an average concentration of 83 ± 18 µg/m³, which was higher than the WHO standard value of 50 µg/m³. Industrial districts showed concentrations of 1.10 ± 0.59 µg/m³ for Lead (Pb) and an average of 0.04 ± 0.02 µg/m³ for Cd, both related to vehicular emissions and sources from industry. During the afternoon, PM₁₀ was 15% higher than under typical traffic conditions.

PM₁₀ levels remained higher than the normal range (119 ± 48 g/m³) (Sabourmoghaddam, (2017), as in Tabriz City, average lead concentration of PM₁₀ was reaching 662 ng/m³, of cadmium 92 ng/m³ and of Hg 8 ng/m³. Different Pb levels were higher than the WHO air quality guidelines (500 ng/m³) in high traffic areas and Cd levels were more than the WHO/guidelines of 50 ng/m³. Monthly changes showed the highest levels in winter, followed by heating emissions and poor dispersion.

Sadheesh et al., (2022), in Coimbatore, average PM₁₀ levels in industrial areas were 108 µg/m³, which also exceeded the Indian national ambient air quality standard of 100 µg/m³. Heavy metals, Zn had a higher concentration (2.56 mg/kg), followed by Pb (0.85 mg/kg) and Cd with 0.11 mg/kg. Vehicle exhaust gas, construction dust and industrial pollution were the primary sources.

According to Leili et al., (2008), mean PM₁₀ levels in Tehran were $90 \pm 38 \mu\text{g}/\text{m}^3$, and entrained total suspended particulates (TSP) in high traffic conditions rose to $187 \mu\text{g}/\text{m}^3$. Pb levels was $150.36 \pm 157.01 \text{ ng}/\text{m}^3$, Cr $9.12 \pm 2.14 \text{ ng}/\text{m}^3$ and Cd $6.87 \pm 2.22 \text{ ng}/\text{m}^3$ where Pb and Cd levels were higher than those regulated by EPA for urban air quality. Pollution was primarily caused by traffic, construction and industrial production.

Actions and measures taken by different governments for the management of Heavy metals in roadside soil and air.

1. Acerra, Italy

According to Di Vaio et al., (2018), in Acerra, remediation interventions target both industrial and vehicular emissions, and according to the authors, these sources are indeed the main contributions to the load of heavy metals accumulated in roadside soils. It is suggested that advanced air-purifying systems in industrial areas, as well as cleaner production technologies, should be used to avoid metal deposition. Public education campaign on reducing leaded material use is promoted. Regular air and soil quality survey and monitoring especially during summer and spring, which are the pollution heavy season, is emphasised as being important for effective contamination control.

2. Nairobi, Kenya

Mutua et al., (2021) point out urban planning interventions such as decongestion, and catalytic converters as vital in alleviating heavy metal emissions in Nairobi. The specific recommendations include Routine soil testing focusing in high-trafficked areas and community-based programs to educate residents about the hazards of farming in contaminated soils. The study also supports transitioning to cleaner fuels to further reduce levels of lead and cadmium in roadside environments.

3. China

Chen et al., (2015) describe the lengthy and comprehensive national soil pollution survey of China, which invested \$125 million into determining the extent and impact of contamination. The study highlights the need for more rigid regulation of the

environment, shift to clean industrial energies and implementation of remediation efforts targeting those most risky metals such as Cd, Pb, Hg. It is also advisable to apply advanced analytical techniques of pollution hotspot monitoring.

4. Coimbatore, India

They emphasize on the reduction of industrial emissions and traffic related pollution load to minimize the accumulation of heavy metal in the soils of Coimbatore. The use of plants such as *T. caerulescens* or rotation of a field among crops, in conjunction with regular soil testing, for phytoremediation is advised. Promotion of bio-barriers and implementation of more stringent emission policies for the industries which located around residential areas were the two main strategies to avoid the further source of contamination, (Bochhicchio et al., 2022).

5. Dhanbad, India

Kumari et al., (2021) propose the management of heavy metal pollution in Dhanbad by enforcing stringent traffic rules and enhancing the practice of coal transportation. Routine monitoring of soil quality, especially in the heavily coal mining area, and the use of bio-barrier via vegetative strips are recommended. Phytoremediation with hyperaccumulators is emphasised as being a low-cost tool for reclamation of Pb, Cd and Zn contaminated soils.

6. Iran

According to the findings of Sabourmoghaddam (2017), more stringent emissions controls for industry and vehicles could help to ameliorate the quality of urban air and soil in Tabriz city of Iran. It is suggested to continuously monitor the levels of heavy metals in soil, particularly in industrial areas. Emphasizing a shift toward cleaner fuels and public awareness of the health risks of heavy metals are also seen as important actions to reduce contamination.

7. Bangladesh

Salam et al., (2011) suggest that construction activities be restricted, and better traffic management undertaken to minimize heavy metal pollution of urban soils in Bangladesh. The promotion of cleaner fuels, consistent monitoring of soil quality,

and public awareness campaigns to curb the application of contaminated soils for cultivation are important measures. These measures are intended to lower Cd and Pb levels in the roadside habitat.

8. Bangladesh

Salam et al., (2011) recommend focused interventions in urban Bangladesh involving restricting construction of high-emission industries near residential localities and enforcing improved emission standards for vehicles. Public education programmes on the risks associated with use of roadside soils contaminated with heavy metals for agriculture, and the promotion of clean fuel substitutes to decrease lead and cadmium levels are recommended.

9. Nigeria

It stress on the urgency of the stricter fuel quality standards and vehicle emission control in Nigeria. Land use management to minimize cropping close to busy roads and a ban of sun drying food items at roadsides are important recommendations. Good management of the roadside vegetation is recommended in order to minimize the accumulation of heavy metals such as Pb and Cd by plants (Yahaya et al., 2009).

10. Tehran, Iran

According to Leili et al., (2008), the reduction of heavy metal pollution in the curb-side soils of Tehran should be carried out by enforcement of more restrictive laws concerning industrial and vehicular emissions, and adoption of cleaner fuels. Regular monitoring of heavy metal deposits in busy places, and public awareness on the dangers related to soil pollution are also recommended.

11. Tabriz, Iran

According to the findings of Sabourmoghaddam (2017) highlights that the need for continuous monitoring programs for urban soils applies to Tabriz, particularly in view of heavy metal pollutants like Pb and Cd. Long-term solutions, such as cleaner industrial processes and electric or hybrid vehicles, would help to lower emissions.

12. Nairobi, Kenya

Mutua et al., (2021), including building more public transport and low-emission zones for traffic reductions there. The intermittent surveillance of soil and air quality, particularly in industrialised regions, as well as measures taken to implement cleaner fuel technologies are highlighted as key recommendations to mitigate against heavy metal pollution in Nairobi.

13. Nigeria

Yahaya et al., (2009) stress the importance of improved regulatory policies in the management of vehicle emission and the quality of fuel in Nigeria. The study suggests public education campaigns promoting against activities such as sun-drying food along roadsides or grazing livestock near contaminated areas. Improvement in stabilization and detoxification by maintaining the roadside vegetation and mitigate soil erosion and heavy metal bioavailability are noticed.

Correlation between Heavy metals and the environmental factor

1. pH level

This pH relationship and metal sludge science is based on metal ion chemistry. Low pH (acidic conditions) has the effect of increasing the solubility of metal cations, increasing their availability to plants and their mobility in the soil/water. This means there is a direct pathway that these metals can take to get into plants, ground water and finally, the food chain.

Mechanism At low pH (<5), hydrogen ions (H^+) compete with metal cations (Cd^{2+} and Pb^{2+}) for adsorption sites at the surface of soil particles and thus displace metals into the soil solution. On the other hand, under neutral or basic pH, hydroxide ions (OH^-) can bind to form insoluble metal hydroxide, which pollen metal mobility.

In the UTHM Campus of Malaysia, Cd concentrations rose from 0.8 mg/kg in near neutral soils (pH,6.0) to 1.5 mg/kg in acidic soils (pH <4.5) (Radin Mohamed et al., 2014). This shows that metal availability is further increased at low pH.

Impact: Acidic soils in industrial or traffic-pollution hotspots are the 'reservoirs' of the mobile heavy metals, increasing the possibility of underground water contamination and crop uptake.

2. Temperature Variations

Heavy metals are released, transported and accumulate in the environment under the influence of seasonal temperature changes.

Winter Inversions: Cold temperatures lead to temperature inversions, where pollutants, such as heavy metals, are confined in the air near the earth's surface.

Tabriz, Iran: Cd levels varied from 124 ng/m³ in winter to 75 ng/m³ in summer, and Pb levels reached 1150 ng/m³ in winter, probably as a result of air emissions from heating and because of poor atmospheric dispersion (Sabourmoghaddam, 2017).

Summer Resuspension: High summer temperature forces the dust to remain suspended, leading to high metal concentration in the air and road-side soil.

Acerra, Italy: Cd concentrations reached maximum values of 0.31 µg/m³ in spring and 0.28 µg/m³ in summer corresponding to the larger amount of industrial and vehicular activities in warm seasons (Di Vaio et al., 2018).

Implications: Seasonal differences are responsible for determining the levels of exposure to heavy metals in urban and industrial areas, both for short term air quality and for permanent soil contamination.

3. Rainfall

Rainfall is a double-edged sword; it washes away air pollution and simultaneously delivers soil pollution. Wet deposition removes HM from the atmosphere and deposits it into terrestrial and aquatic way.

Wet deposition: Rain entraps dust particles Filled with heavy metals and sinks them to the ground, lowering the amount of the pollutants in the air.

Dust-storm-derived lead alloys captured in Central Iran (Zanjan) reached above 840 ng/m³ at the during the dry-season, where Pb content in wet precipitation ranged from 5.8 to 22.2 µg/L (Farahmandkia et al., 2010).

Dry deposition: In xerophytic areas, lack of rain causes heavy metals to accumulate on/within the ground where they are released back into air.

Bangladesh (Dhaka): Pb in PM₁₀ (485 ng/m³ to 320 ng/m³) and Zn (801.26 ng/m³ to 560.14 ng/m³) were reduced in wet months from dry periods (Salam et al., 2011).

Impact: Rain reduces airborne metal concentrations but promotes their deposition to soil and water, which results in a complicated balance of benefits in the improvement of air quality versus contamination of the terrestrial environment.

Traffic: Heavy metals are mainly caused by vehicular emissions, contributing to the air and soil pollution through tire abrasion, brake lining, and exhaust gas.

Direct air emissions: Vehicles emit metals like Pb and Cd directly into the air when fuel is burned.

India (Dhanbad): Maximum content of Pb in the roadside soil was 84.3 mg/kg followed by Cd 12.6 mg/kg, due to vehicular exhaust and poorly controlled fuel burn (Kumari et al., 2021).

Wear of Tires and Brakes: Metals like Zn, Cu, and Sb come from tire wear and brake pads.

Japan (Tokyo): Mean level of Zn in roadside soil was 145 mg/kg and Cu 92 mg/kg; contamination rapidly decreased beyond 50 m from roadways (Ozaki et al., 2004).

Traffic density and bad vehicle maintenance strongly enhance metal content in urban soils, resulting in local pollution with direct health and ecological consequences.

Interactions Between Factors

1. pH and Rainfall: Soil pH is temporarily diluted by rainfall, which in turn increases metal mobility in acid soils. For instance, during times of wet precipitation, particularly in acid areas, metallic leaching into the ground water is much higher.

2. Traffic and Weather: Traffic-generated airborne heavy metals, are further affected by seasonal occurrences of weather. During summer high temperatures resuspend road dust and almost on the opposite we have polluting being trapped close to the soil surface by temperature inversions in winter.

3. Rainfall and Soil Pollution: Though rainfall decreases the aerial concentration, it important role in soil accumulation. This dual role requires region-specific strategies to manage heavy metal contamination.

The correlation of pH, temperature, rainfall and traffic among the participants' resulted in the complicated dynamic characteristics of heavy metals. These metal accumulation and deposition were strengthened by acidic condition, seasonal heating, and vehicle exhaust, but is alleviated and complicated by precipitation at the same time. These results highlight the importance for monitoring of the environment and an individual planning of the mitigation measures of the urban/industrial areas.

Chapter 3

Materials and Methods

3. MATERIALS AND METHODS

3.1 Study Area Description

The present study was conducted in Aizawl District of Mizoram. Fig 1a. talking about its geographical location, it is the capital of Mizoram state that lies in the northeastern India, located just north of the Tropic of Cancer, Aizawl is at an elevation of 974 m of AM. This district is divided into four rural development blocks and 71 villages.

Aizawl is the administrative capital of Mizoram. The city is consists of residential homes, etc. government offices, the state assembly house, and civil secretariat with a total population about 293,416. Aizawl serve as the cultural, administrative and economic capital of the state and presents a unique blend of natural beauty and modern urbanisation Aizawl is a beautiful city where the hill station and urban setting coalesce in perfect harmony.

As of 2021 Census of India, Aizawl district has a total population of 400,309. Aizawl district has a relatively moderate population density with 113km². In addition, the sex ratio of Aizawl is 1009 females per 1000 males which is little higher than national average. There is very high literacy rate in Aizawl, 98.5%.

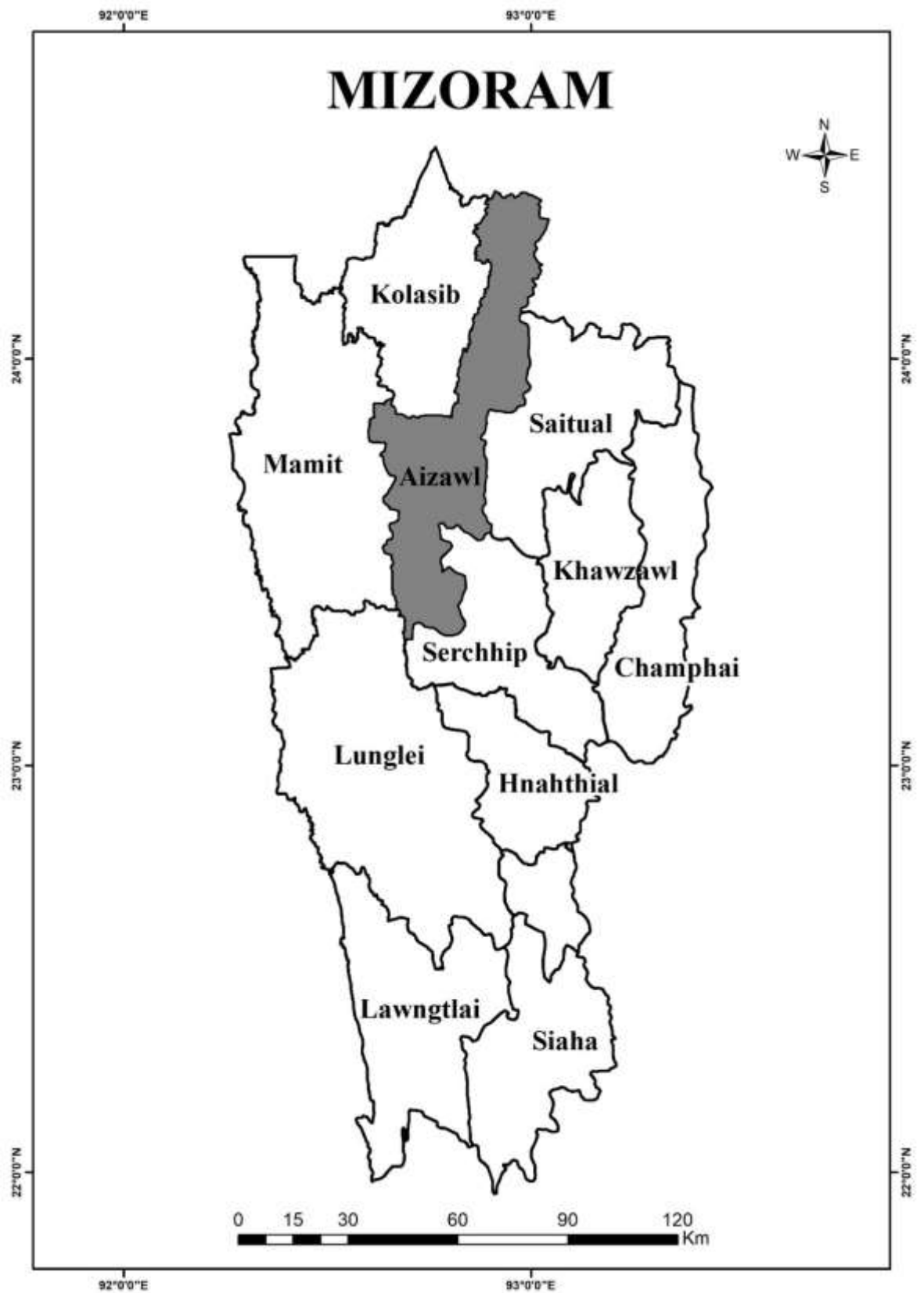


Fig. 3a. Map of Aizawl district.

3.2. Climatic pattern of Aizawl District

Mizoram belongs to a rainfall heavily administered area, with an average rainfall of 2500–3000 mm per year. Land topography is hilly, with rugged terrain between 50m and 2000m asl. Mizoram enjoys a moderate climate, the temperature in Mizoram in the winter's ranges from 11 - 21°C and in the summers 20 - 30 °C. Climate in Aizawl is mild sub- tropical. The average annual precipitation to the city was 209 cm which had received from May to September and temperature ranging from 20 °C to 30°C and 11°C to 21°C in winter (Fig. 1b.).

The study area has a monsoonal climate with warm summer and cool winter (high humidity and low humidity). On the basis of this meteorological observation, it may be said that during the period from May to October are contributing wet months while in the months of December to April become were dry months. Rainfall increases steadily from January to a peak in July and August and then declines gradually until December (Fig.1c). Throughout the study period (2020 – 2022), the minimum temperature ranged from 11.8°C (January) to 20.1°C (August) and the maximum temperature ranged from 21.9°C (January) to 29.6°C (April). The average monthly precipitation varied between 12.6 mm (in February) and 354.5 mm (in July). Minimum humidity ranged from 47.7 g/m³ (March) to 69 g/m³ (June) and average maximum humidity from 59.5 g/m³ (March) to 83 g/m³ (October) (Fig.3.).

3.2.1 Pre-monsoon season

The months (February, March, April and May) before the monsoon. This season account for 21.16 % of the annual rainfall. Precipitation ranged between 12.6 mm (February) and 1891.4 mm below the annual average. The average maximum temperature ranged from 23.7°C in February to 29.6°C in April, while the average minimum temperature varied from 12°C in February to 20°C in May. Mean maximum humidity was ranging between 59.5 g/m³ (March) and 74.5g/m³ (May) and the mean minimum between 47.7 g/m³ (March) and 62.1 g/m³ (May).

3.2.2 Monsoon season

The wettest time of the year is during the monsoon season, commonly referred to as the rainy season in Pakistan, which lasts from June until September with rainfall ranging from 354.5 mm (July) to 262.7 mm (August). 60.69 % of annual rainfall was recorded in this season. The mean maximum temperature showed little variation of 19.8 (September) to 20.1°C (July and August) whereas the mean minimum temperature also showed little variance 21.1°C (June) to 28.6°C (September). The average maximum humidity ranged from 79.7 g/m³ (September) to 81.8 g/m³ (July) and the average minimum humidity ranged from 62.8 g/m³ (September) to 69.0 g/m³ (June).

3.2.3 Post-monsoon season

The post- monsoon begins from October to January this season has cool temperatures and very little rain. It accounts to 18.14% of annual rainfall. Monthly rainfall ranged from 25 mm (January) to 250.4 mm (October). The mean maximum temperature ranged from 21.9°C (January) to 27.5°C (October) and the average minimum temperature ranged from 11.8°C (January) to 20.2°C (October). The mean maximum humidity ranged from 69.7 g/m³ (December) to 83 g/m³ (October) and the mean minimum humidity varied between 57.7 g/m³ (December) to 67 g/m³ (October).

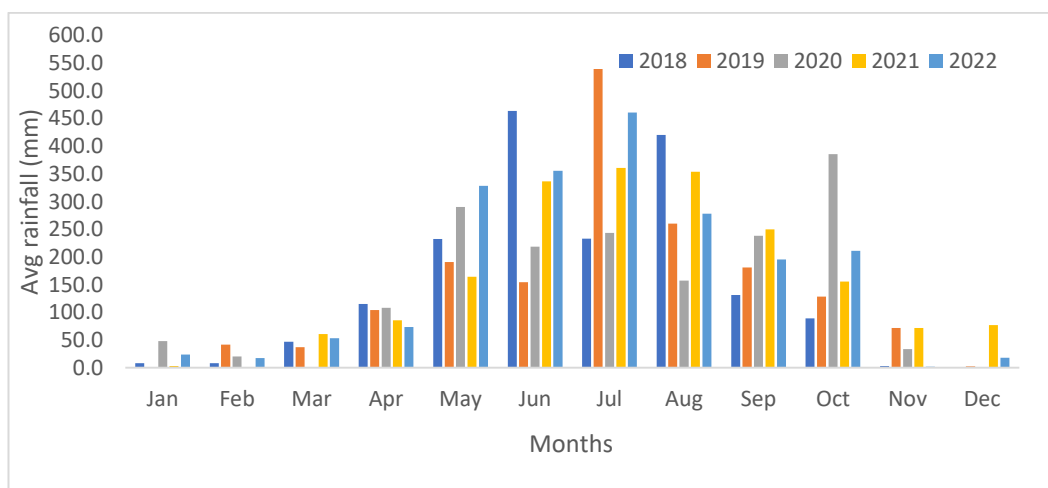


Fig. 3b. Monthly total rainfall of Aizawl in the last 5 years (Directorate of Science and Technology)

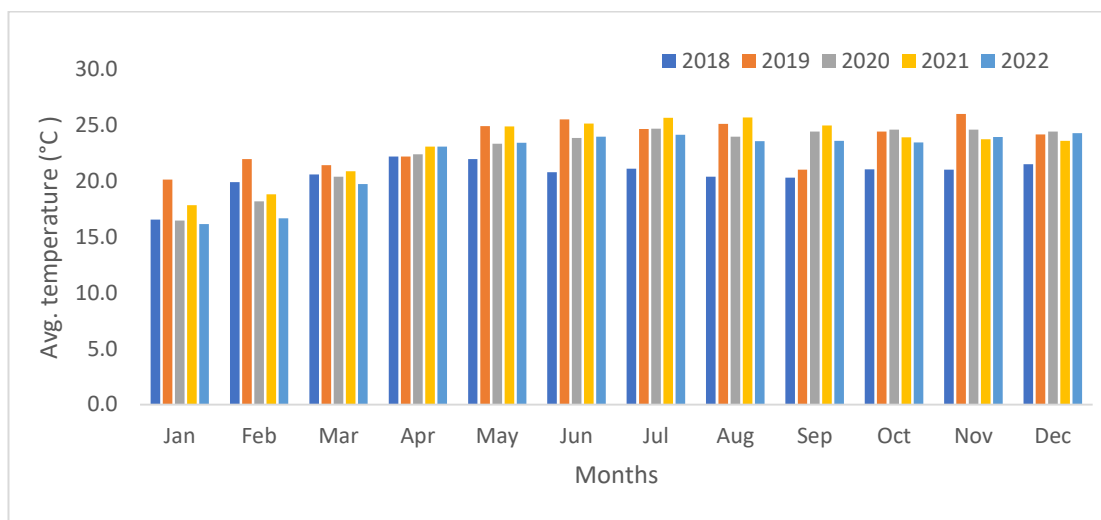


Fig. 3c. Monthly averaged of temperature of Aizawl for the last 5 years (Directorate of Science and Technology)

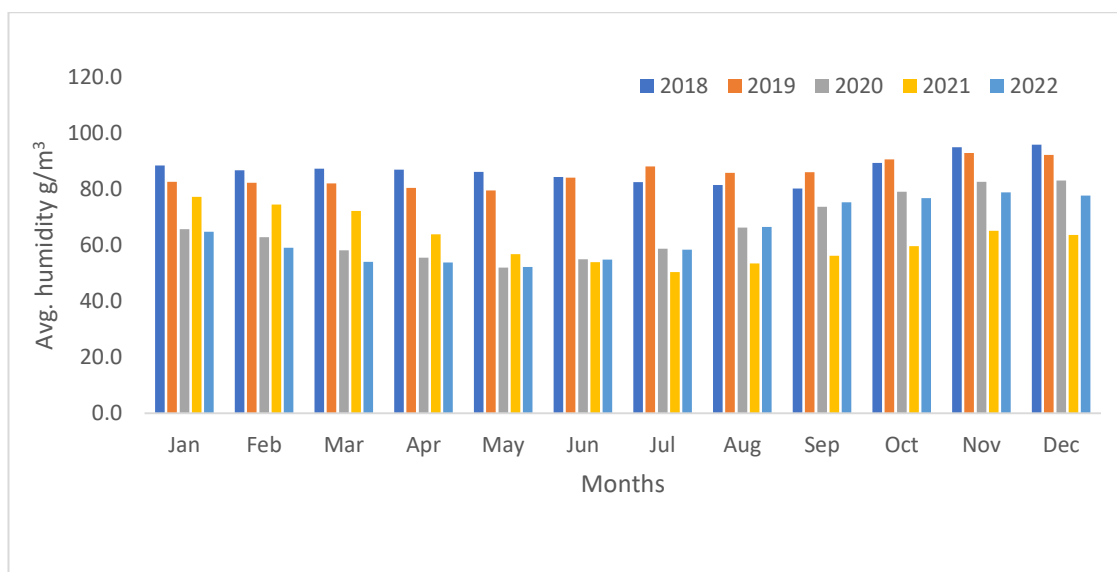


Fig.3d. Mean monthly humidity of Aizawl during the last 5 years (Directorate of Science and Technology).

3.3 Aizawl District: Demographic and Socioeconomic

As of 2011 India census, Aizawl had a population of 400,309 of which male and female were 199,270 and 201,039 respectively. Children (0-6) years were 36012 as per figures from the Census India report published in 2011, among them 18159 were boys and 17853 were girls. Aizawl District's population was 36.48 % of total

Mizoram population. Average total number of Household was 82524 in Mizoram. On an average, a household in Mizoram contained 4.5 persons. 20 % of homes are headed by women, and 18 % of population live in homes headed by women. Aizawl district also stands first in literacy 98.50 % compared to 91.3 % of the states. The district has a population density of 112 persons per km² which is higher than the average of 52 per km².

3.4 Study sites

The study was conducted in 12 locations within Aizawl city and 12 outside Aizawl city. For roadside soil samples are taken whereas PM in the air samples are collected from 4 locations within Aizawl city.

3.4.1 Sites from Aizawl city for roadside soil

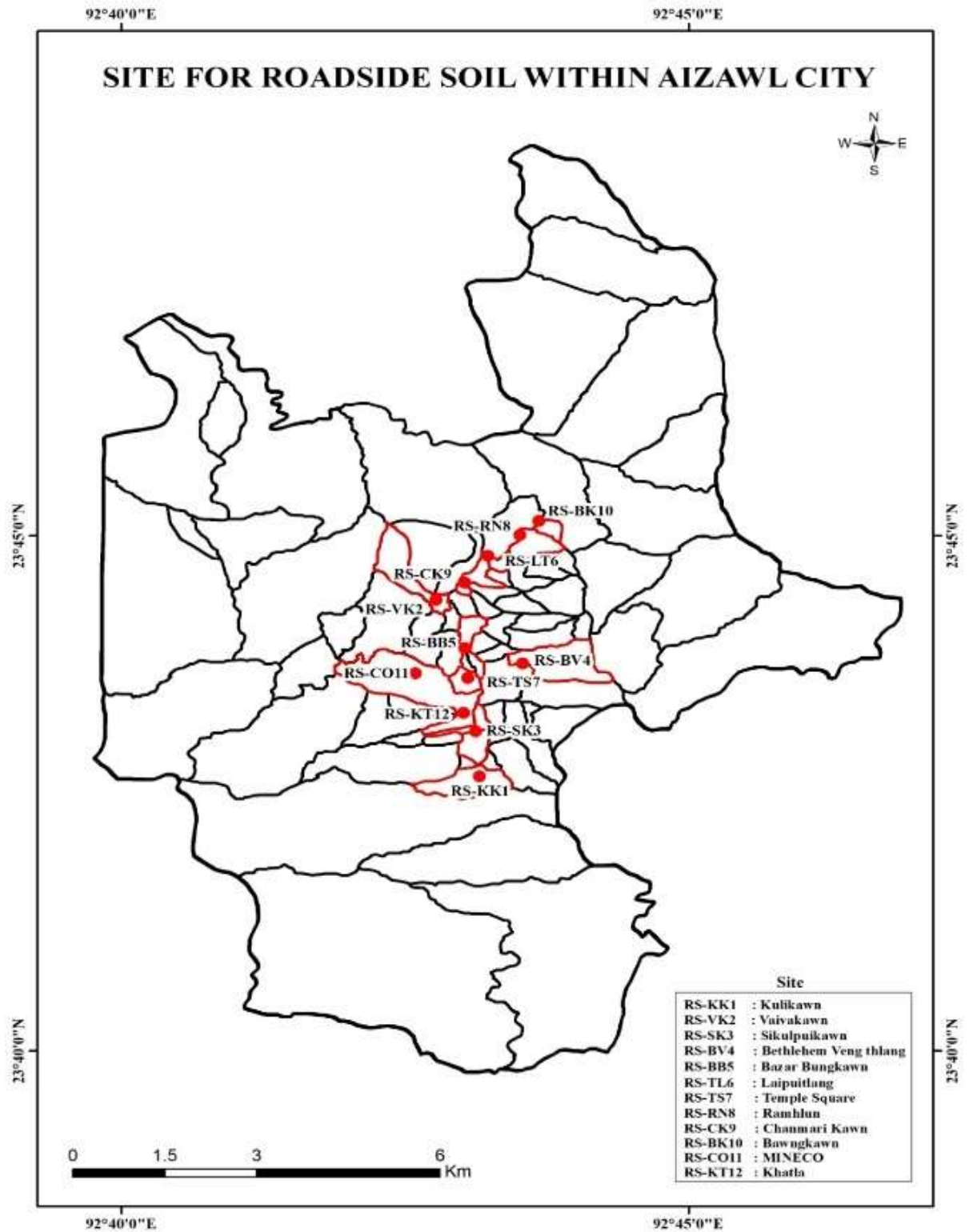


Fig. 3e: District map of Mizoram from which soil samples were collected.

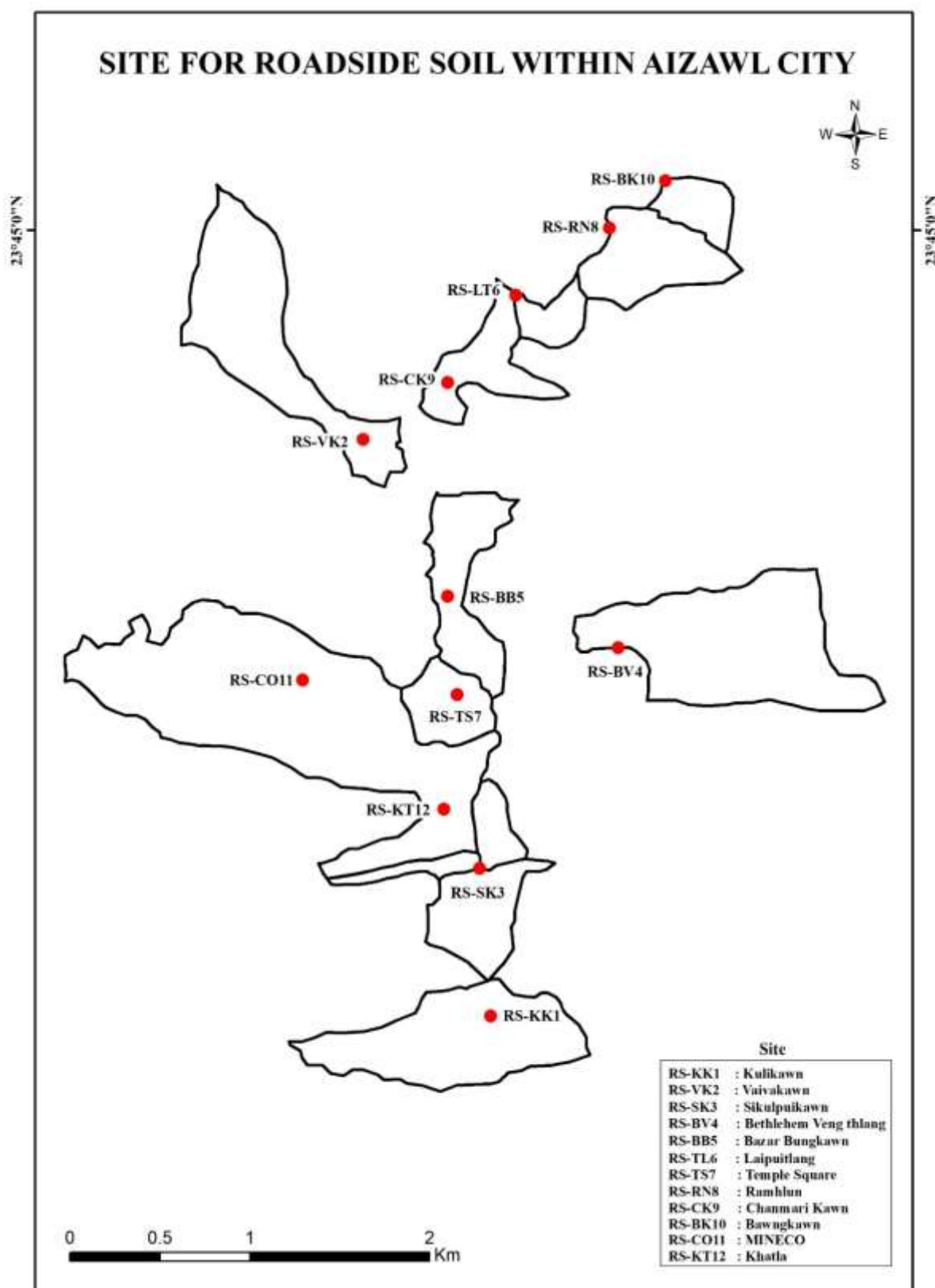


Fig. 3f. Locations of sampling for roadside soil at Aizawl city.

3.4.1.1 Kulikawn (RS-KK1)

Kulikawn is a locality in Aizawl, between 23.7082°N, 92.7220°E and can be reached by the National Highway 54 that is one of the major roads to Aizawl from the different parts of the country. Kulikawn had a population of 6,073 with 2,823 males and 3,250 females whereas the average sex ratio was 877 females per 1,000 males compared to the national average of 940 per 1,000 males. Kulikawn has 855 households with an area of 0.360 km² in 2002. As the area is located in the heart of the city, there are quite a few educational institutions and hospitals such as Kulikawn Hospital, BN Hospital and Alpha Hospital. The separation took place close to the traffic junction.

3.4.1.2 Vaivakawn (RS-VK2)

Vaivakawn is the one of the localities in Aizawl, Mizoram State, India. From the geographical co-ordinates of 23.727°N latitude and 92.718°E longitude. It lies on the National Highway 54, situated 1–2km south from city center. It is 57.03km² and had a population of 73,870, where of 36,625 were men and of 37,245 were women. This neighbourhood is a mix of residential and commercial properties, including schools, churches, shops and a clinic. The Vaivakawn junction is a strategically important traffic point connecting trade centres and gateway to northern parts and southern districts with the city centre.

3.4.1.3 Sikulpuikawn (RS-SK3)

Sikulpuikawn (23.4302°N 92.4307°E) is a key traffic route linking different parts of the city. It's a mix of businesses and residential properties. Sikulpuikawn is home to Government Aizawl College which is among one of the colleges in Aizawl. Sikulpuikawn in Mission Veng locality has 10562 people population with 4978 males and 5584 females across 2194 houses. The sampling was near the traffic intersection.

3.4.1.4 Bethlehem Vengthlang (RS-BV4)

Bethlehem Vengthlang is a locality in Aizawl, Mizoram, India, located at 23.4342°N 92.4351°E in the norther part of Aizawl. It has a population of 9,012 with 4,212 males and 4,800 females residing in 1,840 households. Market area/a taxi stand is

established within the locality with shops for daily need on both of its sides. The area also benefits from World Bank Road connectivity with other parts of the city. The samples were taken in the vicinity of the traffic intersection.

3.4.1.5 Bazar Bungkawn (RS-BB5)

Aizawl, Mizoram Bazar Bungkawn is a crowded neighbourhood in Dawrpui area of Aizawl in Mizoram. The Civil Hospital, Aizawl is a major medical institution in the area, located in the locality. The locality also contains a number of stores such as Cell care – mobile phone repairs and other similar businesses. As of 2011 India census, Dawrpui had a population of 3214 with 1509 males and 1705 females, is spread across 689 Households. The sample was collected near the traffic intersection.

3.4.1.6 Laipuitlang (RS-LT6)

Laipuitlang, a residential area in Aizawl, Mizoram, is located at an altitude of 1,134 m which is about 3,720ft asl., and is considered as one of the highest among the study sites. It has a population of 2,069 comprising 1,001 males and 1,068 females across 520 households. Laipuitlang is predominantly a residential area with some schools, shops, and government establishments adding to its infrastructure. Although scenic, the place is geologically vulnerable due to its height and rocky strata. The sample collection was carried out at waiting shed enroute to Govt. Office and schools.

3.4.1.7 Temple Square (RS-TS7)

Temple Square is a major traffic junction and commercial and residential area located in the Tuikual South locality of Aizawl, Mizoram. The area is home to one of the Salvation Army's most famous churches and sumo stand that receives many visitors providing a transit function to the-city-and-thus. It is geographically located below Vanapa Hall (one of the biggest community halls in Aizawl) and it passes through Mizofed, Zodin petrol filling station. The wider Tuikual South area has 5,895 inhabitants (2,740 men and 3,155 women) as at 12,809 households. A sample was taken around the junction.

3.4.1.8 Ramhlun South (RS-RN8)

Ramhlun South is a residential locality in the Aizawl city of Mizoram that is located at Precisely 23.25741°N, 92.83186°E. It has 1,620 houses which can be categorized into 3,228 male and 3,480 female inhabitants. The area is served by the Ramhlun Sub Post Office, several schools, and shops, where the sample collections were carried out in the vicinity of traffic junction.

3.4.1.9 Chanmari (RS-CK9)

Chanmari located at 23.7407°N 92.7172°E in Aizawl (Mizoram) is one of the best mixed commercial and residential area. The population of Chanmari is 4172, there are 1503 males and 2185 females in the region (as of 2011 census, out of a total of 1260 households in the city). Chanmari features among the city's major market areas. The locality is surrounded by Hrangbana College, taxi stands and a bus stand, and the sample collection was done at the vicinity of the traffic junction.

3.4.1.10 Bawngkawng (RS-BK10)

One of the busiest localities of the city of Aizawl, Mizoram, Bawngkawng is located at 23°45'20.5"N 92°44'23.5"E and is right on the highway of the NH-54, the busiest road of Aizawl and hence the main entrance of all large carrier vehicles. An area with a blend of residential and commercial zones, it is home to several educational institutions like schools, colleges and a hospital at its vicinity. At the 2011 census, Bawngkawng had a population of 10,562 with 4,978 males and 5,584 females, and an average sex ratio of 1,122. The average literacy rate was 95.45% The figures for male and female literacy were 95.99 and 95.04 % respectively. Bawngkawng is a key link in Aizawl's urban fabric and infrastructure. Sampling was also taken close to the traffic junction.

3.4.1.11 MINECO (RS-CO11)

Aizawl's most important government office building is the Mizoram New Capital Complex (MINECO) located in Khatla with the coordinates of 37°44'31.089" N 77°2' 52.313" W and the State Assembly House is situated in the middle. School locality. It hosts the significant offices of the state government and the government's

House of the State of Mizoram. MINECO also provides public services, including a multi-storey car park for both government staff and the public. MINECO is located in Khatla, an overpopulated 9,500 people urban area including 4,550 males and 4,950 females divided in 16,504 households. The samples were collected close to the office premises.

3.4.1.12 Khatla (RS-KT12)

Khatla is a mixed-industrial town area in Aizawl, Mizoram (23.7263°N and 92.7096°E) in India. The area has a number of nearby schools, banks, and a police station which provides residents with all a necessary facility. It is also the road leading to the MINECO which is the biggest concentration of government offices within the city. The village had a population of 4,550 males and 4,950 females which constituted a total of 9,500 persons with a population density of 1,034 persons per km² of the 16,504 households counting 9,500 houses. Sample was collected near the traffic intersection.

3.4.2 Sites outside Aizawl city for roadside soil

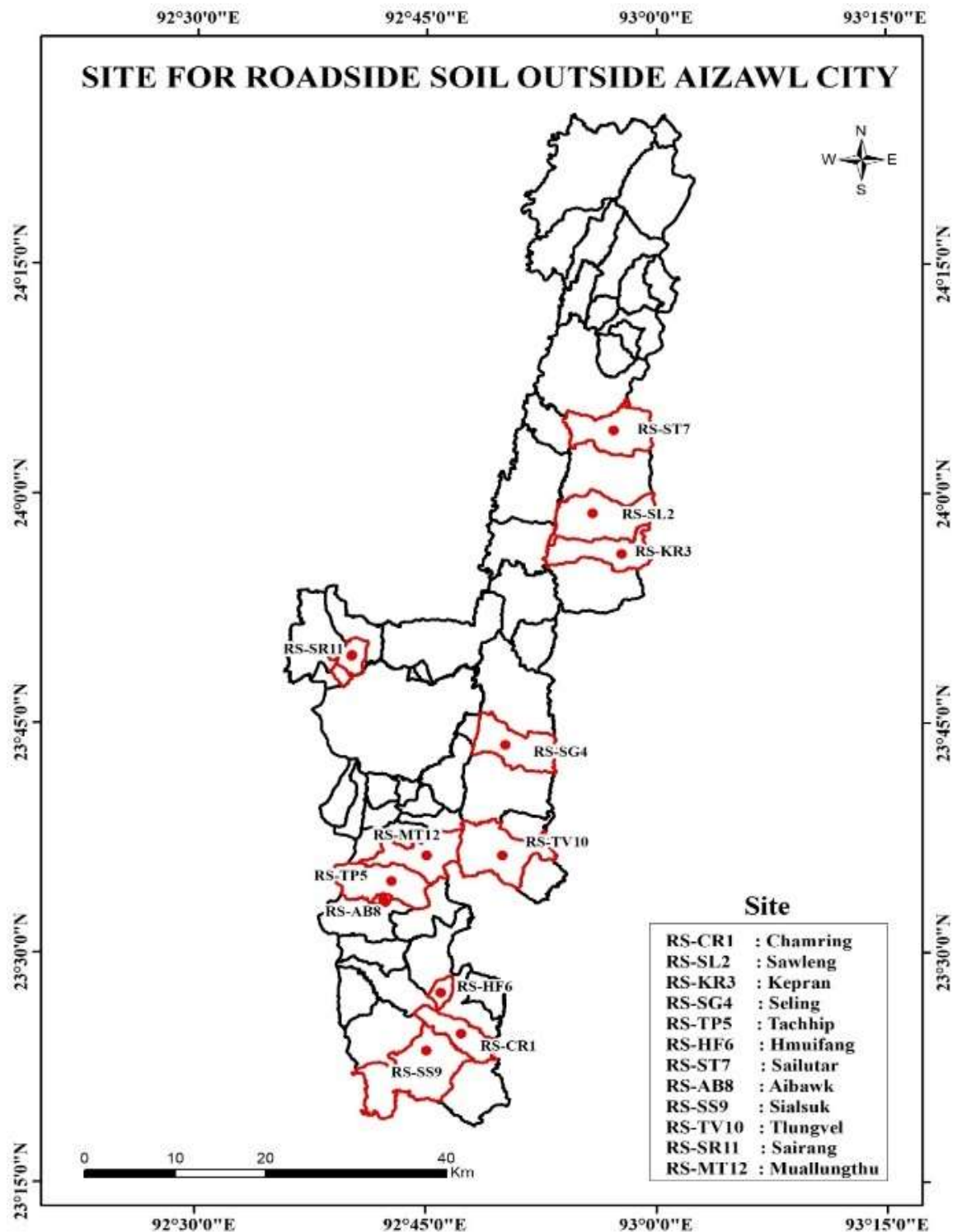


Fig. 3g. Sampling sites for the road side soil away from Aizawl.

3.4.2.1 Chamring (RS-CR1)

Chamring is a village situated at 23.4287°N 92.7624°E in Aibawk sub division of Aizawl district. It is a small village with a population of 301 people in 74 households including 160 males and 141 females. Chamring is 55 km south of Aizawl, and is just a residential area and basic educational and healthcare facilities are available. Sampling was performed close to the traffic junction.

3.4.2.2 Sawleng (RS-SL2)

Sawleng is situated at 23.9816°N 92.9319°E of Aizawl district in Mizoram. It has a population of 1,452 as per census, 727 males and 725 females in 301 households. Sawleng is situated around 39 km north of Aizawl and is mostly residential with some minimal educational and health centre facilities. Sampling was performed at the crossroads.

3.4.2.3 Kepran (RS-KR3)

Kepran is located at 23.9446°N, 92.9360°E in Darlawn block of Aizawl district of Mizoram. As of 2011 India census, Kepran has a total population of 708 individuals, including 366 males and 342 females, residing in 167 households. Kepran is situated about 109 km on the northeastern side of the State Capital, Aizawl. It is residential and has elementary and health facilities. The sample location was close to the traffic intersection.

3.4.2.4 Seling (RS-SG4)

Seling is a village situated at 23.7333°N and 92.8500°E in Aizawl district, Mizoram and consists of 2,289 people in 468 households, with 1,138 males and 1,151 females. Located on the NH-54 (National Highway 54), about 25 miles south east of Aizawl. Seling is an important and well-known oasis for travellers, the town has a great selection of restaurants and places to rest in a place that will set you up for the rest of your road journey. Collection site for the sample was close to traffic intersection.

3.4.2.5 Tachhip (RS-TP5)

Tachhip, situated at coordinates of 23.5828°N 92.7206°E, falls under the jurisdiction of Aibawk block in Aizawl district of Mizoram, and has a population of 983 people (514 males, 469 females) who live in 197 households. Tachhip is one of the popular convenient places for traveller, offering farm fresh vegetables so that people could stop by and refresh themselves and buy some veggies and eatables. Samples were obtained near a vendor area that was heavily trafficked, a center where travellers typically stop for a break or something to drink.

3.4.2.6 Hmuifang (RS-HF6)

Hmuifang, situated on the bank of the river, is a village located in the Aibawk section of the Aizawl district of Mizoram (23°27'00"N 92°45'28"E), India with a total of 53 houses. It is famous for the picturesque Hmuifang Tlang (mountain) a major tourist and local sightseeing spot which pulls many visitors to the village every year. Located half-way between 40 km before Aizawl. It comes handy for travellers as there are restaurants and shops for eating and refreshment along the Highway. Sampling was carried out near the Hmuifang tlang.

3.4.2.7 Sailutar (RS-ST7)

Sailutar is a village situated at 24.0143°N, 92.9244°E, in the Darlawn R.D block of Aizawl district of the State of Mizoram in India. In the village the population is 536 of which 265 are males while 271 are females as per Population Census (2011) with 97 households. 120 km from the district Aizawl. The national highway passing through village is NH150. Sailutar is residential and has some elementary healthcare and educational facilities. The sampling was performed at a road intersection.

3.4.2.8 Aibawk (RS-AB8)

Aibawk, situated at 23.5595°N by 92.7064°E, in the Aizawl district of Mizoram, India, has a population of 1,325 people, 651 males, 674 females living in 310 households. Located about 30 km south of Aizawl, Aibawk is a sub-district headquarters linked by NH-54. The village provides rest and eating places for

tourists. Sample collection was carried out at the village playground next to the traveller rest-end restaurant shops.

3.4.2.9 Sialsuk (RS-SS9)

Sialsuk situated at 23.400°N and 92.750°E in the Aibawk block of Aizawl district, Mizoram, has 396 households and its population is 1,881 people, it contains 945 males and 936 females. Located about 45 km south of Aizawl, Sialsuk is accessible through Aizawl-Lunglei Road and is thus a favourite tourist stopover. The village is popularly known for its scenic beauty especially and for the highest peak Sialsuk Tlang from where one can have a panoramic view and is visited by the tourists and locals. Sample collection was performed in the close vicinity of the traveller stop place.

3.4.2.10 Tlungvel (RS-TV10)

Tlungvel is situated at coordinates 23°36'17.08"N 92°51'10.38"E in Thingsulthliah Block in Aizawl District of Mizoram. The population is 2,529, including 1,238 men and 1,291 women, living in 559 households; there are 339 children. It is about 65 km in the southeast of Aizawl and is linked by NH-54. It's predominantly residential, with schools and health care services. A sample was also obtained around traffic junction.

3.4.2.11 Sairang (RS-SR11)

Sairang is situated in the Aizawl District of Mizoram(23°48'32.2128" N 92°39' 22.1652" E) in the Tlangnuam block and is about 12km north-west of the city. It is linked by NH-44A, a key route for bringing goods into the region, so Sairang is a crucial transit point for supply vehicles. The village is home to 5,950 people, among them 2,992 men and 2,958 women, in 1,308 households. Its strategic position and its contribution in the Bhairabi–Sairang railway line make it more relevant in the context of improvement of transportation and connectivity in Mizoram. The sampling was performed close to traffic intersection.

3.4.2.12 Muallungthu (RS-MT12)

Muallungthu is a village in Aibawk block of Aizawl district, Mizoram, India, with coordinates of 23.7082°N 92.7219°E. As of 2011 census, it had a population of 1,160, with 603 males and 557 females who live in 256 households. It is largely residential, and includes educational and medical facilities. The village is around 10 km south of Aizawl and reachable via its interior roads linked to NH-306. Muallungthu is identifiable with the Tropic of Cancer passing through the area, making it geographic importance. The sampling sites located in the vicinity of traffic intersection.

3.4.3 Air sample sites

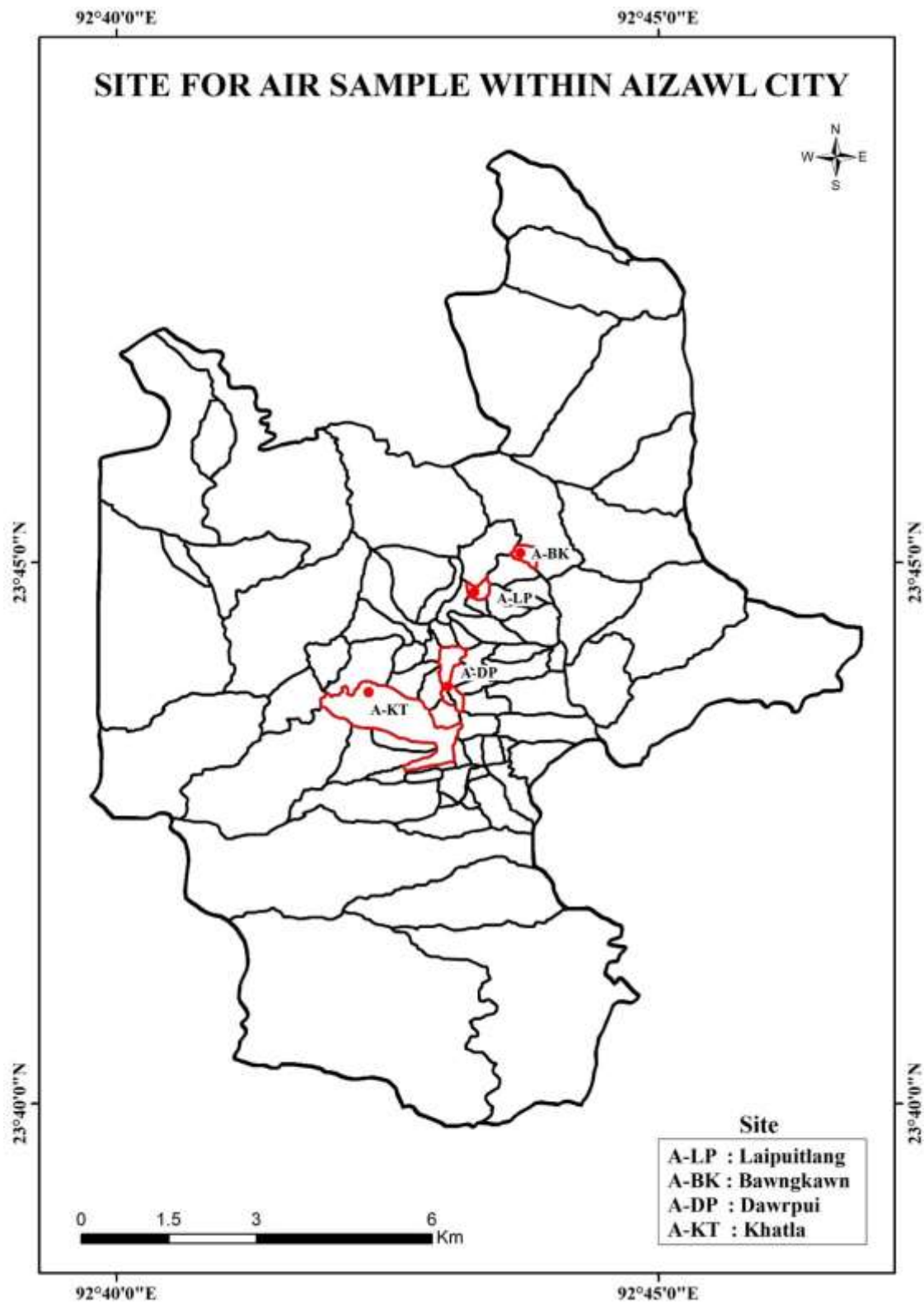


Fig. 3h. Air samples site within Aizawl city.

3.4.3.1 Laipuitlang (A-LP)

Laipuitlang (altitude 1,134 metres) is a residential settlement and is the one of the highest points among the study sites (23°44'33"N 92°43'11"E). The population of the locality in 2002 was 2,069 in 520 households 1,001 males and 1,068 females. Though residential, it has few schools, shops, government offices to aid in its infrastructure. While it appears calm, the region has had its share of geologic issues – mainly landslides because of how high it is and the type of rocks that comprise this elevation. Sampling was performed at the residential area close to the location.

3.4.3.2 Bawngkawn (A-BK)

Bawngkawn, lies at 23°45'35" N and 92°42'32"E in Aizawl, Mizoram is an important locality in the city and it acts as the main entry point for the National Highway 54 (NH-54) which is the busiest road in the city and used for entry of Large Goods Carriers. It is a residential and commercial neighbourhood, with several schools, colleges, and a hospital located in the vicinity. According to Census 2011, it has a population of 10,562 including 4,978 males and 5,584 females with 2,194 households — a significant node in the urban and infrastructural fabric of Aizawl. The sampling point was close to human habitation.

3.4.3.3 Dawrpui (A-DP)

Dawrpui locality of Aizawl, is a busy place known for its various markets and also houses a number of educational institutions. The place has a Civil Hospital, Aizawl, a major health facility in the region. The section also contains several businesses, such as mobile phone shops like Cell Care, further adding to its commercial importance. The population of Dawrpui consists of 1,509 males and 1,705 females across 689 households. The sampling site was near the traffic junction.

3.4.3.4 Khatla (A-KT)

Khatla is a mixed residential and commercial neighbourhood, situated in Aizawl, Mizoram at 23.7263°N 92.7096°E. It also acts as the link to the MINECO, the city's largest government office cluster. It has a population of 9500 of which 4550 are

males while 4950 are females with 16504 households. The sampling was carried out at Mizoram Pollution Control Board Office, Khatla, Aizawl information.

3.5. Soil samples collection and preparation

Soil samples were collected monthly from 24 pre-selected locations for two years (2020-2022). These places comprised of 12 sites in Aizawl city and 12 sites outside Aizawl city. We sampled three replicates of soil from each site, approximately 10 meters apart on the roadside. The monthly samples thus received were later grouped in three seasons that is Pre-Monsoon (February-May), Monsoon (June-September) and Post Monsoon (October-January). In total, the collected samples per months were 72 samples.

Soil sampling was performed with a collection plate and then, placed in plastic bags, and was mixed in all the three replicates. The afore-said fresh soil sample was homogenized, then divided into two equal portions. New soil samples were taken for conducting the soil pH and moisture content estimation.

The remaining half of each sample was air-dried to constant weight and ground in powder and sieved through 2mm and kept in polythene bags. After sieving the fresh soil were used for analysis of soil samples such as organic C, total N, available P and available K in powdered whereas the dry and sieved soil samples were used for heavy metals (Cu, Fe, Mn, Ni, Pb and Zn) analysis in soil.

3.5.1 Analysis of soil Soil

3.5.1.1 pH

20 g of fresh soil samples was added to a beaker with 40 ml of distilled water (1:2). The H₂O was stirred with a magnetic stirrer for 30 min and then allowed to remain overnight. Digital pH meter was used to determine pH of the soil samples.

3.5.1.2. Soil Moisture Content (SMC)

Mass of SMC was determined by Gravimetric Method (Novák and Hlaváčiková., 2019). 10 g of fresh soil was oven-dried at a temperature of 105 °C for 24 h using a

hot air oven. The weight of the soil samples was measured again after drying. SMC was calculated as follows:

$$\text{SMC (\%)} = \frac{\text{Weight of fresh soil (g)} - \text{Weight of oven dried soil (g)}}{\text{Weight of oven dried soil}} \times 100$$

3.5.1.3 Soil Organic Carbon (SOC)

SOC was determined based on the Walkley and Black, 1934 titration method. 1 g of soil sample was placed in an Erlenmeyer flask. 1N $\text{K}_2\text{Cr}_2\text{O}_7$ 10ml and 20 ml of conc. H_2SO_4 was added. The flask was swirled for 1 min and maintained for 30 min. One after the other, 200ml deionized water. 10ml H_3PO_4 and diphenylamine indicator were placed. Titrated with 0.5 N $\text{FeSO}_4(\text{NH}_4)_2 \cdot \text{SO}_4 \cdot 6\text{H}_2\text{O}$ the blue colour turned to green. The same process was followed for control. SOC was calculated as follows:

$$\text{SOC (\%)} = N \times 0.003 \times \frac{(B-S)}{\text{Weight of soil taken (g)}} \times 100$$

Where, B = Volume of $\text{FeSO}_4(\text{NH}_4)_2 \cdot \text{SO}_4 \cdot 6\text{H}_2\text{O}$ required for blank titration (ml)

S = Volume of $\text{FeSO}_4(\text{NH}_4)_2 \cdot \text{SO}_4 \cdot 6\text{H}_2\text{O}$ required for soil sample (ml)

N = Normality of standard $\text{FeSO}_4(\text{NH}_4)_2 \cdot \text{SO}_4 \cdot 6\text{H}_2\text{O}$

3.5.1.4 Total Nitrogen (TN)

TN was measured by wet-digestion and the methods of Kjeldahl (Bremner and Mulvaney, 1990). 5g was added to the digestion tube of the soil sample. digestion and the digestion mixture and 20ml of conc. were slowly poured, one by one. Digestion continued until the solution becomes light green or colourless. 10ml of distilled water was added and mixed. The distillation was performed with the appropriate reagents and titrated with 0.1 N HCl to pink colour occurrence of endpoint. TN was calculated as follows:

$$\text{TN (\%)} = N \times 14 \times \frac{(S - B)}{\text{Weight of soil taken (g)} \times 1000} \times 100$$

Where, B = Volume of H_2SO_4 required for blank titration (ml)

S = Volume of H_2SO_4 required for soil sample (ml)

N = Normality of H₂SO₄ solution (0.01 N)

3.5.1.5 Available Phosphorus (P)

P from soil samples was obtained by the Bray and Kurtz (1945) method. 2.5 g of soil and 25 ml of Bray and Kurtz were put in a conical flask. Suspension was shaken and it was filtered through Whatman filter paper No.42 followed by addition of Activated charcoal. A portion of the extract was transferred into a volumetric flask. Then, p-nitrophenol indicator and sodium bicarbonate were also added. All standard extracts samples were acidified (2ml, H₂SO₄), diluted and read the absorbance in a spectrometer within 10 min. Calculation was performed according to:

$$P \text{ (kg/ha)} = R \times \frac{\text{The volume of extractant (ml)}}{\text{Volume of aliquot (ml)} \times \text{Weight of soil taken (g)}} \times 2.24$$

Where, R = ppm or $\mu\text{g mL}^{-1}$ of P in the aliquot (obtained from the standard curve)

The phosphorus content in the extract was estimated calorimetrically using the molybdenum blue method as described by Murphy and Riley (1962).

3.5.1.6 Available Potassium (K)

5 g soil samples were mixed with 25 ml of 1 N NH₄CH₃CO₂ solution. The flask was shake for 30 minutes with the help of mechanical shaker. After which it was filtered through Whatman no, 42 to the clear filtrate. The K was extracted from Flame Photometer (Jackson, 1973) as follows:

$$K \text{ (kg/ha)} = R \times \frac{\text{The volume of extractant (ml)}}{\text{Weight of soil taken (g)}} \times 2.24$$

Where, R = ppm of K obtained from the standard curve

3.5.1.7 Cu, Fe, Mn, Ni, Pb, and Zn

Soil samples were dried in an oven at 75°C for 12 h and then passed through a 2-mm sieve to remove coarse debris. The desiccated soil was then ground with mortar and pestle the soil until all particles passed through a 0.15mm sieve. 1 g quantity of soil sample was taken into a 250 mL Pyrex Erlenmeyer flask and added 10 ml of 8.5 M HNO₃. The mixture was heated on the challenge device at about 95°C (just below

boiling), and this temperature was held for 15 minutes. After cooling to less than 70 °C, 5 ml of 17 M HNO₃ was added and refluxed for 30 minutes at about 95°C, and this particular process was repeated twice for each sample and heat for 2hrs. After that, the samples were cooled to less than 70°C and 2 ml of distilled water was added and then 3 ml of 8.8 M H₂O₂ was slowly added and was again heated for 10 mins. The solution was heated again until it stopped effervescing, and 8 ml of 8.8 M H₂O₂ was added dropwise, then added in portion (in 1ml additions), and the mixture was subjected to reflux once more. The refluxed contents were allowed to cool, below 70° C and 10 ml of 12 M HCl was added to it. The sample was then refluxed for 15 mins and cooled down to room temperature and the extract filtered through a 0.45 μm PVDF filter. The samples were then diluted to 100 ml using distilled water (HPLC grade). The last diluted solution was used to determine the levels of heavy metals (Cu, Fe, Mn, Pb, Ni, and Zn) by Atomic Absorption Spectroscopy (AAS).

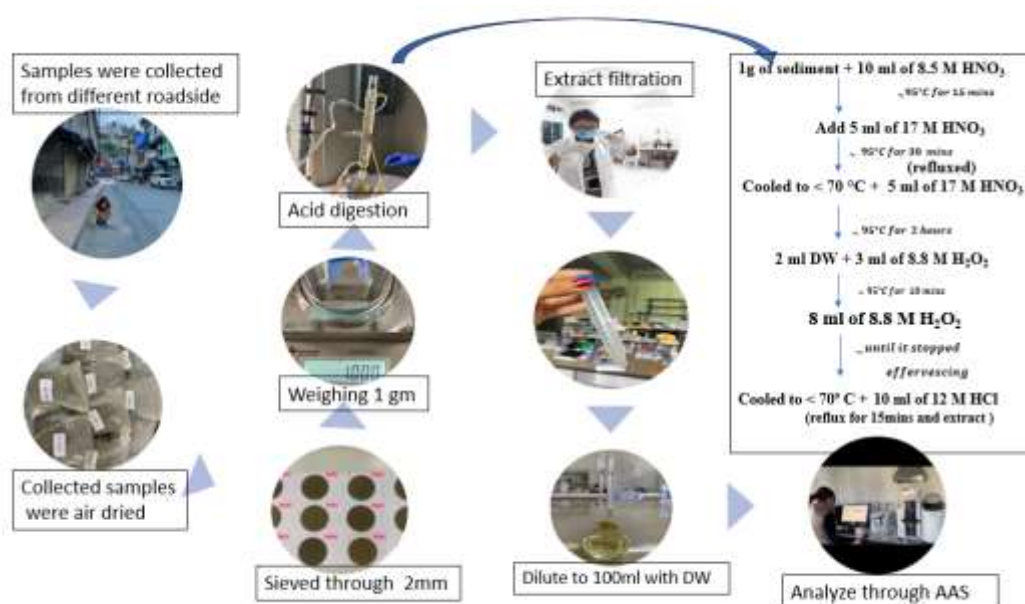


Fig. 3i. Sample collection and analysis

3.6 The Enrichment factor (EF), the geo-accumulation index (Igeo) and pollution load index (PLI) values were determined in order to evaluate the level of heavy metal contamination in the sediments of roadside.

3.6.1 Enrichment factor (EF)

To determine the degree of heavy metal enrichment and estimate the proportion of each metal attributable to anthropogenic and natural origins, EF were applied (Yang et al., 2022).

The EF was calculated by:

$$EF_i = \frac{\frac{C_i}{CR} \text{ soil}}{\frac{C_i}{CR} \text{ background}}$$

Where, EF_i is the Enrichment factor of trace metal, C_i is the metal concentration of sample and CR is the concentration of the reference metal. $EF < 1.5$ suggests that metal is derived mainly from the bedrock. If the EF is greater than 1, it infers that anthropogenic loading is costing more than natural sources.

3.6.2 Geo accumulation index (Igeo)

The I_{geo} is one of the geochemical index for assessing degree of pollution toward one element (Ioniță and Radu, 2024). It is defined as:

$$I_{geo} = \log_2 \frac{C_n}{1.5 B_n}$$

Where, C_n is the measured concentration of metal n in soils or sediments, B_n is the geochemical background value of metal n .

3.6.3 Pollution load index (PLI)

The PLI of the metals was calculated based on the following equation (Shirani et al., 2020):

$$PLI = (CF_1 \times CF_2 \times \dots \times CF_n)^{1/n}$$

Where, CF = concentration of a given heavy element in the soil sample and n = No of heavy metals.

Moreover, the short-term study of HM during covid and post-covid was also conducted as it comes under this period. The during covid period was August, 2020 to July 2021 and the after-covid period was August 2021 to July 2022.

3.7 Sampling of air and sample preparation

Air samples were collected at sites as outlined above under study sites. Mizoram Pollution Control Board (MPCB), had set up High Volume Air Sampler at these locations. A High Volume Air Sampler (HVAS) is an instrument used to collect suspended particulate matter (SPM), mainly PM₁₀ and total suspended particles, from ambient air by drawing a large volume of air—typically 1 to 1.3 m³ per minute—through a filter medium. In this study, a quartz microfiber filter paper (20cm x 25 cm) was used, which is preferred for its high thermal stability, low background contamination, and suitability for heavy metal and chemical analysis. The sampler consists of an inlet or dust hood that directs ambient air into the system, a filter holder assembly that supports the quartz filter, a powerful vacuum pump or blower that maintains constant suction, and a flow measurement system such as an orifice meter and manometer to monitor the airflow rate. During operation, air enters through the dust hood and is pulled through the quartz filter by the vacuum pump, creating negative pressure. As the air passes through the filter, particulate matter including dust, soot, smoke particles, and heavy metal-laden aerosols is trapped on the filter surface. The sampler typically runs for a fixed duration, often 24 hours, using a timer to ensure consistent sampling. After sampling, the quartz microfiber filter requires periodic replacement every 8 hours to ensure high sampling efficiency. Filter paper was coordinated monthly through the State Pollution Control Board.

The concentration of particulates in the air is calculated by dividing the mass of the trapped particles by the total volume of air sampled. HVAS is widely used in environmental monitoring and research, especially in studies involving roadside pollution, industrial emissions, seasonal air quality variation, and heavy metal contamination due to its ability to capture particulate matter efficiently from large air volumes. For sample collection, a specific type of filter paper was used in the air sampler to capture these particles,

The filters were transported from the capture site to the laboratory using a shipping envelop where they were stored in a protective envelop at room temperature (up to 30°C) before analysis. They had been preserved for at least 180days before subsequent treatment. Samples were extracted using hot plate. Air sampling was performed monthly over a period of 2 years (2020-2022). The monthly data was classified as Pre-Monsoon (February–May), Monsoon (June–September) and Post-Monsoon (October–January). A total of 48 samples were collected per month.

3.8 Heavy metal analysis in Air samples

The procedure of Central Pollution Control Board, CPCB (2013) was used using Atomic Absorption Spectrophotometer (AAS). The process includes cutting a filter strip and putting the same in a beaker. 3% HNO₃ and 8% HCl Solution is then poured and stacked to fill the filter, after which is gently refluxed on a hotplate in a fume hood for 30 min. After cooling, the walls of the beaker were rinsed with distilled water, and the sample was left to sediment with the addition of distilled water for 30 min. The solution obtained was filtered through PVDF 0.45 µm and the beaker was washed with distilled water. These washings were added to the flask contents to obtain 100 ml volume. Finally, the filtered sample was prepared for downstream analysis.

Analysis of sample:

The air samples were subjected to analysis for concentration of Cu, Pb, Ni and Zn with the help of AAS (installed in Chemistry Department, Mizoram University).

Calculations:

Sample air volume:

The picked air volume was determined by using the equation:

$$V = (Q)(t)$$

Where,

V = volume of air (m³)

Q = the mean sampling rate (in m³/min)

T = time in minutes

Metal calculation:

$$C = (M_s - M_b) \times V_s \times F_a/V \times F_t$$

Where,

C = concentration (µg/m³) metal

M_s = metal concentration (µg/mL)

M_b = blank concentration (µg/mL)

V_s = total extract volume (ml)

F_a = total exposed filter area (cm²)

V = Volume of air (m³) collected.

F_t = The area of filter used for digestion (cm²)

3.9 Statistical analysis:

A comparison of all the data was performed by one way and two-way ANOVA to test the extent of significant variation within the sites, within the season and within the two years. Karl Pearson's coefficient of correlation among weather data, number of vehicles and in all calculated variables were done. The standard deviation of the monthly and seasonal occurrence was then determined. Measurement of standard error of mean value, for average recorded the replicates were also taken. The statistical analysis was performed by using MS-Excel 365 version.

Photo Plate 1: Sampling sites within Aizawl city



RS-KK1 (Kulikawn)



RS-VK2 (Vaivakawn)



RS-SK3 (Sikulpuikawn)



RS-BB5 (Bazar Bungkawn)



RS-LT6 (Laipuitlang)



RS-TS7 (Temple Square)



RS-RN8 (Ramhlun)



RS-CK9 (Chanmari)



RS-BK10 (Bawngkawn)



RS-CO11 (New capital complex, Mineco)



RS-KT12 (Khatla)

Photo plate 2: Sampling sites outside Aizawl city



RS-CR1 (Chamring)



RS-

SL2 (Sawlung)



RS-KR3 (Kepran)



RS-SG4 (Seling)



RS-TP5 (Tachhip)



RS-HF6 (Hmuifang)



RS-ST7 (Sailutar)



RS-AB8 (Aibawk)



RS-SS9 (Sialsuk)



RS-TV10 (Tlungvel)



RS-SR11 (Sairang)



RS-MT12 (Muallungthu)

Photo plate 3: Location of Air Sampler



A-KT, (Khatla station)



A-DP, (Dawrpui station)



A-BK,(Bawngkawn station)



A-LT, (Laipuitlang station)

Photo plate 4: Sediment sample collection





Photo plate 5: Air sample collection.



Chapter 4

Results and Discussion

4. RESULTS AND DISCUSSION

4.1. Physicochemical properties of roadside soil

4.1.1. pH

The pH at each site studied between 2020-2022 are represented in Fig. 4.1.1a. and 4.1.1b. for the various sites in Aizawl city and outside Aizawl city for three seasons (pre-monsoon, monsoon, post-monsoon) were respectively shown in Table 5.

The pH of roadside soil varied significantly with sites ($p < 0.002$) and seasons ($p < 0.001$) within the Aizawl city. Total pH values are in the range of 7.34 ± 1.13 to 11.4 ± 0.67 . During pre-monsoon season the site RS-KT12 showed maximum pH with 10.64 ± 0.88 and minimum in RS-LT6 with the value of 7.89 ± 0.76 . In the monsoon season maximum was recorded in RS-VK2 with the value of 11.40 ± 0.67 and minimum in RS-LT6 with the value of 7.89 ± 1.65 . During post-monsoon season maximum was recorded in RS-BK10 with the value of 9.17 ± 1.38 and minimum in RS-BB5 with the value of 7.34 ± 1.13 (Table 4.1.1g).

Outside Aizawl city, the pH of roadside soil showed significant variation within the sites ($p < 0.001$). The overall pH ranges from 7.34 ± 1.13 to 11.4 ± 0.67 . The site RS-SG4 showed maximum pH with 9.9 ± 0.42 and minimum in RS-KR3 with the value of 8.11 ± 0.11 during pre-monsoon season. In the monsoon season maximum was recorded in RS-SG4 with the value of 10.2 ± 0.49 and minimum in RS-SS9 with the value of 8.09 ± 0.11 . During post-monsoon season maximum was recorded in RS-SG4 with the value of 9.91 ± 0.07 and minimum in RS-KR3 and RS-ST7 with the value of 8.09 ± 0.05 and 8.09 ± 0.04 .

As seen in Fig. 4.1.1a. and Fig. 4.1.1b. pH was maximum in monsoon when comparing with all seasons within Aizawl city as well as other seasons. The correlation of rainfall with pH by taking average of the three seasons also showed a positive correlation ($r = 0.75$ within Aizawl city, $r = 0.98$ outside Aizawl city), as increase in rainfall leads to increase in level of pH leading to more alkalinity of soil (Table 4.1.1.c).

Within Aizawl city and outside Aizawl city, the pH values vary from 4.55 to 7.22, producing highest since acid rain water make alkalinity to lower and most of soil

covers by the pasture so now soil is getting higher alkalinity, the fact that pH of soil is significantly high which prove that that soil is highly alkaline since that processes which make the leaching and dilution of acidic contents by rainwater that reduces the acidity of soil (Brajendra et al., 2016).

Comparing pH Aizawl City and outside Aizawl city: The higher pH was found within Aizawl city and outside Aizawl city (Table 4.1.1c.) except rainy post-monsoon months (Table 4.1.1e. and Table 4.1.1f.). Heavy metal contamination of road side soil by Ramakrishnaiah and Somashekhar (2002) revealed that the low pH levels in urban soils were largely attributed to organic acids and reduced buffering capacity from human activities.

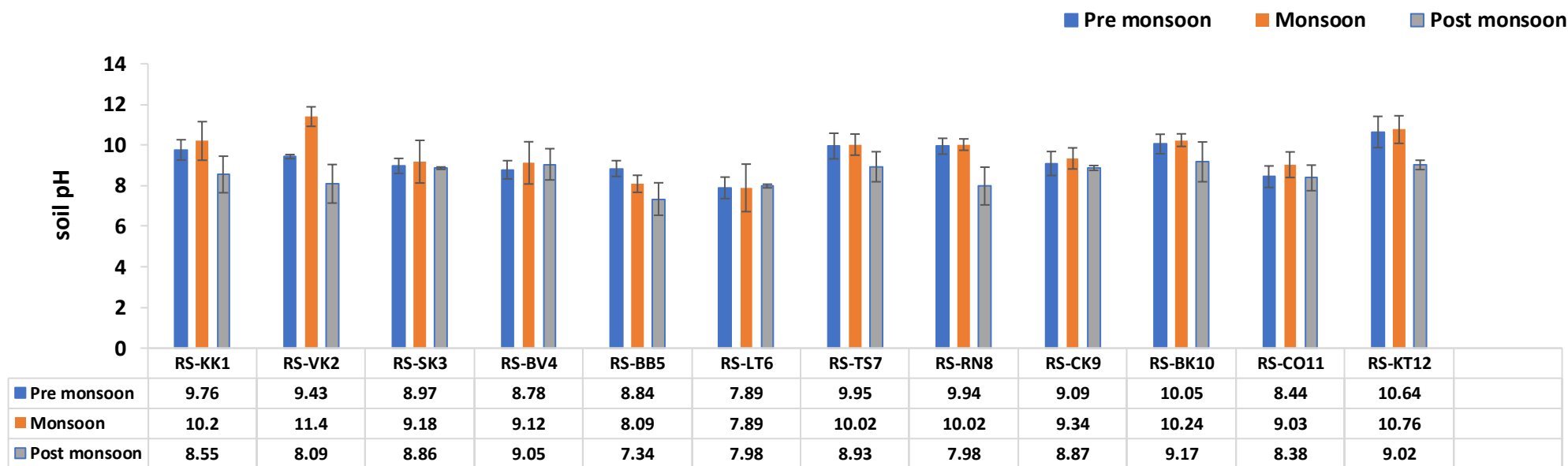
Table 4.1.1a. Anova table indicating significant variation of pH within sites and season within Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	15.081	11.000	1.371	4.340	0.002	2.259
Between the season	7.626	2.000	3.813	12.071	0.000	3.443
Error	6.950	22.000	0.316			
Total	29.656	35.000				

Table 4.1.1b. Anova table showing significant variation of pH within sites outside Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	10.822	11.000	0.984	12.773	0.001	2.259
Between the season	0.374	2.000	0.187	2.425	0.112	3.443
Error	1.694	22.000	0.077			
Total	12.890	35.000				

pH value of roadside soil within Aizawl city



Sampling sites

RS-KK1(Kulikawn) RS-VK2 (Vaivakawn) RS-SK3 (Sikulpuikawn) RS-BV4 (Bethlehem Vengthlang) RS-BB5 (Bazar Bungkawn) RS-LT6 (Laipuitlang)
 RS-TS7 (Temple Square) RS-RN8 (Ramhlun) RS-CK9 (Chanmari kawn) RS-BK10 (Bawngkawn) RS-CO11 (MINECO) RS-KT12 (Khatla)

Fig. 4.1.1a. pH of the roadside soil within Aizawl city.

pH value of roadside soil outside Aizawl City

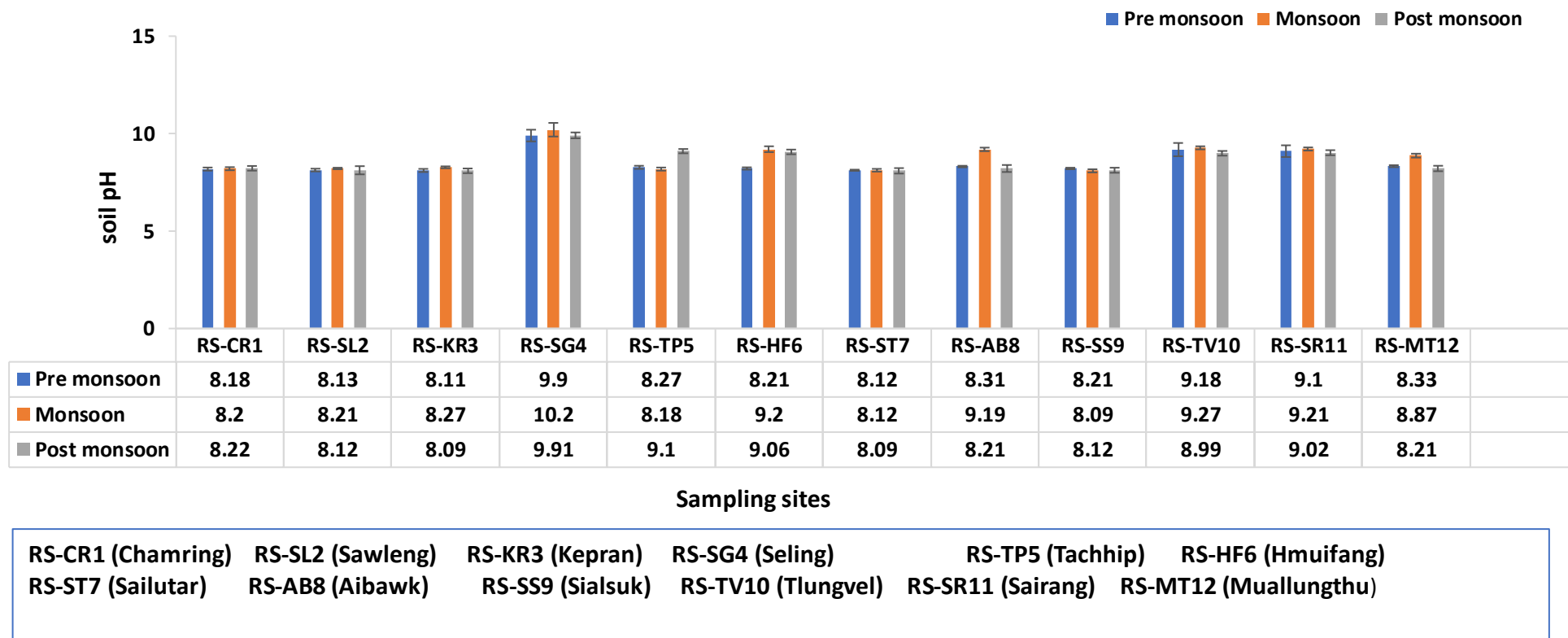


Fig. 4.1.1b. pH of the roadside soil outside Aizawl city.

Table 4.1.1c: Correlation between rainfall and air temperature with pH values within and outside Aizawl city.

	Rainfall	Temperature	pH values within Aizawl city	pH values outside Aizawl city
Rainfall	1	0.861	0.751	0.982
Air Temperature	-	1	0.906	0.565
pH values within Aizawl city			- 1	0.402
pH values outside Aizawl city			-	- 1

Table 4.1.1d. Mean value of pH values with standard deviation of the sites in different seasons within Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-KK1 (Kulikawn)	9.76 ± 0.71	10.2 ± 1.34	8.55 ± 1.27
RS-VK2 (Vaivakawn)	9.43 ± 0.79	11.4 ± 0.67	8.09 ± 1.34
RS-SK3 (Sikulpuikawn)	8.97 ± 0.81	9.18 ± 1.48	8.86 ± 0.08
RS-BV4 (Bethlehem Vengthlang)	8.78 ± 0.68	9.12 ± 1.46	9.05 ± 1.10
RS-BB5 (Bazar Bungkawn)	8.84 ± 0.78	8.09 ± 0.59	7.34 ± 1.13
RS-LT6 (Laipuitlang)	7.89 ± 0.76	7.89 ± 1.65	7.98 ± 0.12
RS-TS7 (Temple Square)	9.95 ± 0.74	10.02 ± 0.74	8.93 ± 1.05
RS-RN8 (Ramhlun)	9.94 ± 0.17	10.02 ± 0.39	7.98 ± 1.31
RS-CK9 (Chanmari kawn)	9.09 ± 0.66	9.34 ± 0.73	8.87 ± 0.17
RS-BK10 (Bawngkawn)	10.05 ± 0.24	10.24 ± 0.44	9.17 ± 1.38
RS-CO11 (Mineco)	8.44 ± 0.71	9.03 ± 0.89	8.38 ± 0.89
RS-KT12 (Khatla kawn)	10.64 ± 0.88	10.76 ± 0.95	9.02 ± 0.32

Table 4.1.1e. Mean value of pH values with standard deviation of the sites in different seasons outside Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-CR1 (Chamring)	8.18 $\pm$ 0.11	8.20 $\pm$ 0.11	8.22 $\pm$ 0.02
RS-SL2 (Sawleng)	8.13 $\pm$ 0.11	8.21 $\pm$ 0.05	8.12 $\pm$ 0.04
RS-KR3 (Kepran)	8.11 $\pm$ 0.11	8.27 $\pm$ 0.07	8.09 $\pm$ 0.05
RS-SG4 (Seiling)	9.90 $\pm$ 0.42	10.2 $\pm$ 0.49	9.91 $\pm$ 0.07
RS-TP5 (Tachhip)	8.27 $\pm$ 0.11	8.18 $\pm$ 0.11	9.10 $\pm$ 0.14
RS-HF6 (Hmuifang)	8.21 $\pm$ 0.08	9.20 $\pm$ 0.21	9.06 $\pm$ 0.04
RS-ST7 (Sailutar)	8.12 $\pm$ 0.04	8.12 $\pm$ 0.11	8.09 $\pm$ 0.06
RS-AB8 (Aibawk)	8.31 $\pm$ 0.05	9.19 $\pm$ 0.13	8.21 $\pm$ 0.05
RS-SS9 (Sialsuk)	8.21 $\pm$ 0.05	8.09 $\pm$ 0.11	8.12 $\pm$ 0.03
RS-TV10 (TlungvelP)	9.18 $\pm$ 0.47	9.27 $\pm$ 0.11	8.99 $\pm$ 0.11
RS-SR11 (Sairang)	9.10 $\pm$ 0.42	9.21 $\pm$ 0.11	9.02 $\pm$ 0.04
RS-MT12 (Muallungthu)	8.33 $\pm$ 0.08	8.87 $\pm$ 0.14	8.21 $\pm$ 0.08

4.1.2. SMC

The SMC values of the selected sites during the study period 2020-2022 are plotted in Fig. 4.1.2a. and 4.1.2b. for the different sites in Aizawl city and outside Aizawl city for three seasons (pre-monsoon, monsoon, post-monsoon) as a whole.

Within Aizawl city the SMC of roadside soil showed significant within season ($P < 0.001$). The SMC varies from 5.21 ± 0.04 % to 14.94 ± 0.62 %. The site RS-LT6 recorded the highest pH ($5.38 \pm 0.01\%$) while the lowest SMC level was recorded by RS-TS7 (5.21 ± 0.04 %) during pre-monsoon season. However, during monsoon season, the maximum SMC level was found in RS-KK1 with a value of 14.94 ± 0.62 % and the minimum in RS-BV4 with a value of 14.27 ± 0.22 %. (maximum) in RS-LT6 (5.58 ± 0.10 %) followed by RS-VK1 (5.27 ± 0.27 %) while minimum in RS-VK2 (5.21 ± 0.23 %) (Table 4.1.1g).

Outside Aizawl city, the SMC values of the roadside soil showed significant variation within the seasons ($p < 0.001$). The SMC is between $6.18 \pm 0.24 \%$ and $18.45 \pm 0.31 \%$. The highest SMC ($6.47 \pm 0.25 \%$) was observed in the RS-SR11 and the lowest number ($6.18 \pm 0.24 \%$) in the RS-KR3 in the pre-monsoon period. Maximum under monsoon season was registered in RS-TP5 which was $18.45 \pm 0.31\%$ and, minimum was observed in RS-HF6 with $17.12 \pm 0.07\%$. Post-monsoon season Maximum was recorded in RS-SG4 with a value of $6.65 \pm 0.35 \%$ whereas minimum was in RS-SL2 with a value of $6.21 \pm 0.03 \%$.

As seen in Fig. 4.1.1a. and Fig. 4.1.1b. the monsoon season has the higher SMC level compared to the other seasons (including outside Aizawl city) in all seasons. The correlation of the rainfall with the SMC on the average of the three seasons also showed positive correlation ($r = 0.99$, $r = 0.82$) (Table 4.1.1d; Table 4.1.1e).

By comparing the SMC among the seasons within Aizawl City and outside Aizawl city a significant higher level was recorded outside Aizawl city ($P < 0.009$) (Table 4.1.2.c). The SMC is generally higher in rural areas outside Aizawl compared to urban areas within the city. This difference could be attributed to urban factors such as increased surface runoff, which affects soil moisture retention (Anand et al., 2021).

Table 4.1.2a. Anova table showing significant variation of SMC within seasons inside Aizawl city.

Source of Variation	SS	df	MS	F	p -value	f - crit
Between the sites	0.363	11.000	0.033	1.485	0.207	2.259
Between the season	686.797	2.000	343.398	15433.106	0.001	3.443
Error	0.490	22.000	0.022			
Total	687.650	35.000				

Table 4.1.2b. Anova table showing significant variation of SMC within season outside Aizawl city.

Source of Variation	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f - crit</i>
Between the sites	1.019	11.000	0.093	1.554	0.182	2.259
Between the season	1003.809	2.000	501.905	8419.398	0.001	3.443
Error	1.311	22.000	0.060			
Total	1006.140	35.000				

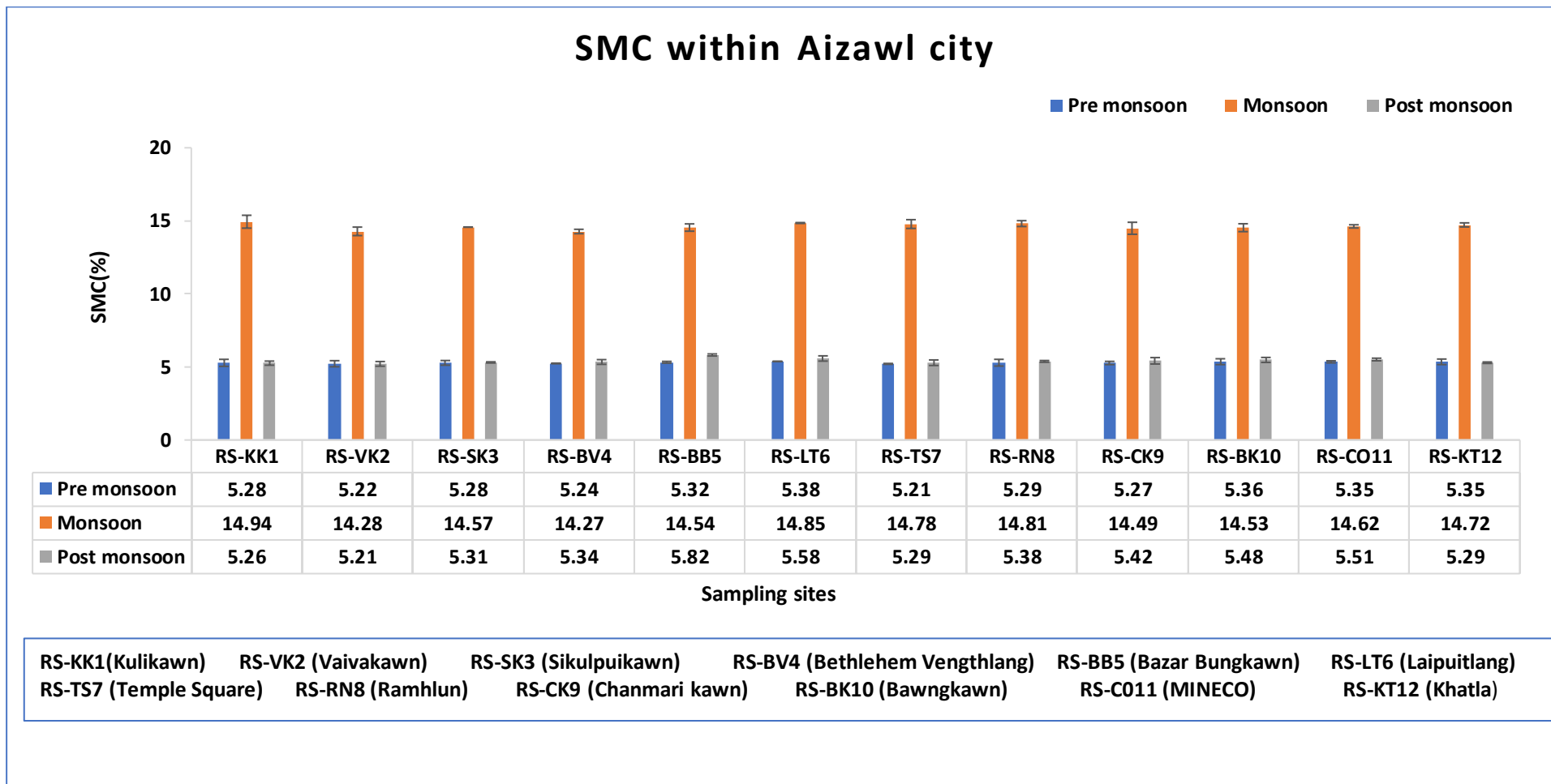


Fig. 4.1.2a: SMC (%) of the roadside soil within Aizawl.

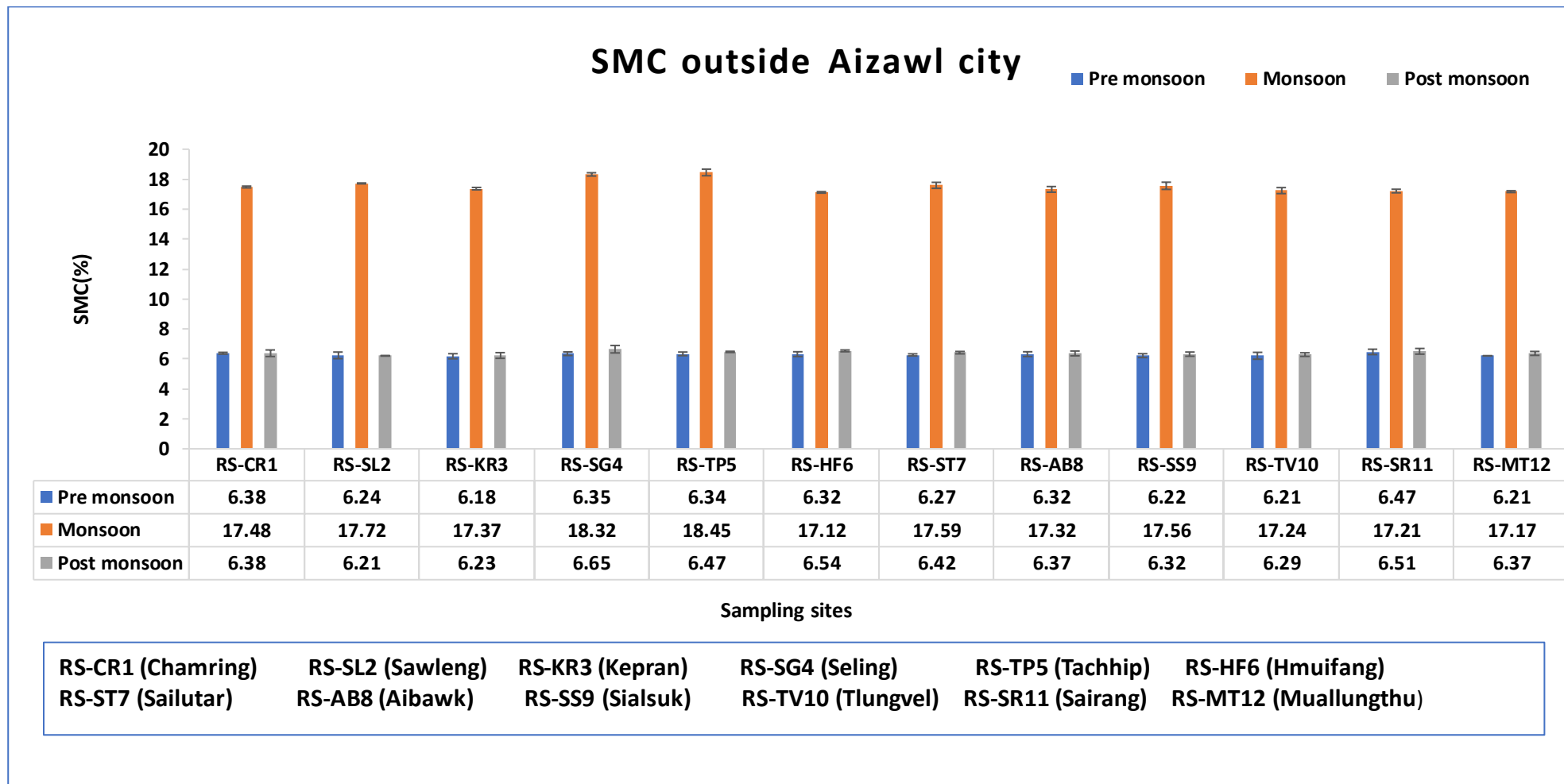


Fig. 4.1.2b: SMC (%) of the roadside soil outside Aizawl.

Table 4.1.2c. Anova table showing significant variation of SMC within Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f - crit</i>
Within Aizawl	139.686	2.000	69.843	111.345	0.009	19.000
Outside Aizawl	4.018	1.000	4.018	6.406	0.127	18.513
Error	1.255	2.000	0.627			
Total	144.958	5.000				

Table 4.1.2d. Correlation between rainfall and air temperature with SMC values within and outside Aizawl city.

	Rainfall	Temperature	SMC Within Aizawl city	SMC Outside Aizawl city
Rainfall	1	0.861	0.997	0.821
Air Temperature	-	1	0.997	0.822
SMC Within Aizawl city	-	-	1	0.999
SMC Outside Aizawl city		-	-	1

Table 4.1.2e. Mean SMC (%) with standard deviation of the sites and different seasons within Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-KK1 (Kulikawn)	5.28 ± 0.34	14.94 ± 0.62	5.26 ± 0.20
RS-VK2 (Vaivakawn)	5.22 ± 0.30	14.28 ± 0.41	5.21 ± 0.23
RS-SK3 (Sikulpuikawn)	5.28 ± 0.23	14.57 ± 0.00	5.31 ± 0.06
RS-BV4 (Bethlehem Vengthlang)	5.24 ± 0.03	14.27 ± 0.22	5.34 ± 0.23
RS-BB5 (Bazar Bungkawn)	5.32 ± 0.08	14.54 ± 0.35	5.82 ± 0.23
RS-LT6 (Laipuitlang)	5.38 ± 0.01	14.85 ± 0.04	5.58 ± 0.10
RS-TS7 (Temple Square)	5.21 ± 0.04	14.78 ± 0.42	5.29 ± 0.25
RS-RN8 (Ramhlun)	5.29 ± 0.33	14.81 ± 0.28	5.38 ± 0.27
RS-CK9 (Chanmari kawn)	5.27 ± 0.00	14.49 ± 0.08	5.42 ± 0.08
RS-BK10 (Bawngkawn)	5.36 ± 0.28	14.53 ± 0.38	5.48 ± 0.31
RS-CO11 (Mineco)	5.35 ± 0.10	14.62 ± 0.16	5.51 ± 0.13
RS-KT12 (Khatla kawn)	5.35 ± 0.27	14.72 ± 0.20	5.29 ± 0.07

Table 4.1.2f. Mean SMC (%) with standard deviation of the sites and different seasons outside Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-CR1 (Chamring)	6.38 ± 0.08	17.48 ± 0.08	6.38 ± 0.31
RS-SL2 (Sawlung)	6.24 ± 0.30	17.72 ± 0.04	6.21 ± 0.03
RS-KR3 (Kepran)	6.18 ± 0.24	17.37 ± 0.11	6.23 ± 0.27
RS-SG4 (Seiling)	6.35 ± 0.17	18.32 ± 0.16	6.65 ± 0.35
RS-TP5 (Tachhip)	6.34 ± 0.17	18.45 ± 0.31	6.47 ± 0.06
RS-HF6 (Hmuifang)	6.32 ± 0.22	17.12 ± 0.07	6.54 ± 0.08
RS-ST7 (Sailutar)	6.27 ± 0.11	17.59 ± 0.28	6.42 ± 0.11
RS-AB8 (Aibawk)	6.32 ± 0.22	17.32 ± 0.27	6.37 ± 0.23
RS-SS9 (Sialsuk)	6.22 ± 0.18	17.56 ± 0.34	6.32 ± 0.20
RS-TV10 (TlungvelP)	6.21 ± 0.32	17.24 ± 0.28	6.29 ± 0.17
RS-SR11 (Sairang)	6.47 ± 0.25	17.21 ± 0.17	6.51 ± 0.27
RS-MT12 (Muallungthu)	6.21 ± 0.02	17.17 ± 0.08	6.37 ± 0.18

4.1.3. SOC

The SOC values of the selected sites during the study period 2020-2022 are plotted in Fig. 4.1.3a. and 4.1.3b. for different sites in Aizawl city and outside Aizawl city for three seasons (pre-monsoon, monsoon, post-monsoon) respectively.

Within Aizawl city, SOC of roadside soil within Aizawl city showed significant variation over the seasons ($p < 0.001$). The SOC ranges from $5.21 \pm 0.04\%$ and $14.94 \pm 0.62\%$. The site RS-LT6 showed maximum pH with $5.38 \pm 0.01\%$ and minimum in RS-TS7 with the value of $5.21 \pm 0.04\%$ during pre-monsoon season. In the monsoon season maximum was recorded in RS-KK1 with the value of 14.94 ± 0.62 and minimum in RS-BV4 with the value of $14.27 \pm 0.22\%$. During post-monsoon season maximum was recorded in RS-LT6 with the value of $5.58 \pm 0.10\%$ and minimum in RS-VK2 with the value of $5.21 \pm 0.23\%$ (Table 4.1.1g)

Outside Aizawl city, the SOC of roadside showed significant variation within the seasons ($P < 0.001$). The SOC ranges from $6.18 \pm 0.24\%$ to $18.45 \pm 0.31\%$. The site RS-SR11 showed maximum SOC with $6.47 \pm 0.25\%$ and minimum in RS-KR3 with the value of $6.18 \pm 0.24\%$ during pre-monsoon season. In the monsoon season maximum was recorded in RS-TP5 with the value of $18.45 \pm 0.31\%$ and minimum in RS-HF6 with the value of $17.12 \pm 0.07\%$. During post-monsoon season maximum was recorded in RS-SG4 with the value of $6.65 \pm 0.35\%$ and minimum in RS-SL2 with the value of $6.21 \pm 0.03\%$.

As seen in Fig. 4.1.3b. SOC content is generally lower across most sites during the monsoon season and increase during pre-monsoon and post-monsoon season within Aizawl city. SOC is one of important indicators in assessing physical properties and fertility of soil with determining infiltration process (Tongway and Hindley., 2004; Dalal, 2007). These trends suggest that SOC levels are mostly lower during the monsoon season, possibly as high precipitation in monsoon season can lead to increased leaching which reduce SOC levels. This aligns with Salonen et al., (2024), which stated that climate, including precipitation, significantly affects SOC content. Fig. 4.1.3b. shows that SOC content at various sampling sites outside Aizawl (RS-CK1

to RS-MT12) across the same seasons. The SOC values are almost identical at various places except at RS-KR3 (1.02%).

The SOC level was higher outside Aizawl city and inside the city (Table 4.1.3e and 4.1.3f) when the SOC among the seasons was compared. SOC is usually higher in rural areas of Aizawl city as compared to its urban counterparts. As reported by Wang et al., (2024) and Chen et al., (2024), the higher SOC stock in the city compared to outside may result from the decrease of runoff and the presence of organic matter derived from decaying plant residues and urban waste, typical features of urban areas. During the pre-monsoon stage, the SOC value continued to decrease, although still higher compared to the monsoon season, indicating that organic matter might become more stabilized in the soil as the environment gets drier, with a consequential decrease in SOC leaching. The SOC stock can be significantly influenced by urban infrastructure and activity (Wang et al., 2024). Deb et al., (2024) reported that road-deposited sediments are greatly influenced by traffic, which leads to variation in SOC content.

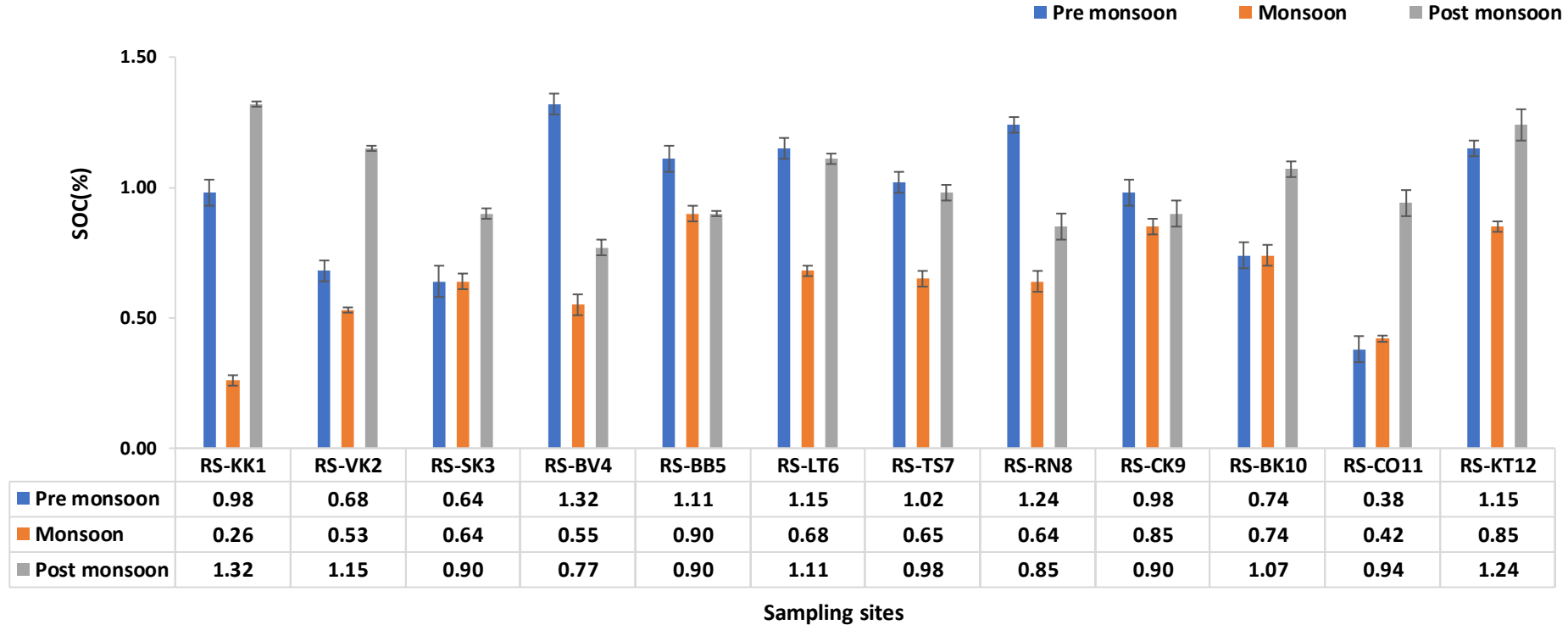
Table 4.1.3a. Anova table showing significant variation of SOC within season inside Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	0.546	11.000	0.050	1.077	0.421	2.259
Between the season	0.934	2.000	0.467	10.137	0.001	3.443
Error	1.014	22.000	0.046			
Total	2.493	35.000				

Table 4.1.3b. Anova table showing significant variation of SOC within sites outside Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	0.632	11.000	0.057	11.360	0.001	2.259
Between the season	0.004	2.000	0.002	0.397	0.677	3.443
Error	0.111	22.000	0.005			
Total	0.748	35.000				

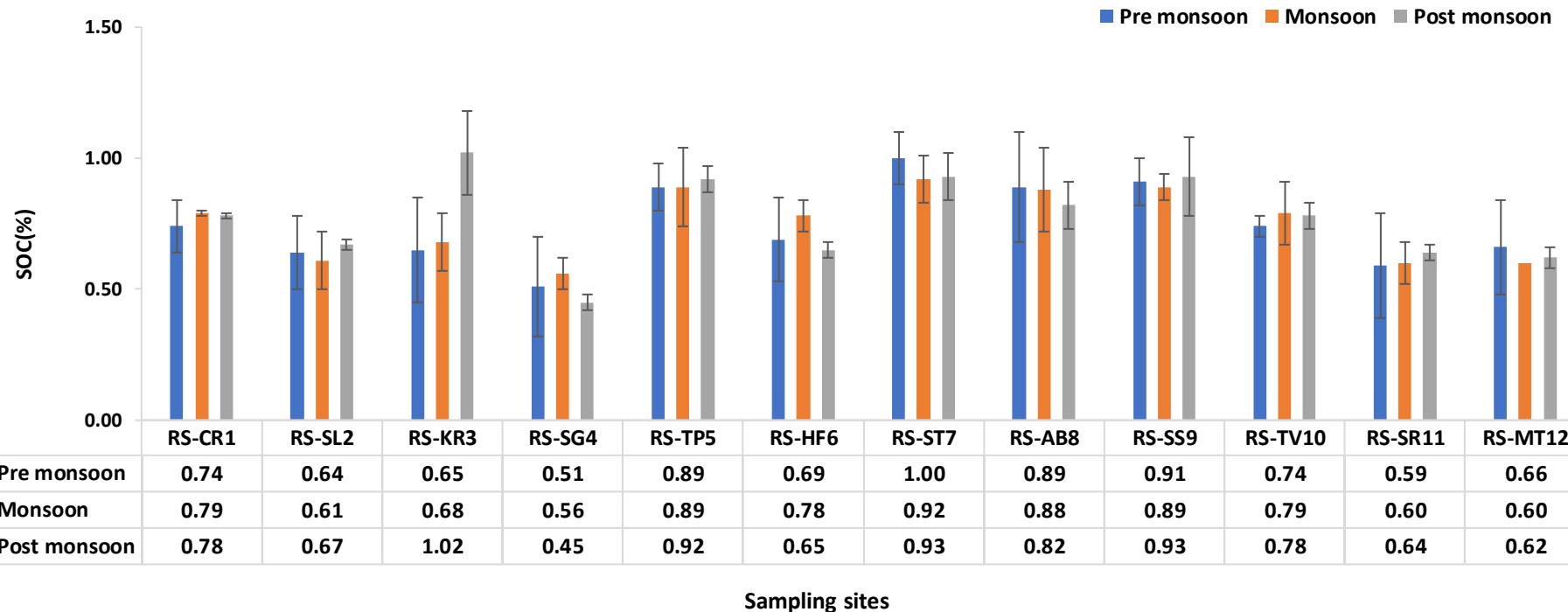
SOC value within Aizawl City



RS-KK1(Kulikawn) RS-VK2 (Vaivakawn) RS-SK3 (Sikulpuikawn) RS-BV4 (Bethlehem Vengthlang) RS-BB5 (Bazar Bungkawn) RS-LT6 (Laipuitlang)
 RS-TS7 (Temple Square) RS-RN8 (Ramhlun) RS-CK9 (Chanmari kawn) RS-BK10 (Bawngkawn) RS-CO11 (MINECO) RS-KT12 (Khatla)

Fig. 4.1.3a. SOC (%) of the roadside soil within Aizawl.

SOC value outside Aizawl City



RS-CR1 (Chamring)	RS-SL2 (Sawlung)	RS-KR3 (Kepran)	RS-SG4 (Seling)	RS-TP5 (Tachhip)	RS-HF6 (Hmuifang)
RS-ST7 (Sailutar)	RS-AB8 (Aibawk)	RS-SS9 (Sialsuk)	RS-TV10 (Tlungvel)	RS-SR11 (Sairang)	RS-MT12 (Muallungthu)

Fig. 4.1.3b. SOC (%) of the roadside soil outside Aizawl city.

Table 4.1.3c. Correlation between rainfall, air temperature and SOC values within and outside Aizawl city.

	Rainfall	Temperature	SOC Within Aizawl city	SOC Outside Aizawl city
Rainfall	1	0.861	-0.996	-0.902
Air Temperature	-	1	-0.251	-0.708
SOC Within Aizawl city	-	-	1	0.335
SOC Outside Aizawl city	-	-	-	1

Table 4.1.3e. Mean value of SOC (%) values with standard deviation of the sites and seasons within Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-KK1 (Kulikawn)	0.98 ± 0.09	0.26 ± 0.10	1.32 ± 0.10
RS-VK2 (Vaivakawn)	0.68 ± 0.17	0.53 ± 0.16	1.15 ± 0.01
RS-SK3 (Sikulpuikawn)	0.64 ± 0.23	0.64 ± 0.21	0.90 ± 0.15
RS-BV4 (Bethlehem Vengthlang)	1.32 ± 0.11	0.55 ± 0.24	0.77 ± 0.13
RS-BB5 (Bazar Bungkawn)	1.11 ± 0.16	0.90 ± 0.14	0.90 ± 0.23
RS-LT6 (Laipuitlang)	1.15 ± 0.18	0.68 ± 0.16	1.11 ± 0.10
RS-TS7 (Temple Square)	1.02 ± 0.16	0.65 ± 0.16	0.98 ± 0.18
RS-RN8 (Ramhlun)	1.24 ± 0.17	0.64 ± 0.04	0.85 ± 0.15
RS-CK9 (Chanmari kawn)	0.98 ± 0.04	0.85 ± 0.16	0.90 ± 0.16
RS-BK10 (Bawngkawn)	0.74 ± 0.07	0.74 ± 0.18	1.07 ± 0.13
RS-CO11 (Mineco)	0.38 ± 0.10	0.42 ± 0.20	0.94 ± 0.13
RS-KT12 (Khatla kawn)	1.15 ± 0.14	0.85 ± 0.16	1.24 ± 0.11

Table 4.1.3f. Mean value of SOC (%) values with standard deviation of the sites and seasons outside Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-CR1 (Chamring)	0.74 ± 0.14	0.79 ± 0.01	0.78 ± 0.11
RS-SL2 (Sawleng)	0.64 ± 0.20	0.61 ± 0.16	0.67 ± 0.03
RS-KR3 (Kepran)	0.65 ± 0.28	0.68 ± 0.16	1.02 ± 0.22
RS-SG4 (Seiling)	0.51 ± 0.26	0.56 ± 0.08	0.45 ± 0.04
RS-TP5 (Tachhip)	0.89 ± 0.13	0.89 ± 0.21	0.92 ± 0.07
RS-HF6 (Hmuifang)	0.69 ± 0.23	0.78 ± 0.08	0.65 ± 0.04
RS-ST7 (Sailutar)	1.00 ± 0.14	0.92 ± 0.13	0.93 ± 0.13
RS-AB8 (Aibawk)	0.89 ± 0.30	0.88 ± 0.13	0.82 ± 0.13
RS-SS9 (Sialsuk)	0.91 ± 0.13	0.89 ± 0.23	0.93 ± 0.21
RS-TV10 (TlungvelP)	0.74 ± 0.06	0.79 ± 0.07	0.78 ± 0.07
RS-SR11 (Sairang)	0.59 ± 0.28	0.60 ± 0.17	0.64 ± 0.04
RS-MT12 (Muallungthu)	0.66 ± 0.25	0.60 ± 0.11	0.62 ± 0.06

4.1.4. TN

The TN values of the selected sites plotted against the data for the period of Study (2020-2022) for Fig. 4.1.4a and 4.1.4b shows for different sources of monitoring inside Aizawl city and outside Aizawl city for Pre-Monsoon, Monsoon and Post Monsoon seasons.

Outside Aizawl city, the soil of roadside showed significant variation within the sites ($p < 0.001$; Table 4.1.4a). The TN varies from $0.08 \pm 0.01\%$ to $1.12 \pm 0.48\%$. The site RS-C011 displayed highest TN during pre-monsoon season ($1.12 \pm 0.48\%$) and lowest in RS-KK1 ($0.08 \pm 0.01\%$). In the monsoon season maximum was observed in RS-SK3 with $1.40 \pm 0.07\%$ and minimum in RS-BB5 and RS-CK9 with $0.60 \pm 0.04\%$. In the post-monsoon the highest was observed in RS-LT6 ($1.50 \pm 0.07\%$) and lowest in RS-CK9 ($0.50 \pm 0.04\%$).

The soil of roadside outside Aizawl city differed significantly among the sites ($p < 0.001$). The TN varies 1.00 ± 0.00 to $1.8 \pm 0.07\%$. Site RS-SG4 demonstrated highest TNC ($1.70 \pm 0.57\%$) and lowest value was recorded in RS-SL2 ($1.00 \pm 0.21\%$) in pre-monsoon season. The highest percentage was found in RS-SG4 ($1.80 \pm 0.14\%$) and the lowest percentage in RS-CR1 ($1.00 \pm 0.00\%$) during the monsoon season. Maximum was observed during post-monsoon season in RS-ST7 ($1.80 \pm 0.07\%$) and minimum in RS-SL2 ($1.10 \pm 0.07\%$).

From Fig. 4.1.4a and Fig. 4.1.4b, among all the season both within and outside Aizawl city, monsoon mostly has higher TN level as compared with other season. Studies shows that, due to increased rainfall leading to greater nitrogen deposition and runoff, which aligns with the findings of Hao et al., (2023) who reported that wet seasons contribute significantly to nitrogen fluxes. Which is seen from the correlation of rainfall with TN by taking average of the three seasons also showed support of a positive correlation ($r = 0.86$, $r = 0.99$) (Table 4.1.4.b).

TN was higher outside Aizawl city when compared to the sites and the seasons within Aizawl City. It is quite evident from the figure that TNs are high outside Aizawl in comparison to the city. As reported by Peng et al., (2024) the fate of pollutants interacting with the road side-sediments is very much depending on environmental conditions such as pH and intensity of rainfall, which may be quite different between urban and non-urban areas. These conditions affect the concentration and mobility of pollutants like heavy metals in road-deposited sediments. Understanding these variations is crucial for analysing pollution dynamics in regions like Aizawl, where such environmental conditions are pronounced.

Table 4.1.4a. Anova table showing significant variation of TN within sites and seasons inside Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f- crit
Between the sites	3.170	11.000	0.288	12.232	0.001	2.259
Between the season	0.016	2.000	0.008	0.330	0.722	3.443
Error	0.518	22.000	0.024			
Total	3.704	35.000				

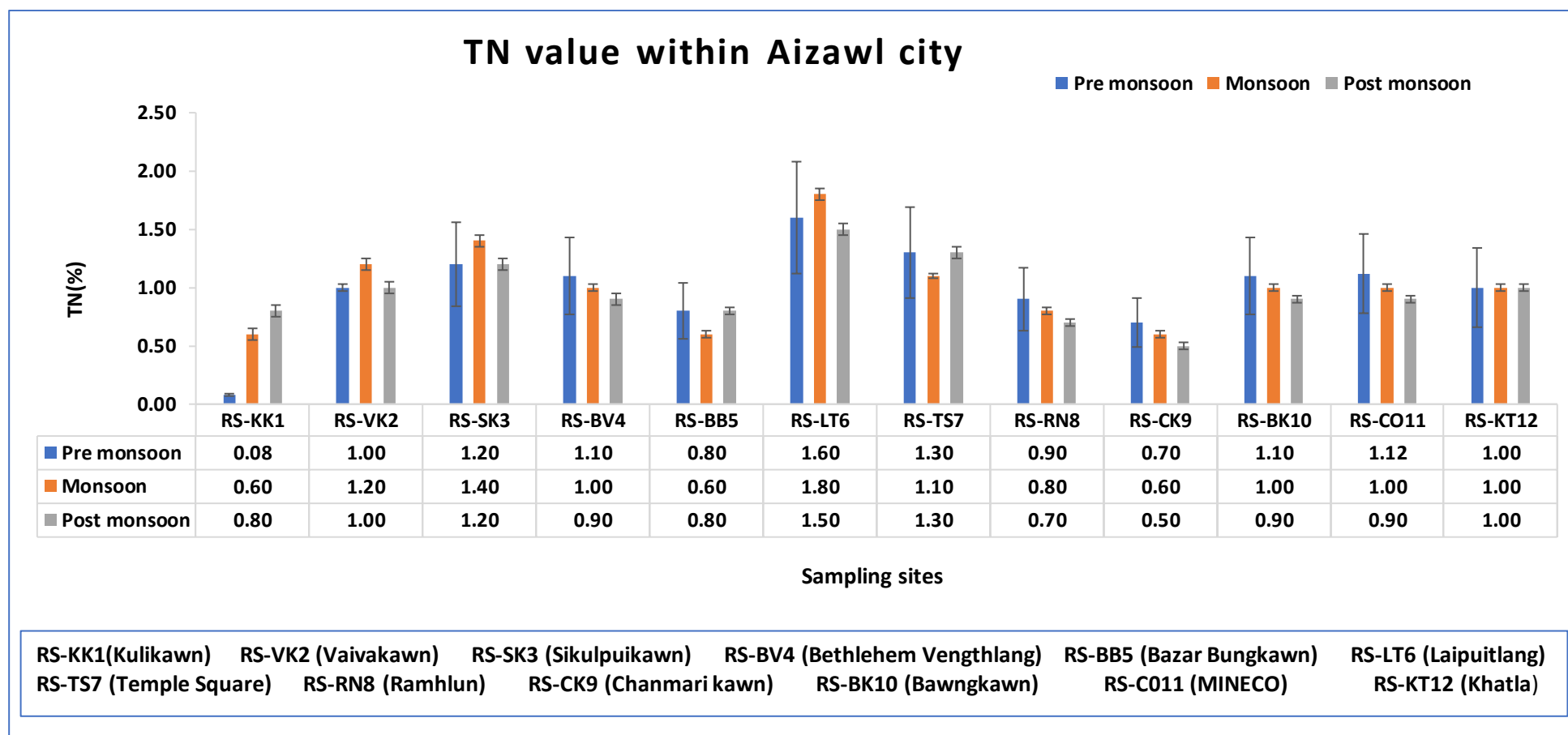


Fig. 4.1.4a. TNC of the selected roadside soil within Aizawl.

TN value within Aizawl City

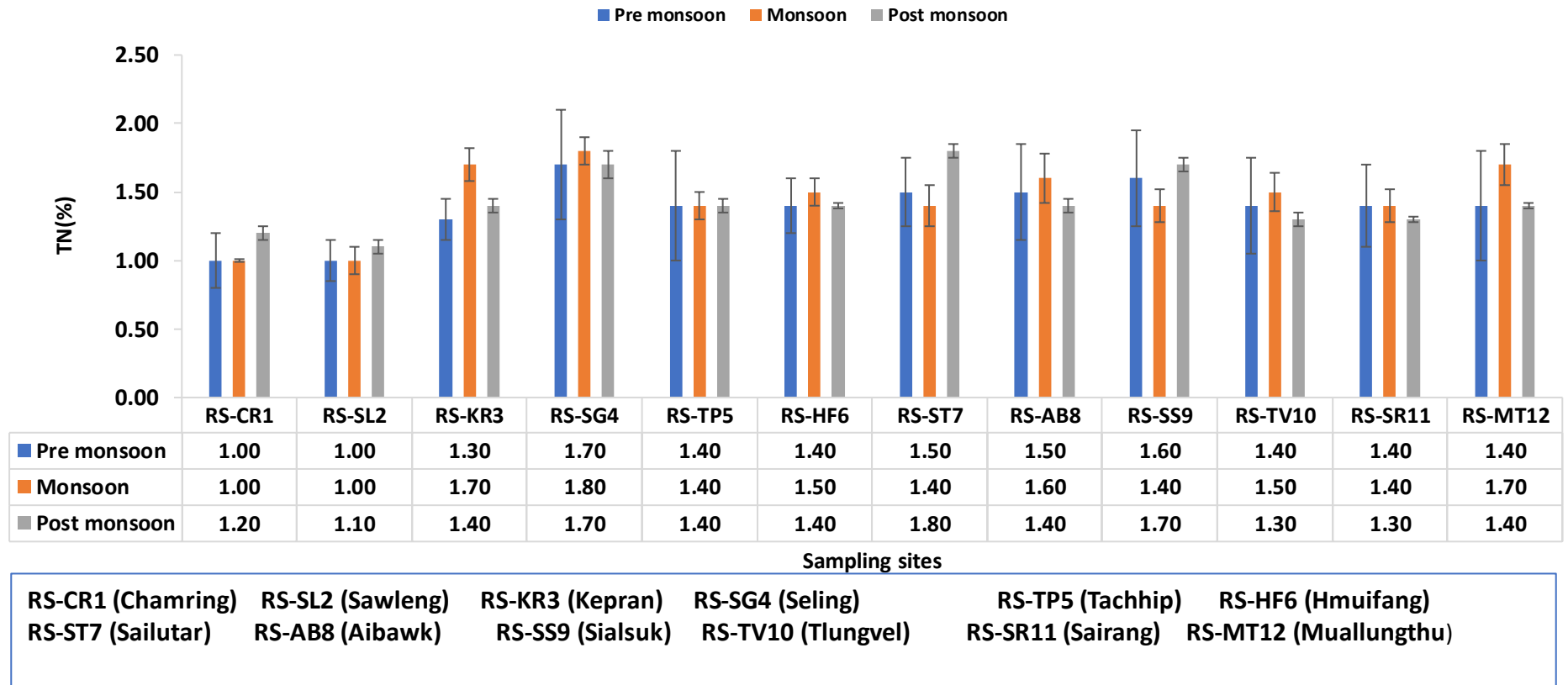


Fig. 4.1.4b. TN of the roadside soil outside Aizawl city

Table 4.1.4b. Correlation between rainfall, air temperature and TN values within and outside Aizawl city.

	<i>Rainfall</i>	<i>Temperature</i>	<i>TN Within Aizawl city</i>	<i>TN Outside Aizawl city</i>
Rainfall	1	0.861	0.839	0.999
Temperature	-	1	0.998	0.827
TN Within Aizawl city	-	-	1	0.803
TN Outside Aizawl city	-	-	-	1

Table 4.1.4c. Mean value of TN (%) values with standard deviation of the sites and season within Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-KK1 (Kulikawn)	0.08 ± 0.01	0.60 ± 0.07	0.80 ± 0.07
RS-VK2 (Vaivakawn)	1.00 ± 0.42	1.20 ± 0.07	1.00 ± 0.07
RS-SK3 (Sikulpuikawn)	1.20 ± 0.51	1.40 ± 0.07	1.20 ± 0.07
RS-BV4 (Bethlehem Vengthlang)	1.10 ± 0.47	1.00 ± 0.04	0.90 ± 0.07
RS-BB5 (Bazar Bungkawn)	0.80 ± 0.34	0.60 ± 0.04	0.80 ± 0.04
RS-LT6 (Laipuitlang)	1.60 ± 0.68	1.80 ± 0.07	1.50 ± 0.07
RS-TS7 (Temple Square)	1.30 ± 0.55	1.10 ± 0.04	1.30 ± 0.07
RS-RN8 (Ramhlun)	0.90 ± 0.38	0.80 ± 0.04	0.70 ± 0.04
RS-CK9 (Chanmari kawn)	0.70 ± 0.30	0.60 ± 0.04	0.50 ± 0.04
RS-BK10 (Bawngkawn)	1.10 ± 0.47	1.00 ± 0.04	0.90 ± 0.04
RS-CO11 (Mineco)	1.12 ± 0.48	1.00 ± 0.04	0.90 ± 0.04
RS-KT12 (Khatla kawn)	1.00 ± 0.42	1.00 ± 0.04	1.00 ± 0.04

Table 4.1.4d. Mean value of TN (%) with standard deviation of the sites and season within Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-CR1 (Chamring)	1.00 ± 0.28	1.00 ± 0.00	1.20 ± 0.07
RS-SL2 (Sawleng)	1.00 ± 0.21	1.00 ± 0.14	1.10 ± 0.07
RS-KR3 (Kepran)	1.30 ± 0.21	1.70 ± 0.16	1.40 ± 0.07
RS-SG4 (Seiling)	1.70 ± 0.57	1.80 ± 0.14	1.70 ± 0.14
RS-TP5 (Tachhip)	1.40 ± 0.57	1.40 ± 0.15	1.40 ± 0.07
RS-HF6 (Hmuifang)	1.40 ± 0.28	1.50 ± 0.13	1.40 ± 0.03
RS-ST7 (Sailutar)	1.50 ± 0.35	1.40 ± 0.14	1.80 ± 0.07
RS-AB8 (Aibawk)	1.50 ± 0.49	1.60 ± 0.14	1.40 ± 0.08
RS-SS9 (Sialsuk)	1.60 ± 0.49	1.40 ± 0.16	1.70 ± 0.06
RS-TV10 (TlungvelP)	1.40 ± 0.49	1.50 ± 0.15	1.30 ± 0.08
RS-SR11 (Sairang)	1.40 ± 0.42	1.40 ± 0.14	1.30 ± 0.03
RS-MT12 (Muallungthu)	1.40 ± 0.557	1.70 ± 0.14	1.40 ± 0.03

4.1.5. AP

AP values of the aforementioned selected sites for the period 2020-2022 are depicted in the respective sites of Aizawl city and outsides-Aizawl city for the three different seasons (pre-monsoon, monsoon and post-monsoon) in Fig. 4.1.5a and 4.1.5b respectively.

In Aizawl city, the intra-site variation for AP values was highly significant ($P < 0.001$). AP of the response varies from 0.11 ± 0.13 kg/ha to 1.65 ± 0.05 kg/ha. The P values were the highest at the site RS-CK9 (1.61 ± 0.05 kg/ha) and the lowest at the site RS-SK3 (0.29 ± 0.13 kg/ha) during pre-monsoon season. During the monsoon maximum was observed in RS-CK9 and the minimum was measured in RS-SK3 with the values of 1.54 ± 0.05 kg/ha and 0.11 ± 0.13 kg/ha, respectively. The maximum was observed during post-monsoon season in RS-CK9 with the value of 1.65 ± 0.05 kg/ha and this value of minimum in RS-SK3 with 0.21 ± 0.13 kg/ha (Table 4.1.5c).

Outside Aizawl city, the AP values of roadside showed significant variation within the sites ($p < 0.001$). The AP values vary between 0.82 ± 0.35 to 4.21 ± 0.78 kg/ha. The site RS-SS9 had highest AP values 4.09 ± 1.74 kg/ha, and lowest was in RS-KR3 - 0.82 ± 0.35 kg/ha in pre-monsoon season. In monsoon season, highest was observed in RS-SS9 with value as 4.21 ± 1.78 kg/ha maximum and in RS-SG4 minimum as 0.87 ± 0.37 kg/ha. In post-monsoon season maximum was observed in RS-SL2 (4.21 ± 0.78 kg/ha) and minimum in RS-SG4 (0.91 ± 0.38 kg/ha) (Table 4.1.5. d).

As seen in Fig. 4.1.5a and Fig. 4.1.5b, this figure highlights the large difference in AP between the soils inside and outside Aizawl with much higher values outside Aizawl for all the three seasons. The relationship of rainfall with AP by talking average of the three seasons confirmed a negative association ($r = -0.99$, $r 0.82$) (Table 4.1.5d)

By comparing the AP values among the seasons within Aizawl city and outside Aizawl city a significant higher level was recorded outside Aizawl city ($p < 0.001$; Table 4.1.5c). The AP value is generally higher in rural areas outside Aizawl compared to urban areas within the city. As urban areas are susceptible to phosphorus fluctuations due to the influence of road-deposited sediments and urban runoff, which are significant sources of phosphorus during dry periods (Chen et al., 2024). Outside urban areas, agricultural runoff and decay organic matters play more prominent role, maintaining higher phosphorus levels across seasons (Hashar and Nasrin., 2024).

Table 4.1.5a. Anova table showing significant variation of AP within sites inside Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	3.170	11.000	0.288	12.232	0.000	2.259
Between the season	0.016	2.000	0.008	0.330	0.722	3.443
Error	0.518	22.000	0.024			
Total	3.704	35.000				

Table 4.1.5b. Anova table showing significant variation of AP within sites outside Aizawl city

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	1.303	11.000	0.118	7.530	0.000	2.259
Within the season	0.027	2.000	0.014	0.865	0.435	3.443
Error	0.346	22.000	0.016			
Total	1.676	35.000				

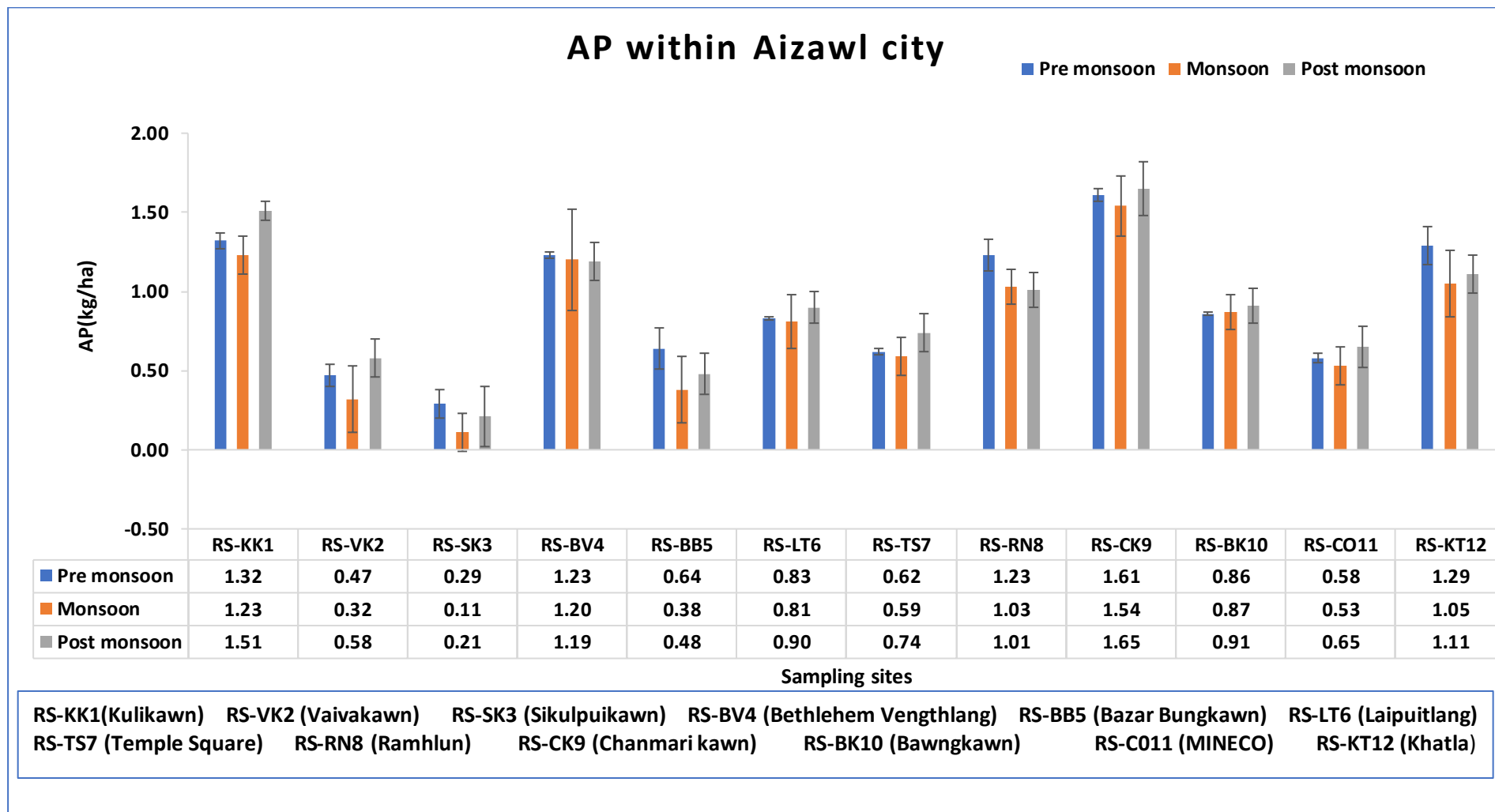


Fig. 5.1.5a. AP of the roadside soil within Aizawl.

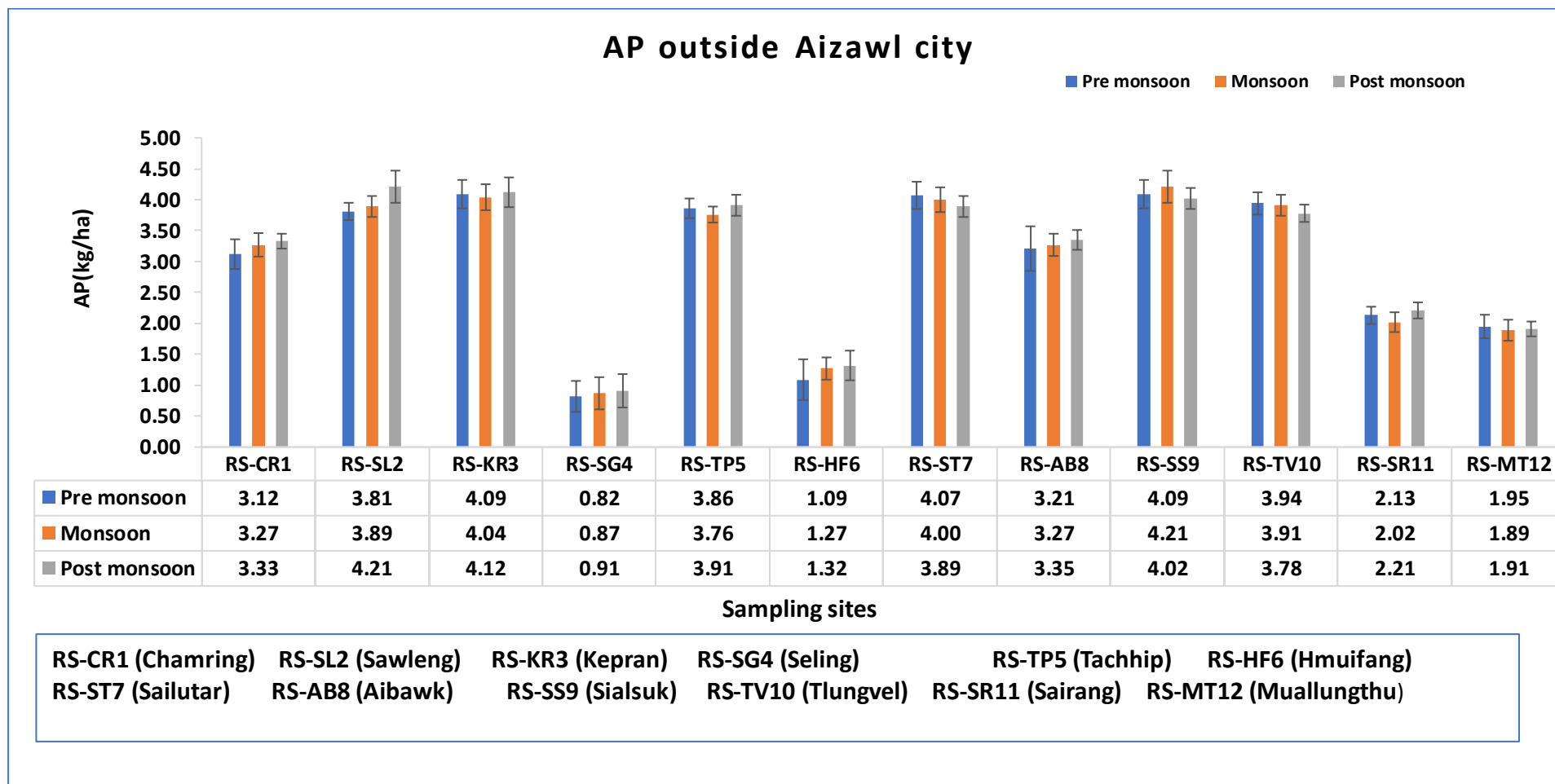


Fig. 5.1.5b. AP values of the roadside soil outside Aizawl city.

Table 4.1.5c. Anova table showing significant variation of AP outside Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Within Aizawl	0.006	2	0.003	1.879	0.347	19
Outside Aizawl	7.042	1	7.042	4642.857	0.001	18.513
Error	0.003	2	0.002			
Total	7.050	5				

Table 4.1.5d. Correlation between rainfall, air temperature and AP values within and outside Aizawl city.

	Rainfall	Temperature	AP Within Aizawl city	AP Outside Aizawl city
Rainfall	1	0.861	-0.998	-0.827
Temperature		1	-0.418	-0.822
AP Within Aizawl city			1	0.359
AP Outside Aizawl city				1

Table 4.1.5e. Mean value of AP (kg/ha) with standard deviation of the sites and season within Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-KK1 (Kulikawn)	1.32 ± 0.06	1.23 ± 0.06	1.51 ± 0.06
RS-VK2 (Vaivakawn)	0.47 ± 0.11	0.32 ± 0.11	0.58 ± 0.11
RS-SK3 (Sikulpuikawn)	0.29 ± 0.13	0.11 ± 0.13	0.21 ± 0.13
RS-BV4 (Bethlehem Vengthlang)	1.23 ± 0.02	1.2 ± 0.02	1.19 ± 0.02
RS-BB5 (Bazar Bungkawn)	0.64 ± 0.18	0.38 ± 0.18	0.48 ± 0.18
RS-LT6 (Laipuitlang)	0.83 ± 0.01	0.81 ± 0.01	0.9 ± 0.01
RS-TS7 (Temple Square)	0.62 ± 0.02	0.59 ± 0.02	0.74 ± 0.02
RS-RN8 (Ramhlun)	1.23 ± 0.14	1.03 ± 0.14	1.01 ± 0.14
RS-CK9 (Chanmari kawn)	1.61 ± 0.05	1.54 ± 0.05	1.65 ± 0.05
RS-BK10 (Bawngkawn)	0.86 ± 0.01	0.87 ± 0.01	0.91 ± 0.01
RS-CO11 (Mineco)	0.58 ± 0.04	0.53 ± 0.04	0.65 ± 0.04
RS-KT12 (Khatla kawn)	1.29 ± 0.17	1.05 ± 0.17	1.11 ± 0.17

Table 4.1.5f. Mean value of AP (kg/ha) with standard deviation of the sites and season outside Aizawl city

Site	Pre monsoon	Monsoon	Post monsoon
RS-CR1 (Chamring)	3.12 ± 1.33	3.27 ± 1.39	3.33 ± 1.41
RS-SL2 (Sawlung)	3.81 ± 1.61	3.89 ± 1.65	4.21 ± 1.78
RS-KR3 (Kepran)	4.09 ± 1.74	4.04 ± 1.71	4.12 ± 1.75
RS-SG4 (Seiling)	0.82 ± 0.35	0.87 ± 0.37	0.91 ± 0.38
RS-TP5 (Tachhip)	3.86 ± 1.64	3.76 ± 1.60	3.91 ± 1.65
RS-HF6 (Hmuifang)	1.09 ± 0.47	1.27 ± 0.54	1.32 ± 0.57
RS-ST7 (Sailutar)	4.07 ± 1.73	4.00 ± 1.70	3.89 ± 1.65
RS-AB8 (Aibawk)	3.21 ± 1.36	3.27 ± 1.39	3.35 ± 1.42
RS-SS9 (Sialsuk)	4.09 ± 1.74	4.21 ± 1.78	4.02 ± 1.71
RS-TV10 (TlungvelP)	3.94 ± 1.67	3.91 ± 1.65	3.78 ± 1.60
RS-SR11 (Sairang)	2.13 ± 0.91	2.02 ± 0.86	2.21 ± 0.93
RS-MT12 (Muallungthu)	1.95 ± 0.83	1.89 ± 0.81	1.91 ± 0.81

4.1.6. AK

The AK values of these sites for the study period 2020-2022 are shown in Fig. 4.1.6a, Fig. 4.1.6b for the samples from sites located within Aizawl city and those outside Aizawl city respectively for three seasons, pre-monsoon, monsoon and post-monsoon.

Within Aizawl city the AK values of roadside soil within Aizawl city showed significant variation within the sites ($p < 0.001$) and among season ($p < 0.012$). The AK values vary from 25.35 ± 3.04 to 87.24 ± 9.55 kg/ha. In pre-monsoon, peak AK values were recorded in RS-BV4 with 86.67 ± 9.01 and minimum in RS-CK9 with 25.35 ± 3.04 kg/ha. Maximum were observed in RS-BV4 and recorded as 87.24 ± 9.55 kg/ha while minimum were in RS-TS7 and 34.24 ± 5.85 kg/ha in monsoon season. In the monsoon season maximum was recorded in RS-BV4 (86.94 ± 11.51 kg/ha) during post-monsoon season and minimum was recorded in RS-TS7 (33.86 ± 6.17 kg/ha) during the post-monsoon season (Table 4.1.6e).

Outside Aizawl city, the AK of roadside showed significant variation within the sites ($p < 0.001$). The AK varies from 54.37 ± 4.92 kg/ha to 100.89 ± 10.41 kg/ha. The site RS-ST7 showed maximum AK values of 100.89 ± 10.41 kg/ha and minimum in RS-SG4 (54.98 ± 6.87 kg/ha) in pre-monsoon season. During the monsoon, the maximum was observed for RS-AB8 (99.89 ± 4.63 kg/ha) and the lowest for RS-SG4 (54.37 ± 4.92 kg/ha). In post-monsoon season, maximum was recorded in RS-AB8 with the value of 98.21 ± 1.19 kg/ha and minimum in RS-SG4 with the value of 55.87 ± 1.06 kg/ha (Table 4.1.6f).

As seen in Fig. 4.1.6a. and Fig. 4.1.6b. among all the season both within and outside Aizawl city. The data reveals that AK levels are consistent during the pre-monsoon, monsoon, and post-monsoon seasons in almost all the selected sites. The AK levels is relatively lower at RS-SG4, RS-SR11, and RS-MT12 than the other sites outside Aizawl city however the data also shows notable fluctuations in K concentrations at different study sites, with the highest level achieved at RS-BV4 in the three seasons. It is seen that the AK values are significantly higher at most of the sampling sites outside Aizawl than in Aizawl. Potassium in soil exists as exchangeable and non-exchangeable forms that govern its availability and retention. Harpreet Kaur, (2019) discussed the various forms of potassium in soils, such as water-soluble, exchangeable, non-exchangeable, and mineral forms, and how these are influenced by soil properties like weathering and parent material. The dynamic equilibrium among these forms is essential for potassium availability. This is similar to the stable potassium levels observed in Aizawl, which can be attributed to specific soil properties.

By comparing the AK contents of Aizawl City and outside Aizawl city between the seasons, a significant higher level ($p < 0.002$) was observed for the latter, as given in Table 4.1.6.c. The correlation of rainfall with AK by taking average of the three seasons showed support of a positive correlation ($r = 0.68$ in Aizawl city and $r = 0.22$ outside Aizawl city (Table 4.1.6d).

Table 4.1.6a: Anova table showing significant variation of AK within sites and season inside Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	7036.234	11.000	639.658	34.030	0.001	2.259
Between the season	204.253	2.000	102.126	5.433	0.012	3.443
Error	413.525	22.000	18.797			
Total	7654.012	35.000				

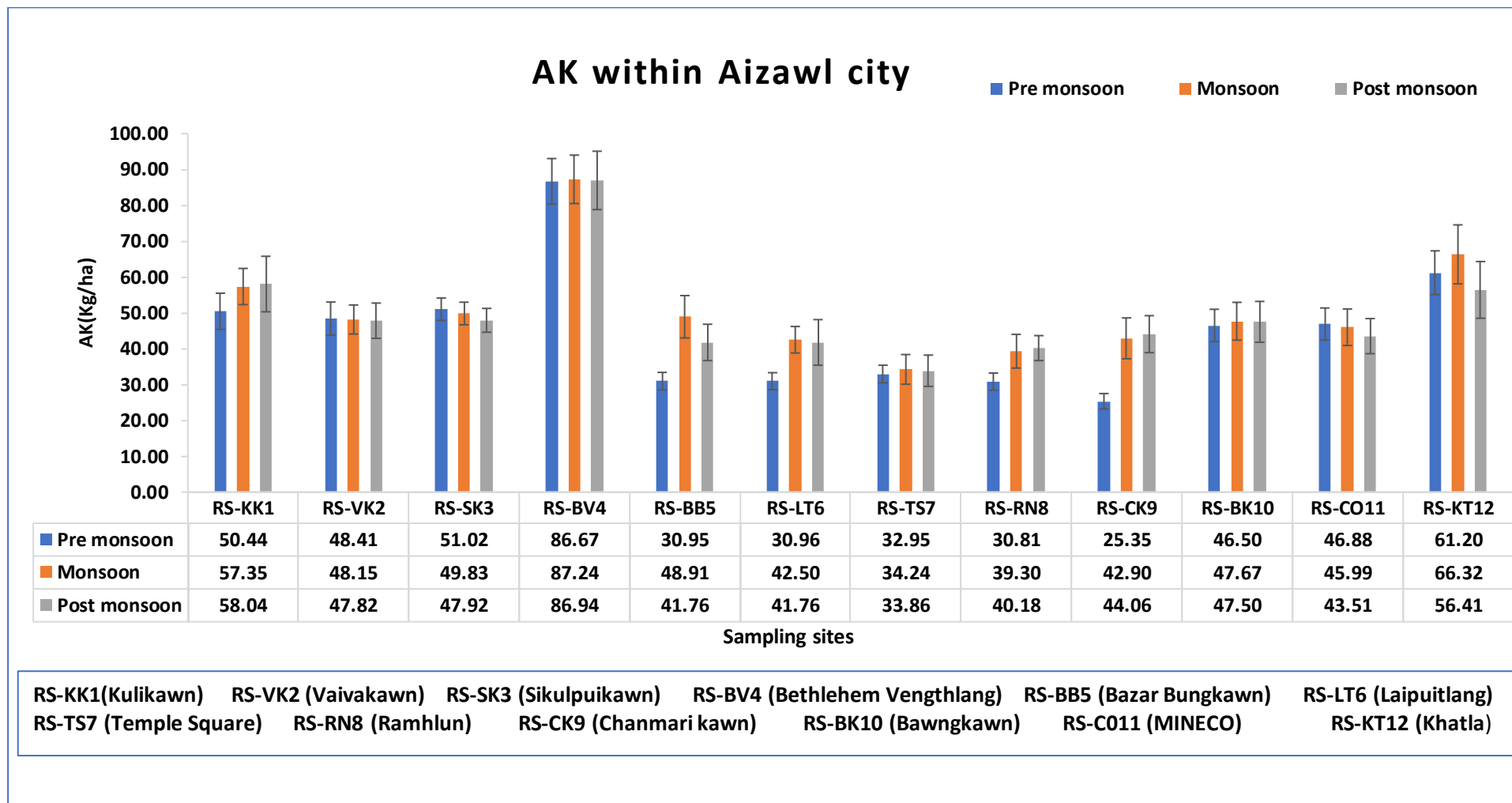


Fig. 4.1.16a. AK (kg/ha) of the roadside soil within Aizawl.

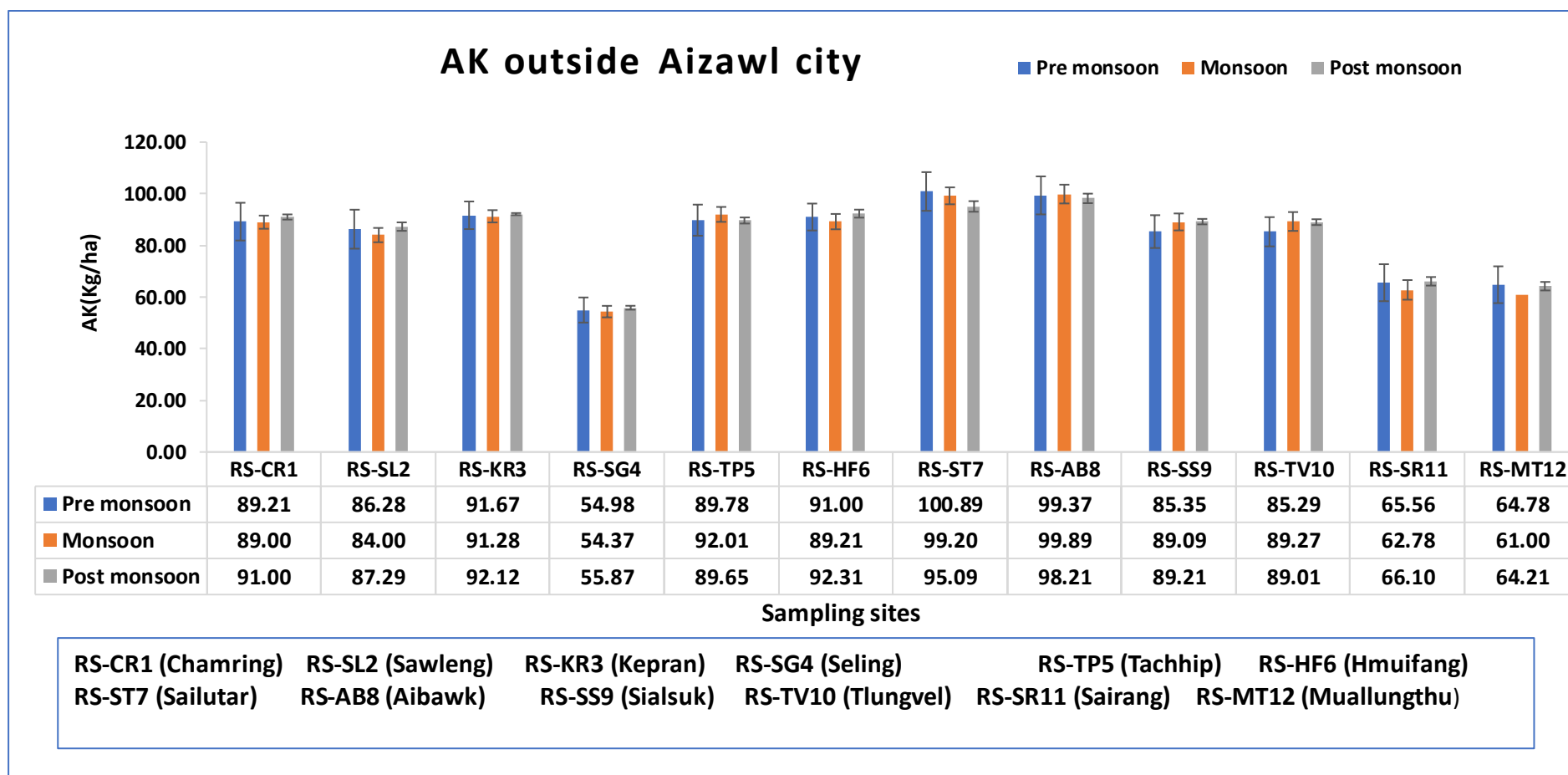


Fig. 4.1.6b. AK (kg/ha) content of the roadside soil outside Aizawl city.

Table 4.1.6b. Anova table showing significant variation of AK within sites outside Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	6847.646	11.000	622.513	201.507	0.001	2.259
Between the season	3.465	2.000	1.733	0.561	0.579	3.443
Error	67.964	22.000	3.089			
Total	6919.075	35.000				

Table 4.1.6c. Anova table showing significant variation of AK outside Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Within Aizawl	8.407	2	4.203	0.943	0.514	19
Outside Aizawl	1875.494	1	1875.494	421.099	0.002	18.512
Error	8.907	2	4.453			
Total	1892.81	5				

Table 4.1.6d. Correlation between rainfall, air temperature and AK values within and outside Aizawl city.

	<i>Rainfall</i>	<i>Temperature</i>	<i>AK Within Aizawl city</i>	<i>AK Outside Aizawl city</i>
Rainfall	1	0.861	0.688	0.224
Temperature		1	-0.799	-0.994
AK Within Aizawl city			1	-0.114
AK Outside Aizawl city				1

Table 4.1.6e. Mean value of AK (kg/ha) values with standard deviation of the sites and season within Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-KK1 (Kulikawn)	50.44 ± 7.13	57.35 ± 7.14	58.04 ± 10.95
RS-VK2 (Vaivakawn)	48.41 ± 6.52	48.15 ± 5.73	47.82 ± 6.96
RS-SK3 (Sikulpuikawn)	51.02 ± 4.41	49.83 ± 4.45	47.92 ± 4.70
RS-BV4 (Bethlehem Vengthlang)	86.67 ± 9.01	87.24 ± 9.55	86.94 ± 11.51
RS-BB5 (Bazar Bungkawn)	30.95 ± 3.46	48.91 ± 8.36	41.76 ± 7. 16
RS-LT6 (Laipuitlang)	30.96 ± 3.34	42.05 ± 5.23	41.76 ± 8.99
RS-TS7 (Temple Square)	32.95 ± 3.46	34.24 ± 5.85	33.86 ± 6.17
RS-RN8 (Ramhlun)	30.81 ± 3. 41	39.30 ± 6.65	40.18 ± 4.92
RS-CK9 (Chanmari kawn)	25.35 ± 3.04	42.90 ± 8.06	44.06 ± 7.30
RS-BK10 (Bawngkawn)	46.50 ± 6.36	47.67 ± 7.45	47.50 ± 8.06
RS-CO11 (Mineco)	46.88 ± 6.34	45.99 ± 7.20	43.51 ± 6.92
RS-KT12 (Khatla kawn)	61.20 ± 8.63	66.32 ± 11.62	56.41 ± 11.19

Table 4.1.6f. Mean value of AK (kg/ha) values with standard deviation of the sites and season outside Aizawl city.

Site	Pre monsoon	Monsoon	Post monsoon
RS-CR1 (Chamring)	89.21 ± 10.34	89.00 ± 3.61	91.00 ± 1.41
RS-SL2 (Sawlung)	86.28 ± 10.68	84.00 ± 3.92	87.29 ± 2.33
RS-KR3 (Kepran)	91.67 ± 7.57	91.28 ± 3.37	92.12 ± 0.59
RS-SG4 (Seiling)	54.98 ± 6.87	54.37 ± 4.92	55.87 ± 1.06
RS-TP5 (Tachhip)	89.78 ± 8.87	92.01 ± 3.15	89.65 ± 1.67
RS-HF6 (Hmuifang)	91.00 ± 7.37	89.21 ± 4.09	92.31 ± 2.19
RS-ST7 (Sailutar)	100.89 ± 10.59	99.20 ± 4.20	95.09 ± 2.91
RS-AB8 (Aibawk)	99.37 ± 10.41	99.89 ± 4.63	98.21 ± 1.19
RS-SS9 (Sialsuk)	85.35 ± 8.99	89.09 ± 5.15	89.21 ± 0.08
RS-TV10 (Tlungvel)	85.29 ± 8.01	89.27 ± 4.65	89.01 ± 0.18
RS-SR11 (Sairang)	65.56 ± 10.13	62.78 ± 5.16	66.10 ± 2.35
RS-MT12 (Muallungthu)	64.78 ± 10.07	61.00 ± 5.37	64.21 ± 2.27

4.2. Heavy Metal Concentration In Roadside Soil.

The following sections provide detailed information on the average concentrations of various metals, specifically Cu, Fe, Mn, Ni, Pb and Zn. The findings indicate that the mean concentrations of these metals in roadside soils are significantly higher than the established average background levels typically found in unpolluted areas. The average background values (ABVs) for Cu, Fe, Mn, Ni, Pb, and Zn are 0.24 ppm, 12 ppm, 1.50 ppm, 0.14 ppm, 0.14 ppm, and 0.49 ppm, respectively. However, the study reveals that the concentrations of these metals across all examined sites significantly exceed these baseline levels, showing pollution in the analysed areas. This increase suggests a notable degree of pollution in roadside soils, primarily attributed to human activities such as vehicular emissions, urban activities and industrial discharges that introduce heavy metals into the environment.

4.2.1. Cu

The Cu values of the sampling positions in 2020–2022 are given in Fig. 4.2.1a. and 4.2.1b. for the various sites of Aizawl city and outside Aizawl city for three seasons (pre-monsoon, monsoon, post-monsoon) separately.

During the first year (2020–2021) within Aizawl city, a significant difference of Cu was observed between sites. Cu concentrations fluctuate seasonally, in response to temperature and precipitation. It is reported that there is an increase in metal ion release with increase in the temperature of the season (Batool et al., 2020; Adachi, K., and Tainosho, Y., 2004), which might explain the higher pre-monsoon copper content in Aizawl. The metal concentration in sediments is also increased in the monsoon season because of metal runoff from precipitation, resulting in a higher concentration of copper in sediments, particularly at the sites within urban areas with inadequate drainage such as RS-CK9, RS-TS7 and RS-BB5.

The increased metal runoff during the monsoon in Aizawl aligns with findings from Peng et al., (2024), which indicate that rainfall enhances metal concentrations in urban sediments. Specifically, monsoon rains raise copper levels at certain sites due to inadequate drainage. Peng et al., (2024) also highlight that the intensity and duration of rainfall significantly impact metal runoff, particularly in areas with limited drainage.

Urbanization exacerbates this issue by increasing the number of impervious surfaces, resulting in reduced infiltration and increased surface runoff, which elevates metal concentrations. The relationship between urban infrastructure, precipitation, and metal runoff is supported by studies showing that heavy rainwater transports metals into sediments, with failures in urban drainage systems intensifying these effects (Pochodyła-Ducka et al., 2023; Milik and Pasela, 2018). Overall, these findings demonstrate the interconnectedness of urbanization, precipitation, and drainage in contributing to increased metal runoff in urban areas.

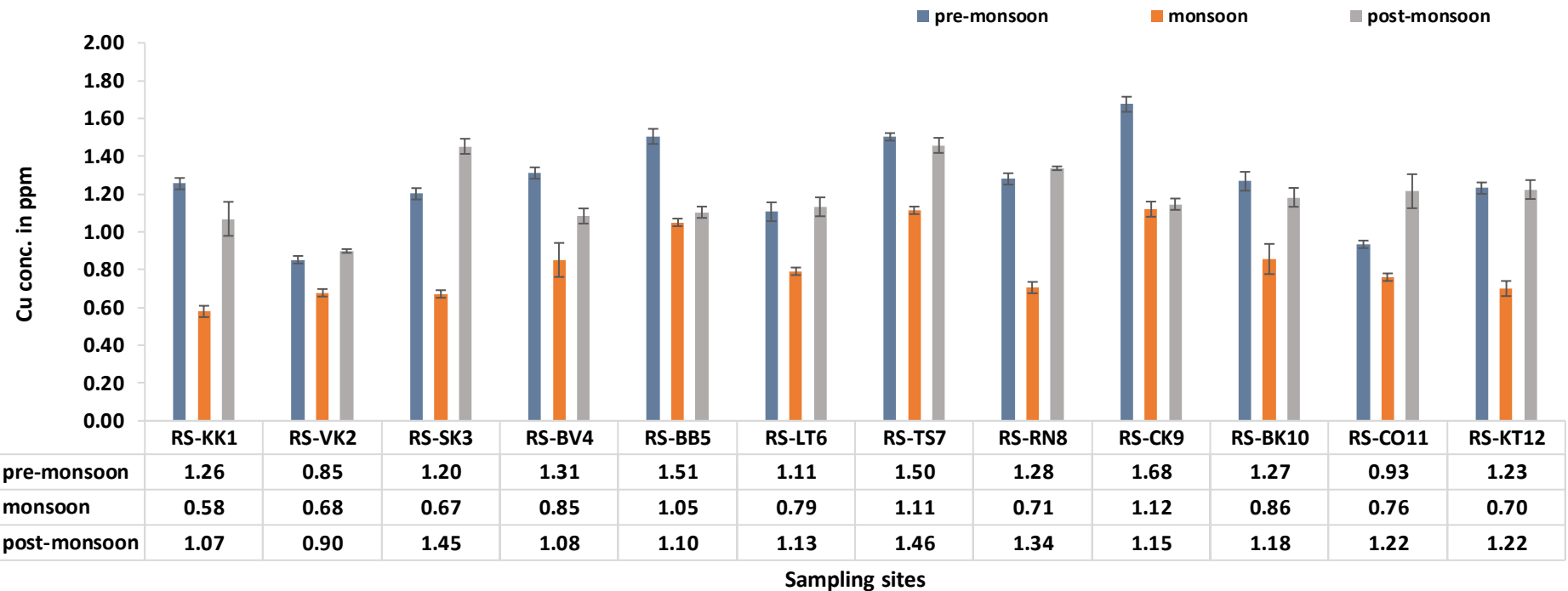
Table 4.2.1a. Anova table showing significant variation of Cu within sites and season within Aizawl city (2020-2021).

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	4.10	11.00	0.37	2.15	0.02	1.87
Between the months	14.73	11.00	1.34	7.72	0.001	1.87
Error	20.99	121.00	0.17			
Total	39.82	143.00				

Table 4.2.1b. Anova table showing significant variation of Cu season within Aizawl city (2021-2022)

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	3.041	11	0.276	1.279	0.244	1.869
Between the months	89.046	11	8.095	37.451	0.001	1.869
Error	26.154	121	0.216			
Total	118.241	143				

Cu Concentration within Aizawl city



RS-KK1(Kulikawn) RS-VK2 (Vaivakawn) RS-SK3 (Sikulpuikawn) RS-BV4 (Bethlehem Vengthlang) RS-BB5 (Bazar Bungkawn) RS-LT6 (Laipuitlang)
 RS-TS7 (Temple Square) RS-RN8 (Ramhlun) RS-CK9 (Chanmari kawn) RS-BK10 (Bawngkawn) RS-CO11 (MINECO) RS-KT12 (Khatla)

Fig. 4.2.1a. Cu concentration of the roadside soil within Aizawl.

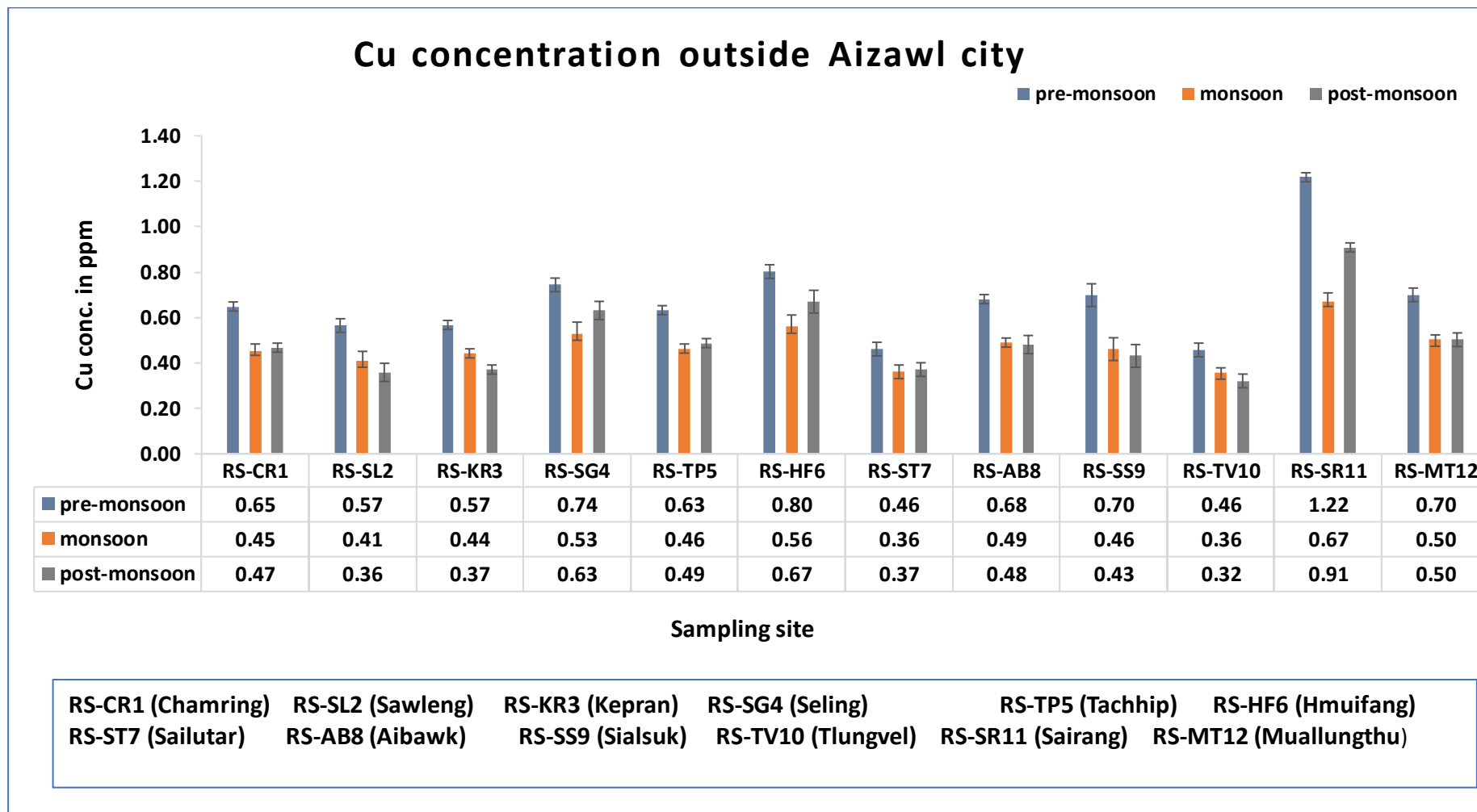


Fig. 4.2.1b. Cu concentration (ppm) of the roadside soil outside Aizawl.

Table 4.2.1c. Anova table showing significant variation of Cu within sites and season outside Aizawl city (2020-2021).

Source of Variation	SS	df	MS	F	p-value	f- crit
Between the sites	0.308	11	0.028	46.247	0.001	1.869
Between the months	0.083	11	0.008	12.489	0.001	1.869
Error	0.073	121	0.001			
Total	0.465	143				

Table 4.2.1d. Anova table showing significant variation of Cu within sites and season outside Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f- crit
Between the sites	8.637	11	0.785	29.504	0.001	1.869
Between the months	13.157	11	1.196	44.948	0.001	1.869
Error	3.220	121	0.027			
Total	25.014	143				

Table 4.2.1e. Anova table showing significant variation of Cu within sites and seasons within Aizawl city for two years.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between sites	0.050	11	0.025	22.586	0.042	19
Between season	0.035	5	0.034	30.981	0.031	18.513
Error	0.002	55	0.001			
Total	0.087	71				

Table 4.2.1f. Anova table showing significant variation of Cu within sites and seasons of the two years outside Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between sites	1.455	11	0.132	6.426	0.001	1.968
Between season	2.832	5	1.166	56.674	0.001	2.383
Error	0.132	55	0.021			
Total	4.419	71				

Table 4.2.1g. Mean value of Cu (ppm) with standard deviation of the sites and season within Aizawl city.

SITE	pre-monsoon	monsoon	post-monsoon
RS-KK1 (Kulikawn)	1.25 ± 0.67	0.58 ± 0.09	1.069 ± 1.04
RS-VK2 (Vaivakawn)	0.85 ± 0.54	0.68 ± 0.16	0.90 ± 0.77
RS-SK3 (Sikulpuikawn)	1.20 ± 0.48	0.67 ± 0.09	1.45 ± 1.05
RS-BV4 (Bethlehem Vengthlang)	1.31 ± 0.31	0.85 ± 0.30	1.08 ± 0.97
RS-BB5 (Bazar Bungkawn)	1.51 ± 0.54	1.05 ± 0.21	1.10 ± 0.96
RS-LT6 (Laipuitlang)	1.12 ± 0.62	0.79 ± 0.05	1.13 ± 1.05
RS-TS7 (Temple Square)	1.50 ± 0.46	1.11 ± 0.19	1.46 ± 1.14
RS-RN8 (Ramhlun)	1.28 ± 0.95	0.71 ± 0.17	1.34 ± 0.85
RS-CK9 (Chanmari kawn)	1.68 ± 0.63	1.12 ± 0.29	1.15 ± 0.47
RS-BK10 (Bawngkawn)	1.27 ± 0.86	0.86 ± 0.18	1.18 ± 0.89
RS-CO11 (Mineco)	0.93 ± 0.90	0.76 ± 0.32	1.22 ± 0.92
RS-KT12 (Khatla kawn)	1.23 ± 0.98	0.70 ± 0.14	1.22 ± 0.75

Table 4.2.1h. Mean value of Cu (ppm) with standard deviation of the sites and season outside Aizawl city.

SITE	pre-monsoon	monsoon	post-monsoon
RS-CR1 (Chamring)	1.00 ± 0.54	0.45 ± 0.24	0.48 ± 0.32
RS-SL2 (Sawlung)	0.57 ± 0.42	0.41 ± 0.18	0.36 ± 0.17
RS-KR3 (Kepran)	0.57 ± 0.42	0.44 ± 0.19	0.37 ± 0.17
RS-SG4 (Seiling)	0.74 ± 0.50	0.53 ± 0.23	0.63 ± 0.42
RS-TP5 (Tachhip)	0.63 ± 0.54	0.46 ± 0.27	0.49 ± 0.35
RS-HF6 (Hmuifang)	0.80 ± 0.68	0.56 ± 0.35	0.67 ± 0.52
RS-ST7 (Sailutar)	0.46 ± 0.27	0.36 ± 0.12	0.37 ± 0.16
RS-AB8 (Aibawk)	0.68 ± 0.54	0.49 ± 0.29	0.48 ± 0.32
RS-SS9 (Sialsuk)	0.70 ± 0.57	0.46 ± 0.25	0.43 ± 0.23
RS-TV10 (TlungvelP)	0.46 ± 0.28	0.36 ± 0.13	0.32 ± 0.11
RS-SR11 (Sairang)	1.22 ± 1.16	0.67 ± 0.40	0.91 ± 0.67
RS-MT12 (Muallungthu)	0.70 ± 0.53	0.50 ± 0.25	0.50 ± 0.27

4.2.2. Fe

Fe contents of the investigated sites enter as functions of times between 2020 and 2022 in Fig. 4.2.2a and 4.2.2b for various sites in Aizawl city and outside Aizawl city for three different seasons respectively.

In the first year (2020-2021) in Aizawl city, there was a significant variation of Fe in between the months ($p < 0.001$). In the second year (2021-2022), there was also a significant variation between the sites as well as between the months ($p < 0.001$) in Table 4.2.2a and Table 4.2.2b). The site 12 recorded maximum Fe concentration with an average value of 28.67 ± 4.98 ppm in RS-CK9 and minimum of 19.94 ± 7.83 ppm in RS-KT12.

There was a very high variation of Fe in between months both during first year (2020-2021) and second year (2021-2022) outside of Aizawl city ($p < 0.001$) indicated in Table 4.2.2c, and Table 4.2.2d. Also, the site 12 recorded maximum Fe concentration

with an average value of 30.35 ± 2.50 ppm followed by minimum by 14.70 ± 4.64 ppm in RS-KR3.

More Fe concentration was recorded in second year when compared to first. There was wide variation between the two years across the sites and seasons ($p < 0.001$) in Aizawl city and outside Aizawl city. In cities like Aizawl, a rise in vehicular density (traffic) markedly enhances the load of roadside soils with heavy metals, and Fe amassed due to vehicular pollution is found to be a major pollutant ($r = 0.86$). The correlation analysis of Bartkowiak (2020), and Li and Preciado, (2004) between the increased vehicular activity and the existence of Fe in road dust, suggest the contribution of urban traffic to the soil metal pollution. Heavy metals such as Fe in RDS are associated with the wear of vehicle parts such as tires and brakes, as well as road abrasion and contribute significantly to the pollution load in urban soils. The metal concentration of road dust texture increases with the increase in traffic volume, and enrichment factors are relatively high, implying a strong human effect, particularly in high traffic density zones as reported by Kim et al., 2023. This correlation also implies that decreasing vehicle emissions could have a positive effect on soil pollution (Stojić et al., 2023).

Fig. 4.2.2b shows the Fe concentration in sites located outside of the city of Aizawl, which has a lesser and unchanging distribution of Fe than inside the city. The highest concentration was observed at RS-SR11 and the corresponding monsoon season registered the lowest concentration. The lower iron concentrations observed in suburban regions compared to Aizawl indicate diminished vehicular pollution and urban activities, leading to reduced heavy metal deposition in roadside soils.

Urban roadside environments are highly susceptible to heavy metal accumulation due to their complex street networks, dense populations, and high traffic intensity, which differ significantly from suburban settings. This vulnerability is compounded by elevated vehicular emissions, which contribute significantly to the presence of metals like Fe in road dust. A study by Chen et al., 2024 reported that heavy metals were more concentrated in the urban alley than in the other samples, which possibly represents a source of concern to the health of the people living in the area.

Table 4.2.2a. Anova table showing significant variation of Fe within season within Aizawl city (2020-2021).

Source of Variation	SS	df	MS	F	p-value	f- crit
Between the sites	5.790	11	0.526	1.320	0.221	1.869
Between the months	5235.225	11	475.929	1194.117	0.001	1.869
Error	48.226	121	0.399			
Total	5289.241	143				

Table 4.2.2b. Anova table showing significant variation of Fe within season within Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f- crit
Between the sites	140.795	11	12.799	1.1828	0.306	1.869
Between the months	7964.885	11	724.080	66.914	0.001	1.869
Error	1309.351	121	10.821			
Total	9415.032	143				

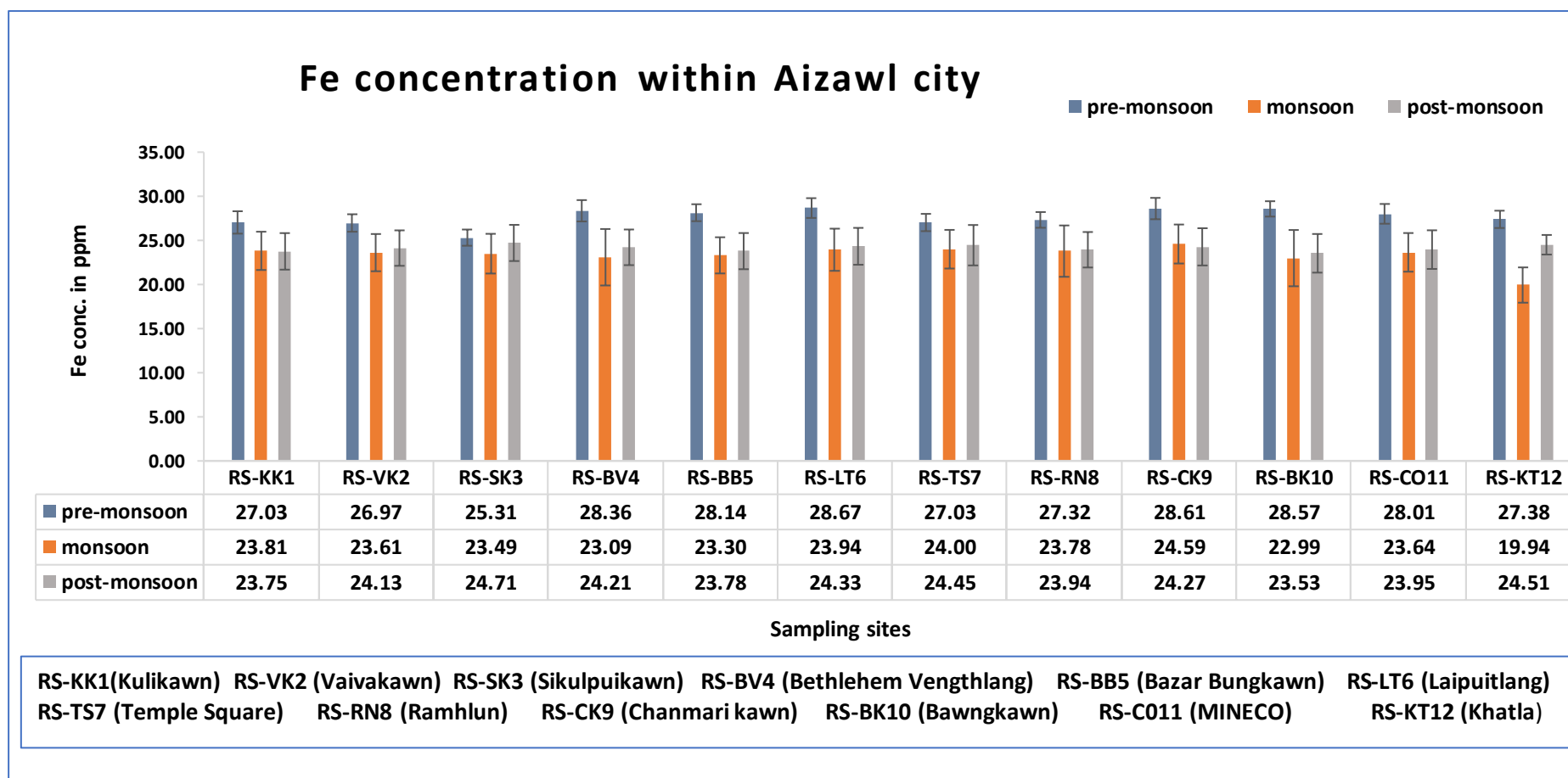


Fig. 5.2.2a. Fe concentration of the selected roadside soil within Aizawl.

Fe concentration outside Aizawl city

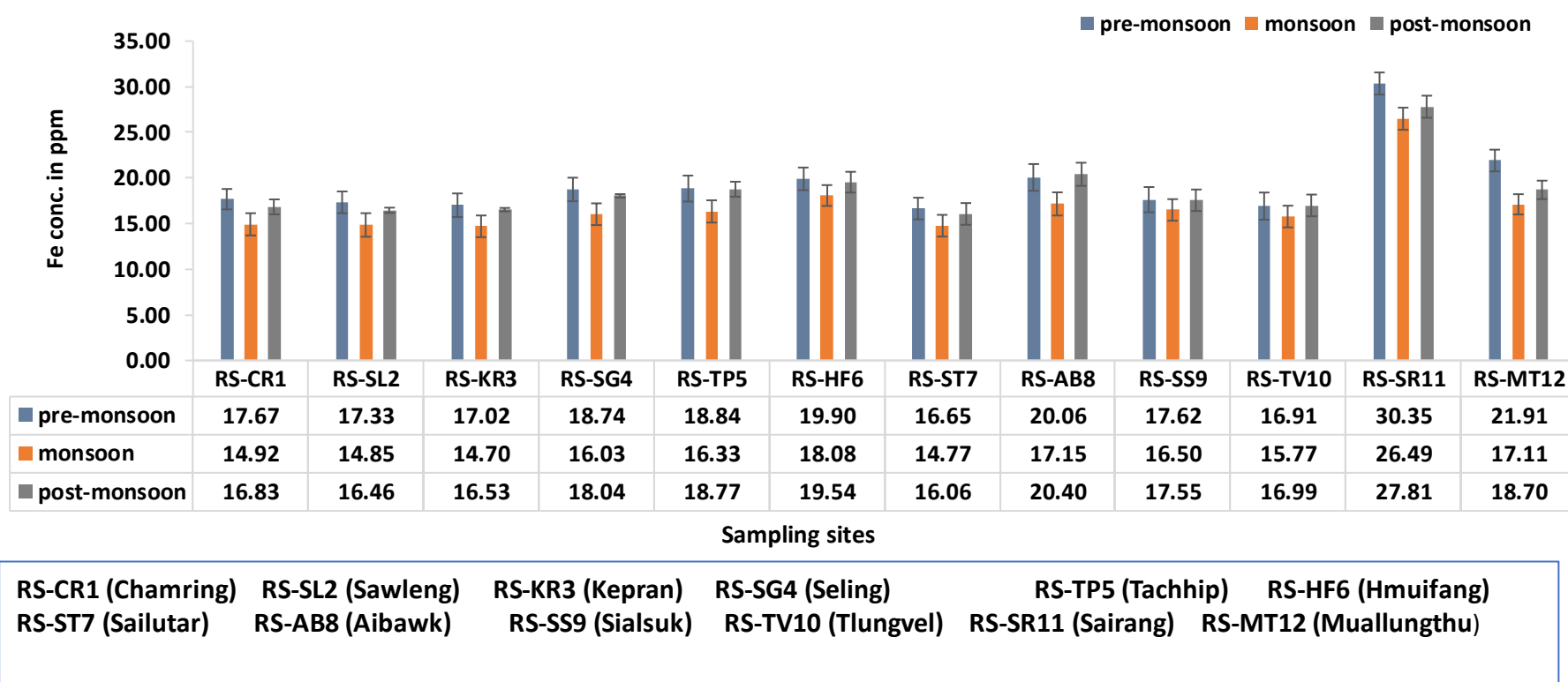


Fig. 5.2.2b. Fe concentration of the selected roadside soil outside Aizawl city.

Table 4.2.2c. Anova table showing significant variation of Fe within sites and season outside Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	728.385	11	66.216	30.391	0.001	1.869
Between the months	240.020	11	21.820	10.014	0.001	1.869
Error	263.637	121	2.1788			
Total	1232.044	143				

Table 4.2.2d. Anova table showing significant variation of Fe within sites and season inside Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	2705.482	11	245.952	145.894	0.001	1.869
Between the months	256.473	11	23.315	13.830	0.001	1.869
Error	203.984	121	1.685			
Total	3165.939	143				

Table 4.2.2e. Anova table showing significant variation of Fe within sites and seasons of the two years within Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between sites	1.532	11	0.139	3.617	0.001	1.967
Between seasons	17.896	5	3.579	92.920	0.001	2.382
Error	2.118	55	0.038			
Total	21.547	71				

Table 4.2.2f. Anova table showing significant variation of Fe within sites and seasons of the two years outside Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between sites	417.510	11	37.955	21.157	0.001	1.967
Between seasons	3024.451	5	604.890	337.19	0.001	2.382
Error	98.665	55	1.793			
Total	3540.627	71				

Table 4.2.2g. Mean value of Fe (ppm) with standard deviation of the sites and season within Aizawl city.

SITE	pre-monsoon	monsoon	post-monsoon
RS-KK1 (Kulikawn)	27.03 ± 2.04	23.81 ± 13.33	23.75 ± 0.24
RS-VK2 (Vaivakawn)	26.97 ± 1.55	23.61 ± 13.30	24.13 ± 1.87
RS-SK3 (Sikulpuikawn)	25.31 ± 0.03	23.49 ± 13.46	24.71 ± 2.09
RS-BV4 (Bethlehem Vengthlang)	28.36 ± 3.19	23.09 ± 12.17	24.21 ± 1.64
RS-BB5 (Bazar Bungkawn)	28.14 ± 3.31	23.30 ± 13.02	23.78 ± 1.70
RS-LT6 (Laipuitlang)	28.67 ± 4.98	23.94 ± 13.15	24.33 ± 1.94
RS-TS7 (Temple Square)	27.03 ± 2.72	24.00 ± 13.45	24.45 ± 2.49
RS-RN8 (Ramhlun)	27.32 ± 3.93	23.78 ± 13.32	23.94 ± 1.71
RS-CK9 (Chanmari kawn)	28.61 ± 4.78	24.59 ± 14.77	24.28 ± 2.17
RS-BK10 (Bawngkawn)	28.57 ± 4.43	22.99 ± 12.10	23.53 ± 1.00
RS-CO11 (Mineco)	28.01 ± 4.67	23.64 ± 12.84	23.95 ± 1.42
RS-KT12 (Khatla kawn)	27.38 ± 3.24	19.94 ± 7.83	24.51 ± 1.63

Table 4.2.2h. Mean value of Fe (ppm) with standard deviation of the sites and season outside Aizawl city.

SITE	pre-monsoon	monsoon	post-monsoon
RS-CR1 (Chamring)	17.67 $\pm$ 4.89	14.92 $\pm$ 3.49	16.83 $\pm$ 4.79
RS-SL2 (Sawlung)	17.33 $\pm$ 5.71	14.85 $\pm$ 3.46	16.46 $\pm$ 4.38
RS-KR3 (Kepran)	17.02 $\pm$ 4.43	14.70 $\pm$ 4.64	16.53 $\pm$ 4.52
RS-SG4 (Seiling)	18.74 $\pm$ 3.92	16.03 $\pm$ 5.49	18.04 $\pm$ 3.68
RS-TP5 (Tachhip)	18.84 $\pm$ 6.47	16.33 $\pm$ 7.29	18.77 $\pm$ 6.23
RS-HF6 (Hmuifang)	19.90 $\pm$ 6.73	18.08 $\pm$ 3.63	19.54 $\pm$ 7.60
RS-ST7 (Sailutar)	16.65 $\pm$ 4.82	14.77 $\pm$ 6.11	16.06 $\pm$ 3.86
RS-AB8 (Aibawk)	20.06 $\pm$ 7.08	17.15 $\pm$ 5.73	20.40 $\pm$ 8.29
RS-SS9 (Sialsuk)	17.62 $\pm$ 5.01	16.50 $\pm$ 4.94	17.55 $\pm$ 4.97
RS-TV10 (Tlungvel)	16.91 $\pm$ 9.15	15.77 $\pm$ 12.01	16.99 $\pm$ 5.17
RS-SR11 (Sairang)	30.35 $\pm$ 2.50	26.49 $\pm$ 5.86	27.81 $\pm$ 2.90
RS-MT12 (Muallungthu)	21.91 $\pm$ 5.40	17.11 $\pm$ 5.51	18.70 $\pm$ 5.41

4.2.3. Mn

The Mn values for the sites selected for the studied period 2020-2022 have been graphed in o Figures 4.2.3a and 4.2.3b for various sites of Aizawl city and outside Aizawl city for three seasons separately.

There was also significant difference of Mn between sites ($p < 0.013$) and months ($p < 0.001$) in Aizawl city in first year (2020-2021). Significant variation between the sites was there during the second year (2021-2022) and also between the months ($p < 0.001$), (Table 4.2.3a, Table 4.2.3b). The site 12 recorded maximum Mn concentration with an average value of 7.16 ± 5.05 ppm in RS-KT12 and the minimum with 2.90 ± 0.01 ppm in RS-LT6.

In the first year (2020-2021) and second year (2021-2022) at sites away from in Aizawl city, there was a significant variation of Mn in between the sites ($p < 0.001$) and months ($p < 0.001$) Table 4.2.3c, and Table 4.2.3d. Also, the site 12 recorded maximum Mn

concentration with an average value of 4.77 ± 1.55 ppm in RS-HF6 and a lowest of 1.79 ± 0.05 ppm in RS-ST7.

In the second years, second year had higher of Mn concentration. Seasons: Within Aizawl city, large variation was noticed among the seasons ($p < 0.001$). At the same time, there is large variation for the two years for the sites and symptoms ($p < 0.001$), as well outside Aizawl city. There is an association between Mn and traffic activity in both the sampling sites, inside and outside Aizawl city ($r = 0.53$).

Urban areas, characterized by high vehicle density and industrial activities, significantly contribute to elevated levels of Mn in the environment. Several studies have examined the sources and distribution of Mn pollution in these settings. For instance, research conducted on Xiamen Island, China, revealed that traffic-related activities are a major contributor to magnetic pollution in urban dust, with Mn being a prominent component. The study found that roadside dust exhibited higher magnetic properties than topsoil, highlighting the influence of local traffic emissions (Yang et al., 2021). Similarly, a study in Faisalabad, Pakistan, identified elevated concentrations of Mn in urban soils and plants. Clear spatial and temporal variations were linked to traffic load and industrial activity, with Mn levels notably higher during the summer, likely due to increased traffic and industrial emissions during that season (Umer et al., 2021). Additionally, a comparative study in Cantabria, Spain, emphasized that Mn deposition was significantly greater at industrial sites and areas with high traffic than in rural regions. This was attributed to a nearby ferro-manganese production plant and the significant volume of traffic, respectively (Fernández-Olmo et al., 2015). These findings highlight the critical impact of urbanization, particularly as it relates to traffic and industrial activities, on the accumulation of Mn in urban environments.

Fig. 4.2.3b. shows the outside Aizawl sites Mn concentration, and the range of Mn values lies generally lower compared to those inside Aizawl implying that these areas are less influenced anthropogenically compared to the urban sites. The Mn contents are maximum in the study sites during the pre-monsoon season, and the contents are approximately the same in the study sites during the season of monsoon and post-monsoon. Table 4.2.3g and Table 4.2.3h shows the mean Mn levels of the sites inside

and outside Aizawl for three seasons. It reveals higher means inside the city (pre-monsoon: 5.54 ppm; post-monsoon: 4.73 ppm) than those outside Aizawl (pre-monsoon: 3.89 ppm; post-monsoon: 2.70 ppm). Emissions from traffic and human activities are important sources of metal contamination in urban soils, with Mn levels in Aizawl being particularly influenced. Climatic conditions in the region affect the dispersion of pollutants and are strongly linked to the density of urban vehicles and other forms of human activity. These conditions underscore the importance of long-term monitoring and control to prevent ecologically risky high levels of Mn. In contrast, less Mn in areas outside of Aizawl indicate relatively lower risk of contamination. Studies by Carrero et al., (2012) and Lu et al., (2022) focus on the essential problem of manganese contamination in roadside soils, and stress the need to remain vigilant to avoid possible environmental and health threats. These results are useful especially for Aizawl where concerns about roadside soil contamination with heavy metals were raised.

Table 4.2.3a. Anova table showing significant variation of Mn within sites and season within Aizawl city (2020-2021)

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	8.586885	11	0.780626	2.305789	0.013	1.868615
Between the months	39.5623	11	3.596573	10.62345	0.001	1.868615
Error	40.96461	121	0.33855			
Total	89.11379	143				

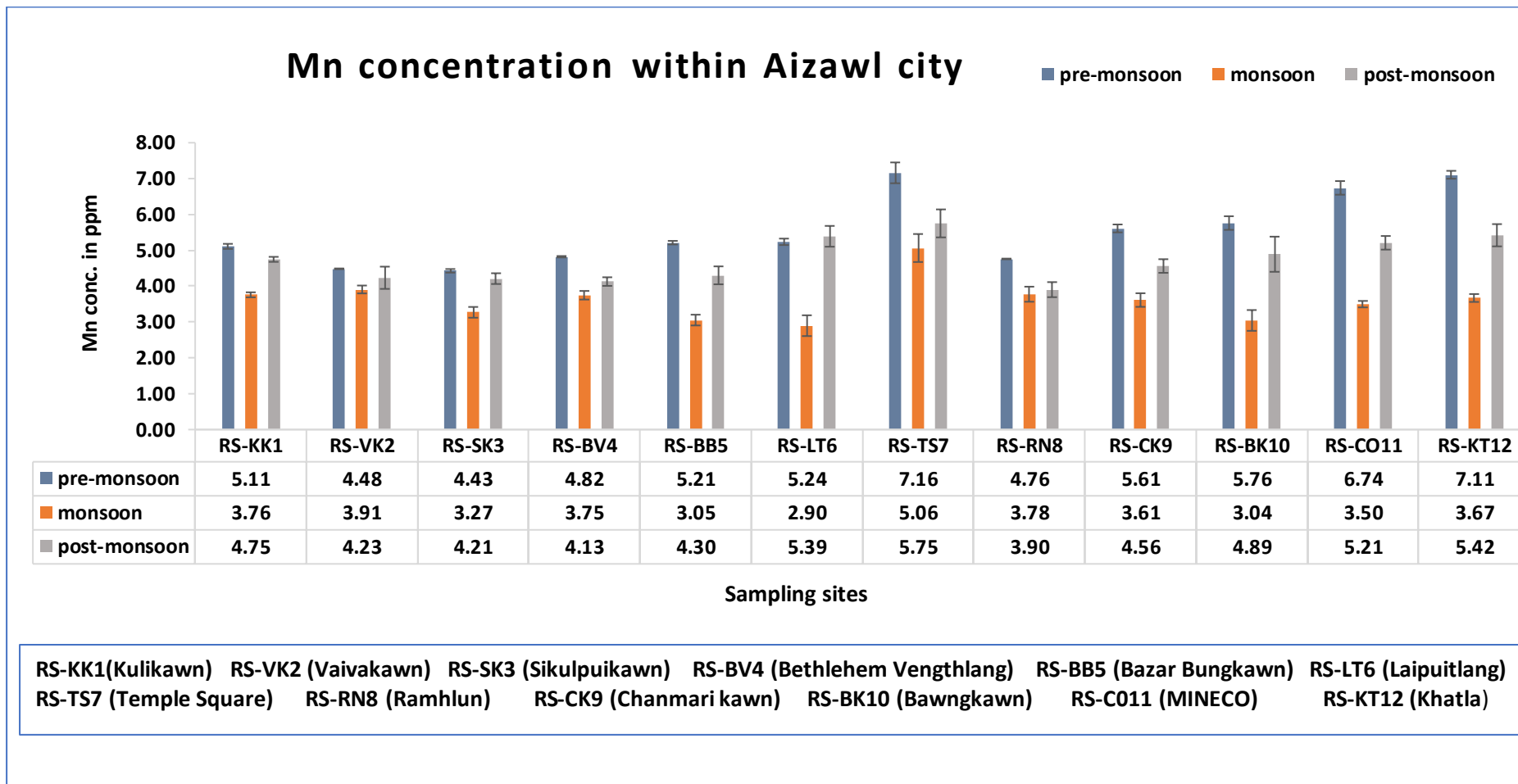


Fig. 4.2.3a. Mn concentration of the roadside soil within Aizawl.

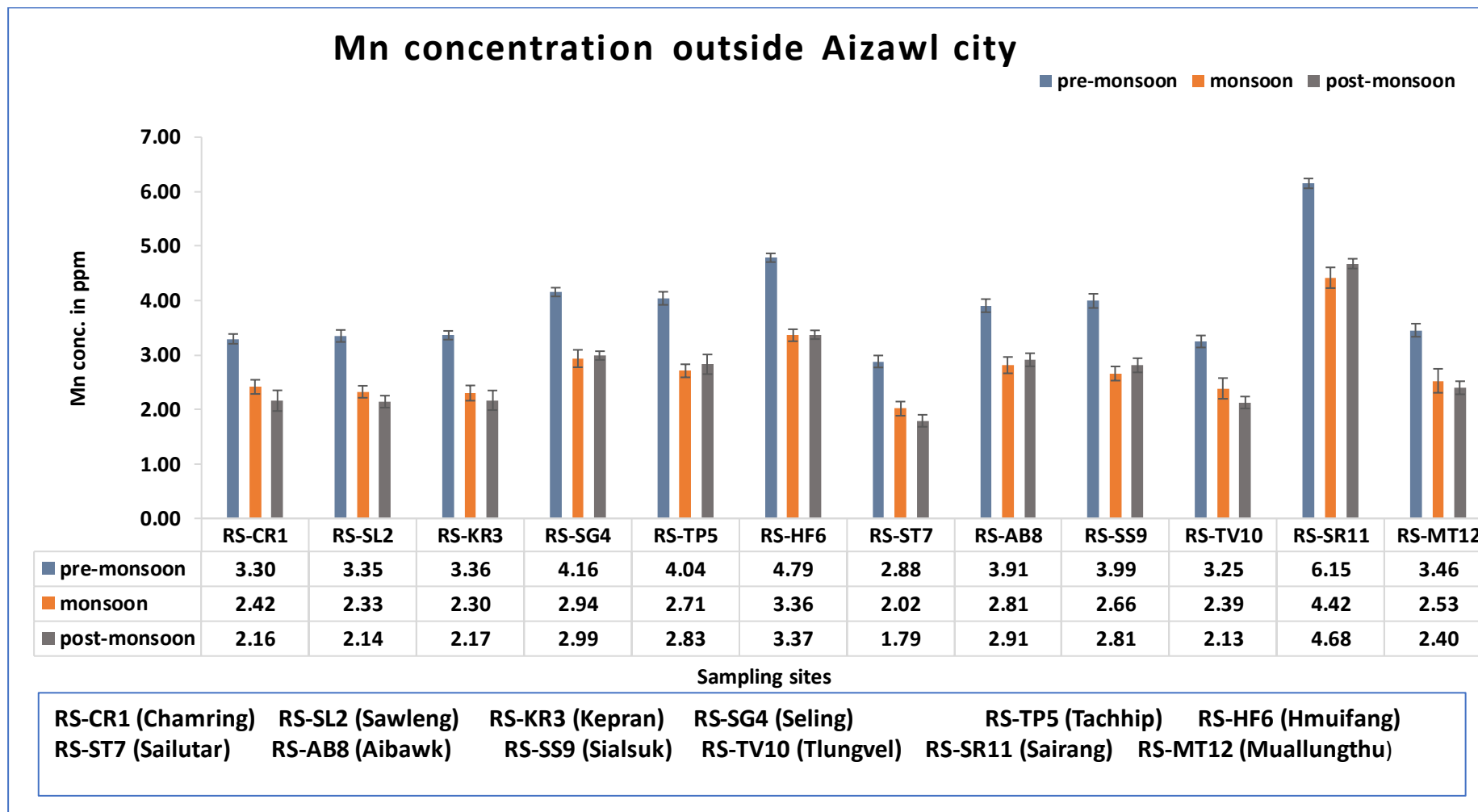


Fig. 4.2.3b. Mn concentration of the roadside soil outside Aizawl city.

Table 4.2.3b. Anova table showing significant variation of Mn within sites and season within Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	151.1151	11	13.73774	4.421591	0.001	1.868615
Between the months	629.475	11	57.225	18.41828	0.001	1.868615
Error	375.943	121	3.106967			
Total	1156.533	143				

Table 4.2.3c. Anova table showing significant variation of Mn within sites and season outside Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	41.22066	11	3.747333	67.12582	0.001	1.868615
Between the months	46.23218	11	4.202926	75.28683	0.001	1.868615
Error	6.754886	121	0.055826			
Total	94.20773	143				

Table 4.2.3d. Anova table showing significant variation of Mn within sites and season outside Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	149.7429	11	13.61299	93.24066	0.001	1.868615
Between the months	281.1121	11	25.55565	175.0406	0.001	1.868615
Error	17.66581	121	0.145998			
Total	448.5208	143				

Table 4.2.3e. Anova table showing significant variation of Mn within sites and season of the two years within Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	15.53417	11	1.412197	0.78958	0.649	1.967547
Between season	2349.062	5	469.8125	262.679	0.001	2.382823
Error	98.36984	55	1.788542			
Total	2462.966	71				

Table 4.2.3f. Anova tables showing significant variation of Mn within sites and season of the two years outside Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f- crit
Between sites	20.383	11	1.853	16.148	0.001	1.967
Between seasons	104.889	5	20.977	182.816	0.001	2.382
Error	6.3111	55	0.115			
Total	131.583	71				

Table 4.2. 3g. Mean value of Mn (kg/ha) with standard deviation of the sites and season within Aizawl city.

Site	pre-monsoon	monsoon	post-monsoon
RS-KK1 (Kulikawn)	5.11 ± 2.55	3.76 ± 0.86	4.75 ± 2.49
RS-VK2 (Vaivakawn)	4.48 ± 2.03	3.91 ± 2.11	4.23 ± 1.76
RS-SK3 (Sikulpuikawn)	4.43 ± 1.20	3.27 ± 1.12	4.21 ± 1.55
RS-BV4 (Bethlehem Vengthlang)	4.82 ± 1.70	3.75 ± 0.79	4.13 ± 1.71
RS-BB5 (Bazar Bungkawn)	5.21 ± 2.43	3.05 ± 0.78	4.30 ± 1.97
RS-LT6 (Laipuitlang)	5.24 ± 4.16	2.90 ± 0.01	5.39 ± 3.08
RS-TS7 (Temple Square)	7.16 ± 5.05	5.06 ± 2.91	5.75 ± 2.99
RS-RN8 (Ramhlun)	4.76 ± 2.55	3.78 ± 1.97	3.90 ± 1.67
RS-CK9 (Chanmari kawn)	5.61 ± 3.92	3.61 ± 1.15	4.56 ± 2.55
RS-BK10 (Bawngkawn)	5.76 ± 4.99	3.04 ± 1.08	4.89 ± 3.10
RS-CO11 (Mineco)	6.74 ± 4.11	3.50 ± 1.54	5.21 ± 3.20
RS-KT12 (Khatla kawn)	7.11 ± 3.18	3.67 ± 1.03	5.42 ± 2.43

Table 4.2.3h. Mean value of Mn (ppm) with standard deviation of the sites and season outside Aizawl city.

SITE	pre-monsoon	monsoon	post-monsoon
RS-CR1 (Chamring)	3.30 ± 1.21	2.42 ± 0.93	2.16 ± 0.15
RS-SL2 (Sawlung)	3.35 ± 0.98	2.33 ± 0.98	2.14 ± 0.08
RS-KR3 (Kepran)	3.36 ± 1.05	2.30 ± 1.00	2.17 ± 0.19
RS-SG4 (Seiling)	4.16 ± 1.26	2.94 ± 1.20	2.99 ± 0.16
RS-TP5 (Tachhip)	4.04 ± 1.01	2.71 ± 1.24	2.83 ± 0.16
RS-HF6 (Hmuifang)	4.77 ± 1.55	3.36 ± 1.46	3.37 ± 0.25
RS-ST7 (Sailutar)	2.88 ± 1.53	2.02 ± 0.86	1.79 ± 0.05
RS-AB8 (Aibawk)	3.91 ± 0.94	2.81 ± 1.00	2.91 ± 0.35
RS-SS9 (Sialsuk)	3.99 ± 1.18	2.66 ± 1.07	2.81 ± 0.09
RS-TV10 (Tlungvel)	3.25 ± 0.95	2.39 ± 0.99	2.13 ± 0.01
RS-SR11 (Sairang)	6.15 ± 2.27	4.42 ± 0.35	4.68 ± 1.56
RS-MT12 (Muallungthu)	3.46 ± 0.41	2.53 ± 1.11	2.40 ± 1.23

4.2.4. Ni

The Ni for chosen sites for the period of study 2020-2022 are shown in Fig 4.2.4a and 4.2.4b for city within Aizawl and city outside Aizawl for three different season (pre-monsoon, monsoon, post-monsoon) respectively.

In the first year (2020-2021) within Aizawl city, there was a significant variation of Ni in between the months ($p < 0.020$). In the second year (2021-2022), there was also a significant variation between the sites as well as between the months ($p < 0.001$), (Table 4.2.3a, Table 4.2.3b).

Table 4.2.3a. the first year (2020-2021) and second year (2021-2022) outside Aizawl city, there is a widely different variation from other sampling in Ni value and there were significant differences of Ni between sites and month ($p < 0.001$) in Table 4.2.3c. and Table 4.2.3d. Similarly, maximum Ni concentration was observed at the 12 sites with an average value of $0.90 \pm 0.90 \pm 0.43$ ppm in RS-SR11 and a minimum of 18.18 ± 0.04 ppm in both RS-SL2 and RS-KR3.

Between the two year, Ni accumulated more between the 2 years. Variation was also high between the two years among the sites ($p < 0.005$) and seasons ($p < 0.001$) in the Aizawl city. But outside the urban area of Aizawl city there is a high significant difference between the two years within the sites and the seasons ($p < 0.001$). In both the sampling location, inside and outside of Aizawl city there is a strong correlation between Ni and traffic activity ($r = 0.98$).

The Ni concentrations at different sampling sites within Aizawl and outside Aizawl are shown in Fig. 4.2.4a and 4.2.4b respectively. The seasonal means are also presented in Fig. 5.2.4g and Fig 4.2.4h. Ni levels are maximum in the pre-monsoon season.

Earlier research, by Van Hassel et al., (1979) and Gao et al., (2022), have reported a positive correlation between heavy metal concentrations, including Ni, and traffic volume. They found that traffic density significantly contributes to nickel pollution due to emissions from diesel fuel and lubricating oil. Additionally, urban areas accumulate higher concentrations of heavy metals in road-deposited sediments compared to rural settings, further increasing Ni levels. These factors could contribute

to the increased Ni levels in Aizawl, an urbanized area characterized by higher traffic density and anthropogenic activities.

Nickel concentrations are highly influenced by seasonal variation. High levels generally are also found during the pre-monsoon period, largely due to decreased water dispersion by rain and more dry atmospheric deposition. On the contrary, during the monsoon period, Ni content may be reduced, due to enhanced runoff some heavy metals from road side sediments can be moderated and redistributed (Min et al., 2023; Pal et al., 2018).

Table 4.2.4a. Anova table showing significant variation of Ni within season within Aizawl city (2020-2021).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	0.901852	11	0.081987	0.739519	0.699	1.868615
Between the months	2.647719	11	0.240702	2.171131	0.020	1.868615
Error	13.41462	121	0.110865			
Total	16.96419	143				

Table 4.2.4b. Anova table showing significant variation of Ni within sites and season within Aizawl.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	0.824947	11	0.074995	9.915923	0.001	1.868615
Between the months	15.01651	11	1.365138	180.4995	0.001	1.868615
Error	0.915136	121	0.007563			
Total	16.7566	143				

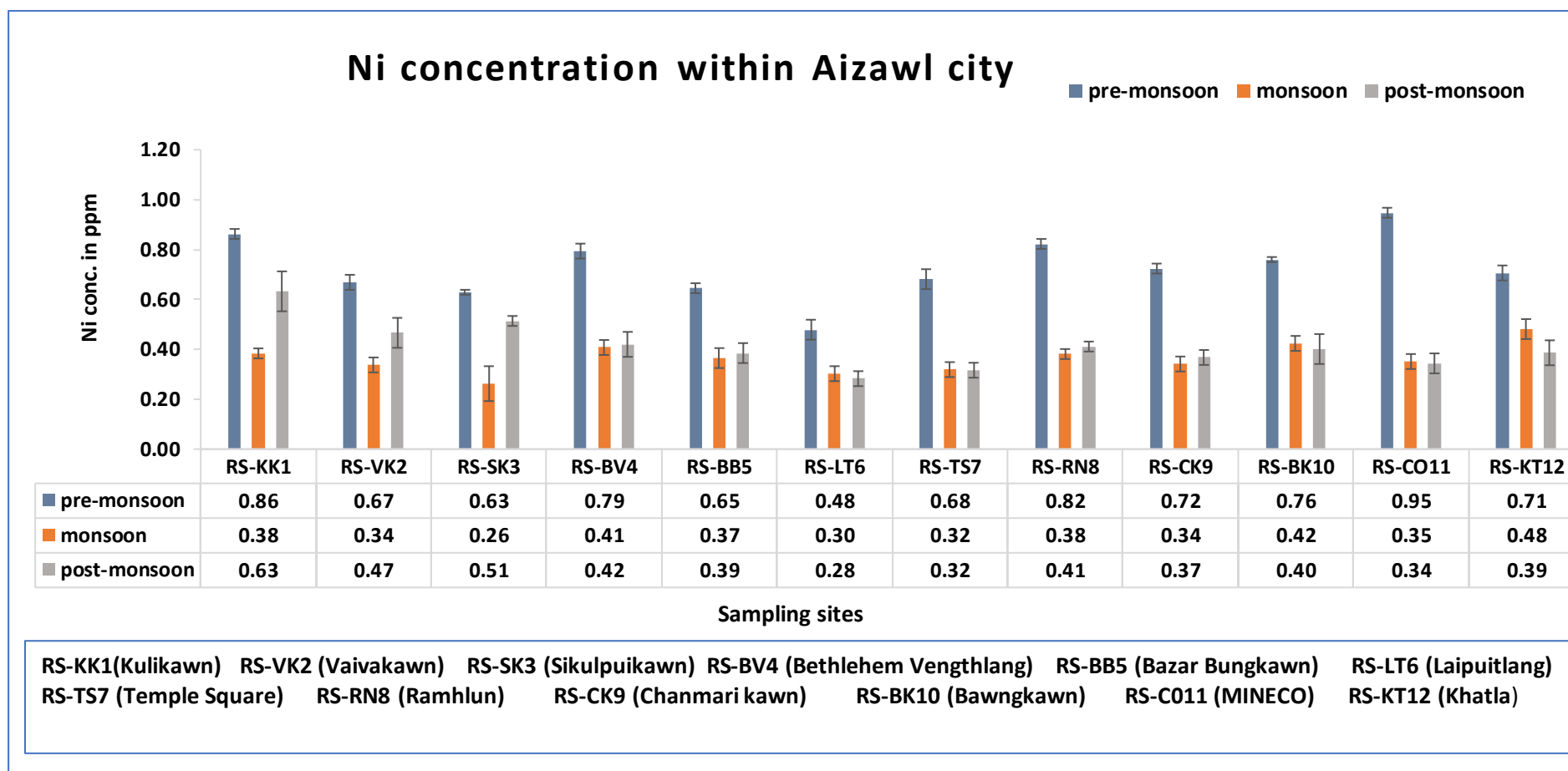


Fig. 4.2.4a. Ni concentration of the roadside soil within Aizawl.

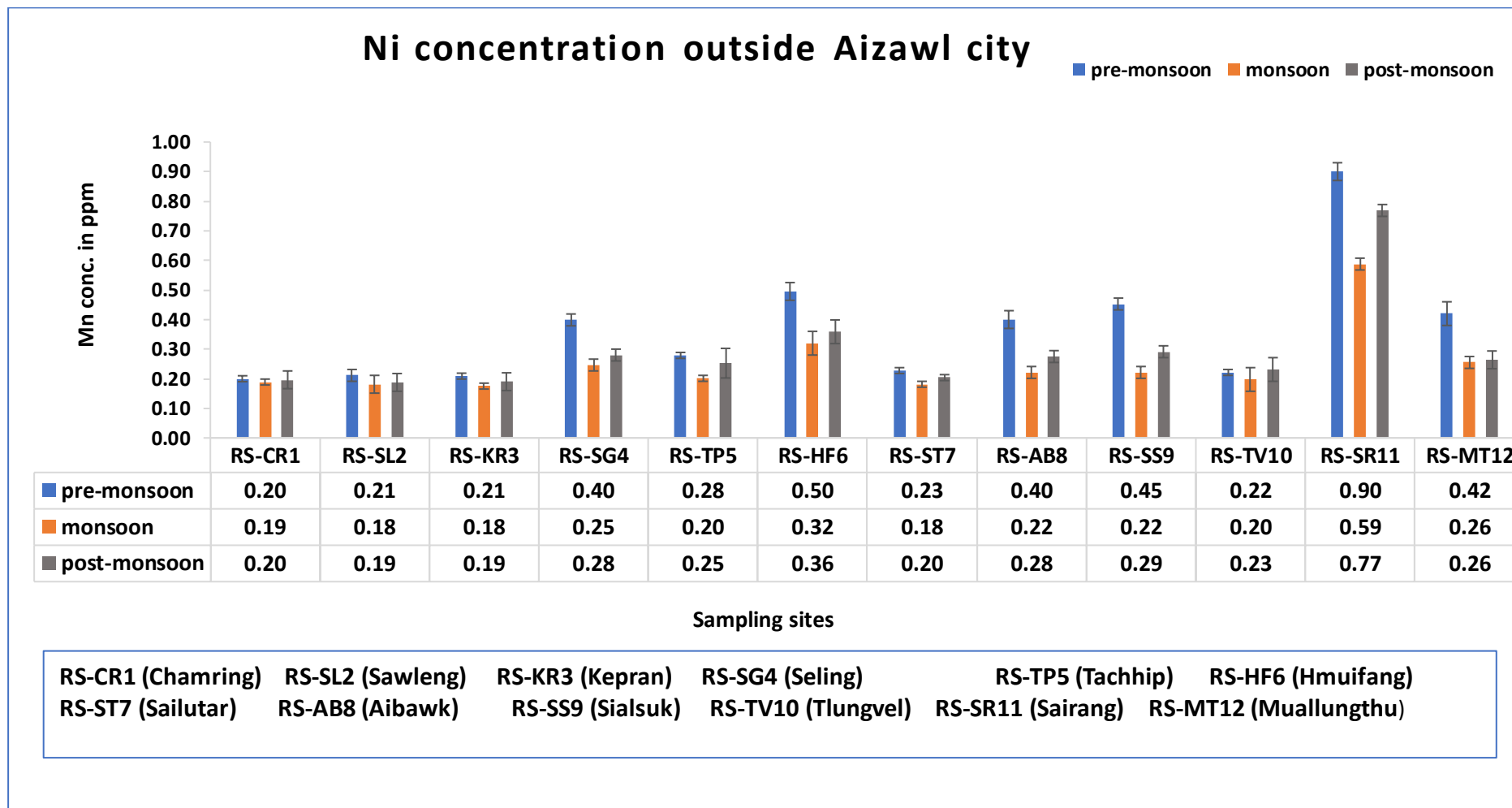


Fig. 4.2.4b. Ni concentration of the roadside soil outside Aizawl city.

Table 4.2.4c. Anova table showing significant variation of Ni within sites and season outside Aizawl city (2020-2021).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	1.193514	11	0.108501	96.98387	0.001	1.868615
Between the months	0.266914	11	0.024265	21.68918	0.001	1.868615
Error	0.135369	121	0.001119			
Total	1.595797	143				

Table 4.2.4d. Anova table showing significant variation of Ni within sites and season outside Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	6.376	11	0.579	59.361	0.001	1.869
Between the months	0.951	11	0.086	8.860	0.001	1.869
Error	1.181	121	0.009			
Total	8.509	143				

Table 4.2.4e. Anova table showing significant variation of Mn within sites and season of the two years within Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	23.66443	11	2.151	2.858	0.001	1.967
Between season	256.361	5	51.272	68.120	0.001	2.382
Error	41.39676	55	0.752			
Total	321.4222	71				

Table 4.2.4f. Anova table showing significant variation of Mn within sites and season of the two years outside Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	1.004132	11	0.091285	20.99394	0.001	1.967547
Between the seasons	0.775874	5	0.155175	35.68759	0.001	2.382823
Error	0.239148	55	0.004348			
Total	2.019154	71				

Table 4.2.4g. Mean value of Ni (ppm) with standard deviation of the sites and season within Aizawl city.

Site	pre-monsoon	monsoon	post-monsoon
RS-KK1 (Kulikawn)	0.86 ± 0.44	0.38 ± 0.07	0.63 ± 0.16
RS-VK2 (Vaivakawn)	0.67 ± 0.65	0.34 ± 0.08	0.47 ± 0.03
RS-SK3 (Sikulpuikawn)	0.63 ± 0.53	0.26 ± 0.05	0.51 ± 0.04
RS-BV4 (Bethlehem Vengthlang)	0.79 ± 0.42	0.40 ± 0.02	0.42 ± 0.25
RS-BB5 (Bazar Bungkawn)	0.65 ± 0.57	0.37 ± 0.06	0.38 ± 0.28
RS-LT6 (Laipuitlang)	0.48 ± 0.41	0.30 ± 0.07	0.28 ± 0.08
RS-TS7 (Temple Square)	0.68 ± 0.32	0.32 ± 0.04	0.32 ± 0.18
RS-RN8 (Ramhlun)	0.82 ± 0.58	0.38 ± 0.11	0.41 ± 0.13
RS-CK9 (Chanmari kawn)	0.72 ± 0.68	0.34 ± 0.11	0.37 ± 0.15
RS-BK10 (Bawngkawn)	0.76 ± 0.68	0.42 ± 0.06	0.40 ± 0.12
RS-CO11 (Mineco)	0.95 ± 0.22	0.35 ± 0.12	0.34 ± 0.16
RS-KT12 (Khatla kawn)	0.71 ± 0.65	0.48 ± 0.09	0.39 ± 0.10

Table 4.2.4h. Mean value of Ni (ppm) with standard deviation of the sites and season outside Aizawl city.

SITE	pre-monsoon	monsoon	post-monsoon
RS-CR1 (Chamring)	0.20 ± 0.02	0.19 ± 0.04	0.20 ± 0.06
RS-SL2 (Sawleng)	0.21 ± 0.04	0.18 ± 0.04	0.19 ± 0.07
RS-KR3 (Kepran)	0.21 ± 0.03	0.18 ± 0.04	0.19 ± 0.06
RS-SG4 (Seiling)	0.40 ± 0.26	0.25 ± 0.06	0.28 ± 0.13
RS-TP5 (Tachhip)	0.28 ± 0.08	0.20 ± 0.06	0.25 ± 0.12
RS-HF6 (Hmuifang)	0.50 ± 0.19	0.32 ± 0.05	0.36 ± 0.12
RS-ST7 (Sailutar)	0.23 ± 0.02	0.18 ± 0.04	0.20 ± 0.05
RS-AB8 (Aibawk)	0.40 ± 0.24	0.22 ± 0.05	0.28 ± 0.11
RS-SS9 (Sialsuk)	0.45 ± 0.34	0.22 ± 0.11	0.29 ± 0.15
RS-TV10 (Tlungvel)	0.22 ± 0.01	0.20 ± 0.15	0.23 ± 0.03
RS-SR11 (Sairang)	0.90 ± 0.43	0.59 ± 0.21	0.77 ± 0.44
RS-MT12 (Muallungthu)	0.42 ± 0.21	0.26 ± 0.12	0.26 ± 0.05

4.2.5. Pb

After the selection of the sites, in fig. 4.2.5a and 4.2.5b, Pb values of these sites are represented for 2020-2022 time period between the different sites in Aizawl city and outside Aizawl city for three seasons respectively.

Variation of Pb was observed among the months ($p < 0.001$) within Aizawl city in the first year (2020-2021). During the second year (2021-2022) there was also a significant difference between the sites ($p < 0.012$) and between the months ($p < 0.001$), (Table 4.2.5a, Table 4.2.5b) The maximum concentration of Pb on the site 12 was recorded with an average of 1.36 ± 0.80 in RS-KT12 and the least of 0.26 ± 0.11 in RS-VK2.

There was variation in between the sites and month ($p < 0.001$), during 1st year (2020-2021) and 2nd year (2021-2022) outside Aizawl city for Pb as presented in Table 4.2.5c and Table 4.2.5d. Further, the site 12 recorded maximum Pb concentration with an average value of 1.03 ± 0.05 ppm RS-SR11 and lowest with 0.19 ± 0.05 RS-TV10.

The second year had a higher average Pb concentration, compared to the first year. There was considerable variation between two years in the sites ($p < 0.047$) and in the seasons ($p < 0.001$) within Aizawl city. However, beyond Aizawl city a statistically significant variation for the two years among the sites and the seasons was recorded ($P < 0.001$). In both the sampling sites, traffic and rain are found to be significantly correlated to Pb within and outside the Aizawl city, ($r = 0.98$; $r = 0.99$).

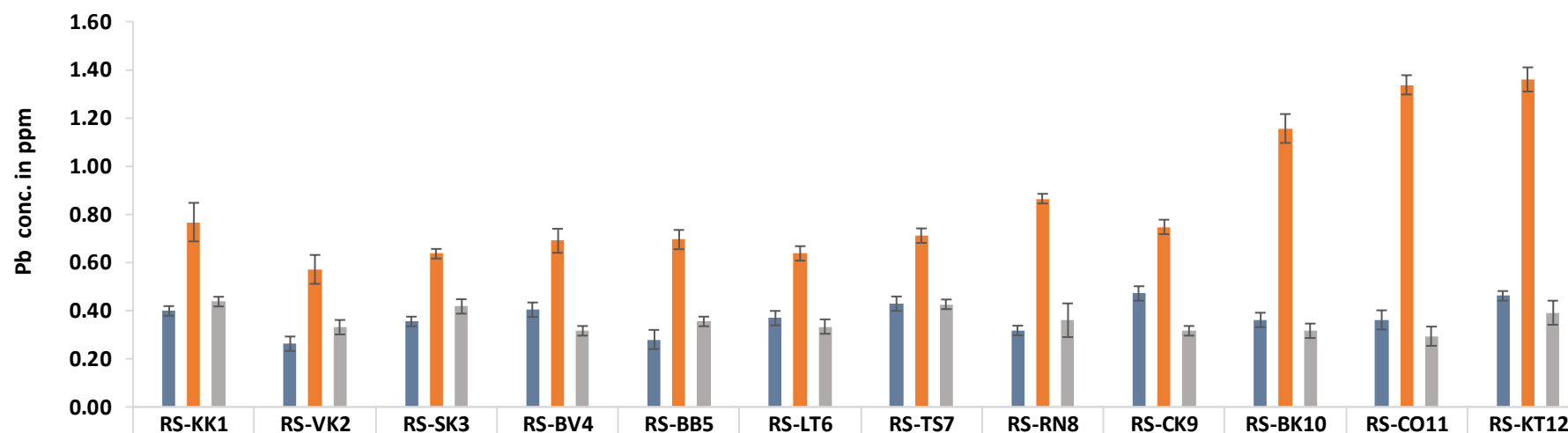
Figure 4.2.5a and 4.2.5b express the Pb content differences among the investigated sampling sites both within Aizawl and outside Aizawl of the area in the mean metal content in the three seasons, which include the three seasons respectively. In Figure 4.2.5a, the Pb concentration in the Aizawl area, as there are marked variations between and among the sampling sites. The loadings of Pb are maximum during the monsoon period. Contamination levels in pre-monsoon and post-monsoon periods are similar, with some minor differences at some stations. The Pb concentrations range between 0.57 ppm (at RS-VK2)—1.36 ppm (RS-KT12) in monsoon, 0.26 ppm (RS-VK2)—0.47 ppm (RS-CK9) in pre-monsoon 0.29 ppm (RS-CO11)—0.44 ppm (RS-KK1) in post-monsoon. Pal et al. (2018) indicated that automobiles are the main source of Pb pollution in the roadside environment. They added that vehicle emissions contribute to 43%-49% of Pb in atmosphere and 35%-40% in road sediments and that seasonal monsoon rains increased Pb level by washing away Pb-laden materials, such as building paints, too which is evident from Pb and rainfall correlation at $r = 0.99$.

Figure 4.2.5b shows Pb concentration in locations outside of Aizawl, which represented a lower and less varying content range than in the city of Aizawl with the exception of site RS-SR11. The site RS-SR11 has maximum metal concentration (pre-monsoon: 0.80 ppm, monsoon: 1.03 ppm, and post-monsoon: 0.76 ppm). In the other study areas, the metal contents range from 0.19 ppm to 0.42 ppm in all the seasons. The average metal concentrations are greater within the city (pre-monsoon: 0.37 ppm; monsoon: 0.85 ppm; post-monsoon: 0.36 ppm) than outside Aizawl city (monsoon: 0.35 ppm, pre-monsoon and post-monsoon: 0.27 ppm each). Hence, average metal concentrations are higher during monsoon than pre- and post-monsoon periods.

The concentrations of Pb in Aizawl are higher during the monsoon season due to increased runoff and sediment transport. This observation is consistent with the report of Pal et al., (2018) who also reported that metal concentrations in road sediments are very highly affected by weather conditions, higher concentrations of the metals are likely to occur during wetter conditions. In Aizawl, point sources of RS-BK10, RS-CO11 and RS-KT12 sites have high concentration of Pb resulting from effect of traffic and urbanisation. On the other hand, the Pb concentrations remain low and relatively consistent from places outside Aizawl where human activities are reduced. Similar trend was reported from Khyber Pakhtunkhwa, Pakistan, where sites with less anthropogenic interventions than mining areas exhibited both lower as well as stable Pb concentrations (Khan et al., 2024). It is in line with the current study in Aizawl wherein human activity is reported to have had a significant effect on Pb concentration in different media. Particularly, the science RS-SR11 along the National Highway with dense traffic generated the highest Pb concentration among the sites outside the Aizawl. Increased Pb content on the other hand is hazardous to health, especially in the case of urban areas with heavy traffic. The source of Pb pollution in those places is mostly due to traffic emissions. For example, traffic was found to be the most important source of Pb in road dust in Jinan, China (Chen et al., 2024), indicating that the air of roadside should be paid attention to with regard to Pb pollution.

Pb concentration within Aizawl city

■ pre-monsoon ■ monsoon ■ post-monsoon



	RS-KK1	RS-VK2	RS-SK3	RS-BV4	RS-BB5	RS-LT6	RS-TS7	RS-RN8	RS-CK9	RS-BK10	RS-CO11	RS-KT12
pre-monsoon	0.40	0.26	0.36	0.40	0.28	0.37	0.43	0.32	0.47	0.36	0.36	0.46
monsoon	0.77	0.57	0.64	0.69	0.70	0.64	0.71	0.87	0.75	1.16	1.34	1.36
post-monsoon	0.44	0.33	0.42	0.32	0.36	0.33	0.43	0.36	0.32	0.32	0.29	0.39

Sampling sites

RS-KK1(Kulikawn) RS-VK2 (Vaivakawn) RS-SK3 (Sikulpuikawn) RS-BV4 (Bethlehem Vengthlang) RS-BB5 (Bazar Bungkawn) RS-LT6 (Laipuitlang)
 RS-TS7 (Temple Square) RS-RN8 (Ramhlun) RS-CK9 (Chanmari kawn) RS-BK10 (Bawngkawn) RS-CO11 (MINECO) RS-KT12 (Khatla)

Fig. 4.2.5a. Pb concentration of the roadside soil within Aizawl.

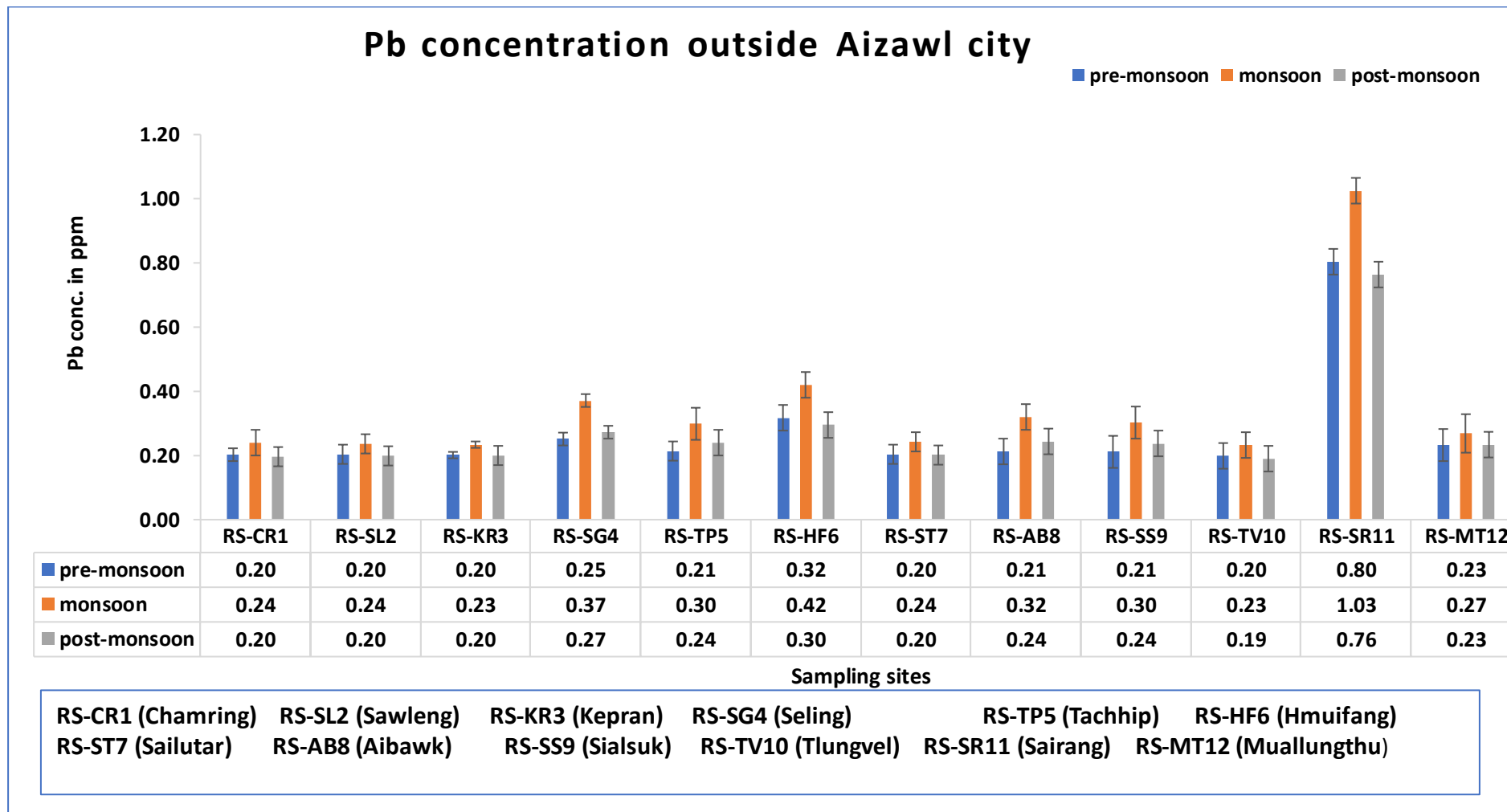


Fig. 4.2.5b. Pb concentration of the roadside soil outside Aizawl city.

Table 4.2.5a. Anova table showing significant variation of Pb within months within Aizawl city (2020-2021).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	0.771	11	0.070	1.255	0.001	1.868
Between the months	13.101	11	1.191	21.313		1.868
Error	6.761	121	0.055			
Total	20.634	143				

Table 4.2.5b. Anova table showing significant variation of Pb within sites and season within Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	5.393	11	0.490	2.328	0.0124	1.868
Between the months	14.008	11	1.273	6.049	0.001	1.868
Error	25.473	121	0.210			
Total	44.874	143				

Table 4.2.5c. Anova table showing significant variation of Pb within sites and season outside Aizawl city (2020-2021).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	0.577	11	0.052	25.466	0.001	1.868
Between the months	0.524	11	0.047	23.121	0.001	1.868
Error	0.249	121	0.002			
Total	1.350	143				

Table 4.2.5d. Anova tables showing significant variation of Pb within sites and season within Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	12.750	11	1.159	185.092	0.001	1.868
Between the months	0.530	11	0.048	7.697	0.001	1.868
Error	0.757	121	0.006			
Total	14.038	143				

Table 4.2.5e. Anova table showing significant variation of Pb within sites and season of the two years within Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between sites	0.302	11	0.027	1.991	0.047	1.967
Between season	5.181	5	1.036	75.030	0.001	2.382
Error	0.759	55	0.013			
Total	6.243	71				

Table 4.2.5f. Anova tables showing significant variation of Pb within sites and season of the two years within Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between sites	2.189	11	0.199	96.891	0.001	1.967
Between Season	0.681	5	0.136	66.354	0.001	2.382
Error	0.112	55	0.002			
Total	2.983	71				

Table 4.2.5g. Mean value of Pb(ppm) with standard deviation of the sites and season within Aizawl city.

Site	pre-monsoon	monsoon	post-monsoon
RS-KK1 (Kulikawn)	0.40 ± 0.04	0.77 ± 0.13	0.44 ± 0.04
RS-VK2 (Vaivakawn)	0.26 ± 0.11	0.57 ± 0.15	0.33 ± 0.16
RS-SK3 (Sikulpuikawn)	0.36 ± 0.14	0.64 ± 0.04	0.42 ± 0.12
RS-BV4 (Bethlehem Vengthlang)	0.40 ± 0.03	0.69 ± 0.19	0.32 ± 0.13
RS-BB5 (Bazar Bungkawn)	0.28 ± 0.11	0.70 ± 0.13	0.36 ± 0.10
RS-LT6 (Laipuitlang)	0.37 ± 0.26	0.64 ± 0.28	0.33 ± 0.05
RS-TS7 (Temple Square)	0.43 ± 0.10	0.71 ± 0.10	0.43 ± 0.15
RS-RN8 (Ramhlun)	0.32 ± 0.22	0.87 ± 0.01	0.36 ± 0.10
RS-CK9 (Chanmari kawn)	0.47 ± 0.25	0.75 ± 0.46	0.32 ± 0.06
RS-BK10 (Bawngkawn)	0.36 ± 0.23	1.16 ± 0.69	0.32 ± 0.15
RS-CO11 (Mineco)	0.36 ± 0.21	1.34 ± 1.11	0.29 ± 0.15
RS-KT12 (Khatla kawn)	0.46 ± 0.30	1.36 ± 0.80	0.39 ± 0.19

Table 4.2.5h. Mean value of Pb(ppm) with standard deviation of the sites and season within Aizawl city.

SITE	pre-monsoon	monsoon	post-monsoon
RS-CR1 (Chamring)	0.20 ± 0.02	0.24 ± 0.07	0.20 ± 0.04
RS-SL2 (Sawlung)	0.20 ± 0.03	0.24 ± 0.06	0.20 ± 0.04
RS-KR3 (Kepran)	0.20 ± 0.03	0.23 ± 0.07	0.20 ± 0.20
RS-SG4 (Seiling)	0.25 ± 0.06	0.37 ± 0.05	0.27 ± 0.10
RS-TP5 (Tachhip)	0.21 ± 0.04	0.30 ± 0.12	0.24 ± 0.07
RS-HF6 (Hmuifang)	0.32 ± 0.00	0.42 ± 0.07	0.30 ± 0.06
RS-ST7 (Sailutar)	0.20 ± 0.06	0.24 ± 0.07	0.20 ± 0.09
RS-AB8 (Aibawk)	0.21 ± 0.05	0.32 ± 0.15	0.24 ± 0.08
RS-SS9 (Sialsuk)	0.21 ± 0.08	0.30 ± 0.06	0.24 ± 0.13
RS-TV10 (Tlungvel)	0.20 ± 0.05	0.23 ± 0.88	0.19 ± 0.05
RS-SR11 (Sairang)	0.80 ± 0.60	1.03 ± 0.05	0.76 ± 0.60
RS-MT12 (Muallungthu)	0.23 ± 0.03	0.27 ± 0.14	0.23 ± 0.02

4.2.6. Zn

The values of Zn at the selected sites for the study period 2020-2022 are shown in Fig. 4.2.6a. and 4.2.6b. at various sites within and outside Aizawl city for three seasons (Pre-monsoon, Monsoon, Post monsoon) deferentially.

Within Aizawl city, Zn concentrations differed significantly between sites in the first year (2020-2021) ($p < 0.019$) and between months ($p < p0.001$). In the second year (2021-2022), there was also a notable difference between sites ($p < 0.012$) and among months ($p < 0.001$), (Table 4.2.5a Table 4.2.5b). Zn concentration minimum and maximum Zn amount was found for RS-SK3 and RS-KT12 (1.16 ± 0.09) and (1.96 ± 0.48) ppm, respectively amongst the 12 sites.

In the first year (2020-2021) and second year (2021-2022) at outskirts of Aizawl city, the variation of Zn was observed to be significant between the sites ($p < 0.013$) Table 4.2.6c and Table 4.2.6d. Amongst the 12 sites, the highest Zn concentration with the mean values of 2.07 ± 0.31 ppm was observed in RS-SR11 and the lowest amount 0.46 ± 0.12 ppm for both RS-ST7 as well.

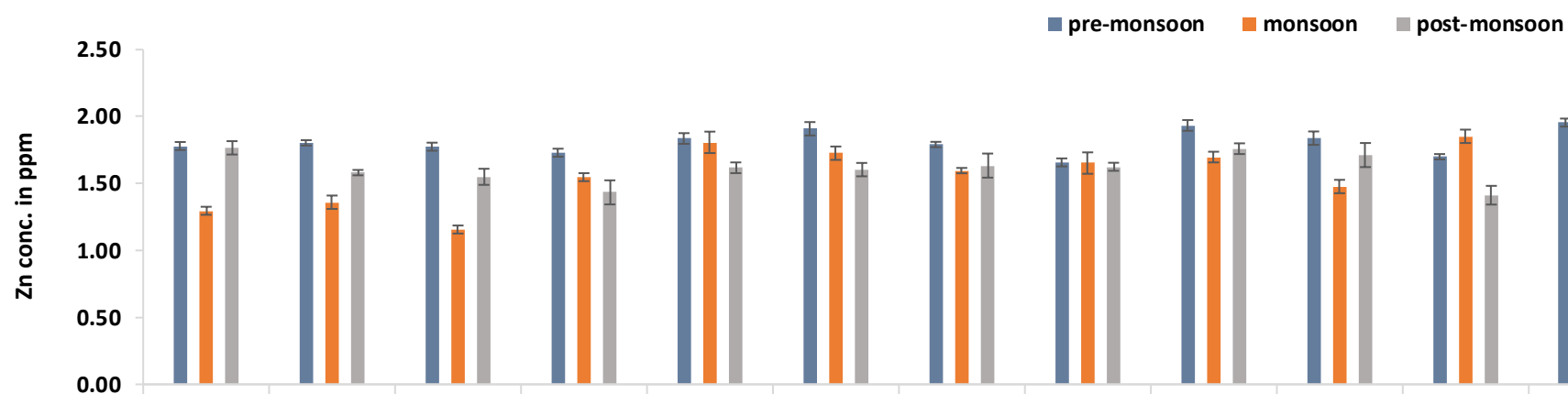
Second year showed higher Zn concentration than first year among the two years. Season showed a marked difference ($p < 0.001$) among Aizawl city. But between Aizawl city high significant variation ($p < 0.001$) is recorded for the two years among sites and seasons and is the same with Aizawl city more ($p < 0.001$). In both the sampling sites, within and outside Aizawl city, is a strong relationship between Zn and traffic activity as well as Pb and rainfall ($r = 0.98$, $r = - 0.67$).

Fig. 4.2.6a and fig. 4.2.6b, depict the changes in Zn levels at various sampling locations in and outside the city of Aizawl as well as its averages in Aizawl's inside and outside the city in the three distinctive seasons (pre-, monsoon, post-monsoon seasons). The Zn concentrations range from 1.66 ppm for RS-RN8 to 1.96 ppm at RSKT12 1.16 ppm at RS-VK2 to 1.85 ppm in monsoon, and 1.41 ppm at RS-CO11 to 1.78 ppm at RS-KT12 in post-monsoon. The influence of sedimentary Zn levels is largely influenced by season as outlined in Kim and Park (2023) with monsoon hydrology strategically redistributing heavy metals. During the pre-monsoon and post-monsoon phases, reduced wash-off leads to higher Zn concentrations, suggesting that

dry conditions facilitate Zn accumulation from human activities. These accumulated metals are largely removed by the intense precipitation associated with the monsoon. In addition, the work of VanHassel et al., (1979) and Ghosh et al., (2020) support this observation, noting that Zn levels peak during drier periods, which highlights the importance of seasonal dynamics in the accumulation and dispersion of metals in urban environments.

The outside Aizawl sites also showed a lower concentration of Zn when compared to that of the city except for RS-CO11. At RS-CO11, the most contamination is shown at by 2.07 ppm Zn in pre-monsoon and by 1.67 ppm, Zn in monsoon and 1.44 ppm Zn in post-monsoon. The pre-monsoon season's Zn concentration from other selected locations (other than Aizawl city) ranges from 0.58 ppm (RS-CR1 and RS-ST7) to 1.09 ppm (RS-HF6), 0.49 ppm (RS-ST7) to 0.89 ppm (RS-HF6) in the monsoon, and 0.48 ppm (RS-ST7) to 0.82 ppm (RS-HF6) in the post-monsoon seasons. City mean values are higher (pre-monsoon = 1.81 ppm, monsoon = 1.56 ppm, post-monsoon = 1.62 ppm) relative to outside (pre-monsoon = 0.94 ppm, monsoon = 0.75 ppm, post-monsoon = 0.71 ppm). Jeong et al., 2022 conducted a study on urban environments in Seoul, South Korea, which found that urbanization increases human activities, leading to significantly higher concentrations of heavy metals in urban areas compared to rural and peri-urban regions. The study emphasizes how the intensified human activities associated with urban growth contribute to metal contamination in densely populated areas.

Zn concentration within Aizawl city



	RS-KK1	RS-VK2	RS-SK3	RS-BV4	RS-BB5	RS-LT6	RS-TS7	RS-RN8	RS-CK9	RS-BK10	RS-CO11	RS-KT12
pre-monsoon	1.78	1.80	1.78	1.73	1.84	1.91	1.79	1.66	1.93	1.84	1.70	1.96
monsoon	1.30	1.36	1.16	1.55	1.81	1.73	1.60	1.65	1.70	1.48	1.85	1.52
post-monsoon	1.77	1.58	1.55	1.43	1.62	1.60	1.63	1.63	1.76	1.71	1.41	1.78

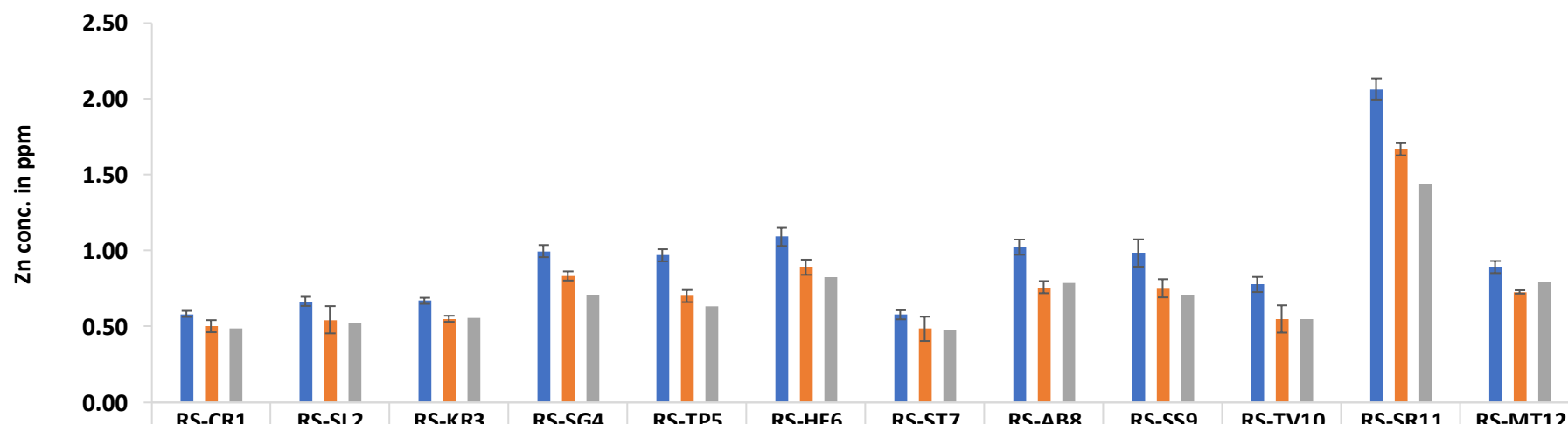
Sampling sites

RS-KK1(Kulikawn) RS-VK2 (Vaivakawn) RS-SK3 (Sikulpuikawn) RS-BV4 (Bethlehem Vengthlang) RS-BB5 (Bazar Bungkawn) RS-LT6 (Laipuitlang)
 RS-TS7 (Temple Square) RS-RN8 (Ramhlun) RS-CK9 (Chanmari kawn) RS-BK10 (Bawngkawn) RS-CO11 (MINECO) RS-KT12 (Khatla)

-Fig. 4.2.6a. Zn concentration of the roadside soil within Aizawl.

Zn concentration outside Aizawl city

■ pre-monsoon ■ monsoon ■ post-monsoon



	RS-CR1	RS-SL2	RS-KR3	RS-SG4	RS-TP5	RS-HF6	RS-ST7	RS-AB8	RS-SS9	RS-TV10	RS-SR11	RS-MT12
pre-monsoon	0.58	0.67	0.67	1.00	0.97	1.09	0.58	1.02	0.99	0.78	2.07	0.89
monsoon	0.50	0.55	0.55	0.83	0.70	0.89	0.49	0.76	0.75	0.55	1.67	0.73
post-monsoon	0.49	0.53	0.56	0.71	0.64	0.82	0.48	0.79	0.71	0.55	1.44	0.80

Sampling sites

RS-CR1 (Chamring) RS-SL2 (Sawleng) RS-KR3 (Kepran) RS-SG4 (Seling) RS-TP5 (Tachhip) RS-HF6 (Hmuifang)
 RS-ST7 (Sailutar) RS-AB8 (Aibawk) RS-SS9 (Sialsuk) RS-TV10 (Tlungvel) RS-SR11 (Sairang) RS-MT12 (Muallungthu)

Fig. 4.2.6b. Zn concentration of the roadside soil outside Aizawl city.

Table 4.2a. Anova table showing significant variation of Zn within sites and season within Aizawl city (2020-2021).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	2.106	11	0.191	2.1860	0.019	1.869
Between the months	38.205	11	3.473	39.642	0.001	1.869
Error	10.601	121	0.087			
Total	50.914	143				

Table 4.2.6b. Anova table showing significant variation of Zn within sites within Aizawl city (2021-2022).

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	2.877	11	0.261	2.304	0.013	1.869
Between the months	1.461	11	0.132	1.1705	0.314	1.869
Error	13.734	121	0.113			
Total	18.073	143				

Table 4.2.6c. Anova table showing significant variation of Zn within sites and season outside of two years within Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	14.635	11	1.330	82.490	0.001	1.869
Between the months	3.863	11	0.351	21.778	0.001	1.869
Error	1.951	121	0.016			
Total	20.451	143				

Table 4.2.6d. Anova table showing significant variation of Zn within sites and season for two years outside Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the sites	14.808	11	1.346	38.378	0.001	1.869
Between the months	6.463	11	0.587	16.751	0.001	1.869
Error	4.244	121	0.035			
Total	25.516	143				

Table 4.2.6e. Mean value of Zn (ppm) with standard deviation of the sites and season outside Aizawl city.

SITE	pre-monsoon	monsoon	post-monsoon
RS-CR1 (Chamring)	0.58 ± 0.15	0.50 ± 0.18	0.49 ± 0.06
RS-SL2 (Sawleng)	0.67 ± 0.27	0.55 ± 0.19	0.53 ± 0.18
RS-KR3 (Kepran)	0.67 ± 0.27	0.55 ± 0.24	0.56 ± 0.24
RS-SG4 (Seiling)	1.00 ± 0.23	0.83 ± 0.17	0.71 ± 0.05
RS-TP5 (Tachhip)	0.97 ± 0.52	0.70 ± 0.23	0.64 ± 0.21
RS-HF6 (Hmuifang)	1.09 ± 0.50	0.89 ± 0.17	0.82 ± 0.27
RS-ST7 (Sailutar)	0.58 ± 0.33	0.46 ± 0.12	0.48 ± 0.27
RS-AB8 (Aibawk)	1.02 ± 0.45	0.76 ± 0.28	0.79 ± 0.36
RS-SS9 (Sialsuk)	0.99 ± 0.75	0.75 ± 0.31	0.71 ± 0.45
RS-TV10 (Tlungvel)	0.78 ± 0.14	0.55 ± 0.06	0.55 ± 0.27
RS-SR11 (Sairang)	2.07 ± 0.31	1.67 ± 0.20	1.44 ± 0.02
RS-MT12 (Muallungthu)	0.89 ± 0.38	0.73 ± 0.25	0.80 ± 0.35

Table 4.2.6f. Correlation of heavy metals with rainfall and traffic activities within Aizawl city.

	Rainfall	Traffic activities	Cu	Fe	Mn	Ni	Pb	Zn
Rainfall	1	0.97**	-0.97**	-0.59	-0.88*	-0.53	0.99**	-0.67
Traffic activities	-	1	0.97**	0.86*	0.53	0.98**	0.98**	0.99**
Cu			1	0.75*	0.96**	0.70*	- 0.98**	0.81*
Fe				1	0.90**	0.99**	-0.62*	0.99**
Mn					1	0.87*	- 0.90**	0.94**
Ni						1	-0.57	0.98*
Pb							1	-0.74*
Zn								1

*: significant at $p < 0.05$; **: significant at $p < 0.01$.

Table 4.2.6g. Correlation of heavy metals with rainfall and traffic activities outside Aizawl city.

	Rainfall	Traffic activities	Cu	Fe	Mn	Ni	Pb	Zn
Rainfall	1	0.99**	-0.87*	-0.45	-0.67*	-0.48	0.99**	-0.49
Traffic activities	-	1	0.81*	0.66*	0.51	0.78*	0.88*	0.91**
Cu			1	0.61*	0.76*	0.60	-0.78*	0.78*
Fe				1	0.84*	0.94**	-0.65	0.99**
Mn					1	0.84*	-0.89*8	0.95**
Ni						1	-0.61*	0.99**
Pb							1	-0.69*
Zn								1

*: significant at $p < 0.05$; **: significant at $p < 0.01$

In the urban environment of Aizawl, rainfall shows strong negative correlations with most heavy metals, particularly Cu ($r = -0.97$), Mn ($r = -0.88$), Zn (-0.67). This indicates that rainfall likely plays a substantial role in washing out heavy metals from the air, especially those associated with surface-level pollution such as from road dust or vehicular emissions. Rainfall, interestingly, shows a very strong positive correlation with Pb ($r = 0.99$), suggesting that Pb may originate from sources unaffected by precipitation or may become resuspended more readily after rainfall.

The variations in traffic within Aizawl show good positive correlation with all the heavy metals though only Cu ($r = 0.97$), Fe ($r = 0.86$), Ni ($r = 0.98$), Pb ($r = 0.98$) and Zn ($r = 0.99$) are significant relationships clearly indicate that vehicular emissions and related urban traffic are major contributors to heavy metal presence in airborne particles. Furthermore, strong inter-metal correlations such as between Mn and Cu ($r = 0.96$), Fe and Ni ($r = 0.99$), and Fe and Zn ($r = 0.99$), suggest common sources—likely vehicular wear and combustion.

The correlation matrix for the sites in the periphery of Aizawl city is also showing negative correlations among rainfall and the heavy metals but with a lesser magnitude

as compared to within the city. For instance, rainfall shows a negative correlation with Cu, ($r = -0.87$), Mn ($r = -0.67$), and Zn ($r = -0.49$), again indicating that rainfall contributes in diminishing concentration of aerial pollutants, but maybe less effective as a result of lower pollution loads. Once again, rain and Pb exhibit a strong positive relationship ($r = 0.99$), parallel to that observed for the urban data, suggesting possibly similar behaviour or sources of Pb between the two regions.

Depending of the traffic activities outside the city relatively weaker, than inside the city, but still significant positive correlation with heavy metals was observed. Strong correlations were observed between traffic and Cu ($r = 0.81$), Fe ($r = 0.66$), Ni ($r = 0.78$), and Zn ($r = 0.91$) indicate that vehicular emissions are an important contributing source in less urbanized zones as well. The metal-metal relationships Fe-Ni ($r = 0.94$), Mn-Ni ($r = 0.84$) and Fe-Zn ($r = 0.99$) are still strong irrespective of core city and suggest common sources such as industrial combustion processes and vehicle parts even beyond the home city.

Periodically, in and around Aizawl city traffic is the major and regular source of HM pollution including Cu, Ni and Zn. Rainfall is found to lower metal levels in general except for Pb as a response of disturbance, possibly resuspension or legacy contamination. Stronger relationships between traffic and metal concentrations are observed in urban context, reflecting the higher traffic density and its related activities, and weaker ones in rural or peripheral zones to the city, with limited but still apparent contributions of pollution sources.

The results have important implications for urban environmental management indicating that the control of traffic emissions and the improvement of rainfall-based mitigation (like green infrastructure and clean drainage) could reduce airborne heavy metals pollution, particularly in heavily populated districts such as Aizawl city.

4.2.7. Impact of COVID-19 Lockdown on Metal Contamination in Soil.

The sampling was conducted during and after the COVID-19 pandemic. The government implemented strict total lockdowns during this global crisis, starting in March 2020, followed by partial lockdowns, that lasted for over a year. These measures significantly restricted vehicle movements and reduced various human activities, including human movements. This unique situation allowed for comparisons to be

made between the pandemic period (August 2020 – July 2021) and the subsequent post-pandemic period (August 2021 – July 2022) regarding the effects of COVID-19, as well as the impacts of vehicular traffic and other human activities on heavy metal contamination levels. The mean metal concentrations at each site during the COVID-19 pandemic period, as presented in this section, are the mean values calculated from the monthly data collected from August 2020 to July 2021. A similar calculation was performed for the mean metal concentrations in the post-COVID period, spanning from August 2021 to July 2022. While Fe is included in the analysis, it is not represented in the graph due to its significantly higher mean concentration compared to the other metals. This disparity makes it difficult to visualize the variations in the concentrations of the other metals in during both the COVID-19 and post-COVID periods.

The comparative plots representing values of some heavy metal, specifically Cu, Mn, Ni, Pb and Zn for various sampling locations in Aizawl are shown in Fig. 4.2.7a under COVID-19 lockdown period and after lockdown (post-COVID period). The solid line shows the data during the COVID-19 pandemic and the dotted lines show the data post-COVID. Levels are in ppm. The illustration displays remarkable variations in the metal deposition in the urban soils, which could reflect variations in human activities linked to the pandemic. During COVID, concentrations in Cu varied between 0.46 and 0.99 ppm across the sites, which also signified a decline when compared to the post-COVID period, where Cu level significantly increased to a range of 1.16 and 1.78 ppm. This fluctuation in metals concentrations through and after the COVID time span also correlated well with reduced road traffic, industrial emissions, and other anthropogenic influence during the pandemic. The increment in Cu concentration is in agreement with the increased regular traffic and industrial activities, because copper is widely sourced from vehicle tires and brake pads, the engine and exhaust emissions (Kim and Park, 2023). Although Zn concentrations were 1.35–1.84 ppm during the COVID period, in the post-COVID period, they ranged from 1.44 to 1.96 ppm. Zinc is a common product of tire wear and road surface weathering, and higher post-COVID concentrations suggest increased traffic inputs.

Mn also shows the greatest increase, from around 2.69–3.43 ppm during COVID pandemic to 4.88 ppm and up to normally 8.57 ppm in some locations in the post-COVID period. This high increase in the Mn levels is alarming, since Mn is mainly associated with wear from metal alloys in car parts, and high concentrations of Mn can be toxic. The pattern of increasing Mn accumulation is consistent with other studies throughout the world in urban areas (Yang et al., 2021 in Xiamen, China; Umer et al., 2021 in Faisalabad, Pakistan), where high Mn concentrations were associated with urban traffic and industrial emissions. Furthermore, the study by Carrero et al., (2012) and Lu et al., (2022) emphasize the influence of climatic conditions on pollutant dispersion. It indicates that atmospheric transportation from other areas of India is also a source of variation, and monsoon and Aizawl's monsoon period could influence the distribution and accumulation of pollutants. During arid periods, metal accumulation will downslope and wash-off may occur during increasing monsoonal rains. There were also remarkable elevations of Ni and Pb. For Ni, from 0.25-0.54 ppm during COVID and 0.46-0.73 ppm after-COVID. In addition, Ni in urban areas predominantly came from fuel combustion and the abrasion of vehicle bodywork, and the rising Ni concentration post-pandemic indicated the vehicle-produced metal pollution during non-pandemic period. Although the emissions of lead are much less common with modern fuels because of regulatory limitations, the levels also increased from 0.29–0.50 ppm in COVID to 0.49–1.04 ppm in post-COVID, perhaps as a consequence of contamination and leaching from other sources. Fe also demonstrated significant differences and ranged between 20.54 and 21.30 ppm in the COVID period to 26.94–30.94 ppm in the post-COVID period.

These results together indicate the impact of anthropogenic activities on heavy metal accumulation in urban soils, especially when vehicular emissions and industrial emissions were restored after the lockdown. Corresponding findings have been reported in other metropolitan cities such as Chattogram, Bangladesh (Deb et al., 2024) and in Seoul, South Korea (Jeong et al., 2022), where higher traffic density and proximity to industrial areas were directly linked to increased heavy metal concentrations in soil and road dust. The patterns observed in Aizawl indicate an urgent need for environmental monitoring and mitigation strategies to address the ecological risks posed by heavy metal pollution. These measures are essential in urban

environments, where elevated metal levels in soil could have long-term health implications for residents through exposure pathways, including inhalation of dust, soil ingestion, and contaminated water runoff.

Fig. 4.2.7b. presents data on heavy metal concentrations, Cu, Mn, Ni, Pb and Zn, measured at various roadside soil sampling sites in selected town areas outside Aizawl City. These areas typically have lower traffic density and industrial activity compared to the city itself, resulting in slightly lower metal concentrations. The reduced population density and diminished vehicular emissions in these locations contribute to this difference. However, post-COVID data reveal a clear increase in metal levels, reflecting the resurgence of human activities, such as traffic and small-scale industrial operations, even in these less populated regions. The study by Jeong et al., (2022) explains how anthropogenic activities, particularly traffic and localized industries, affect metal accumulation in less dense areas, indicating that even semi-urban environments can experience significant pollution due to the resumption of human activities

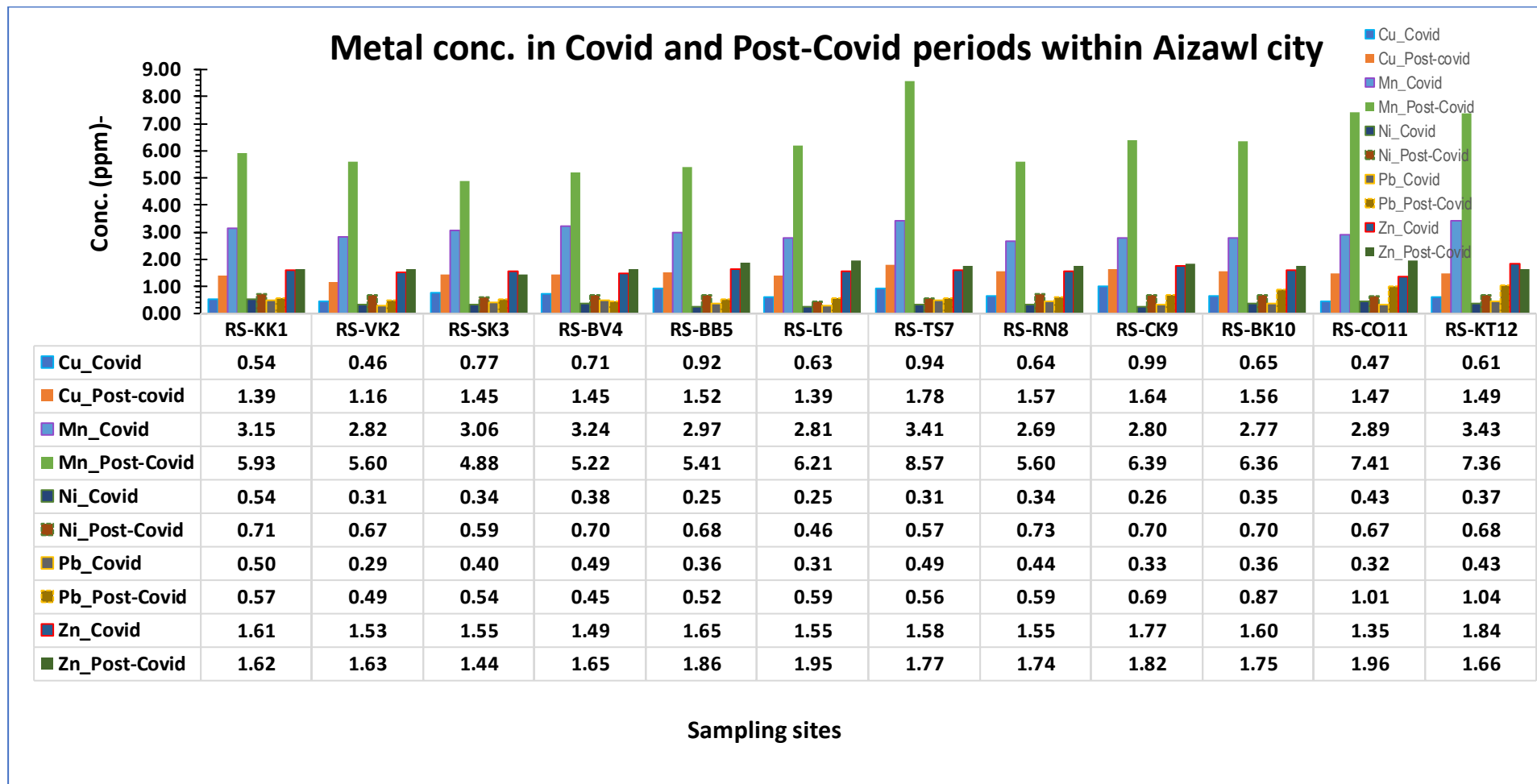


Fig. 4.2.7a. Metal concentration in Covid and Post-Covid periods within Aizawl.

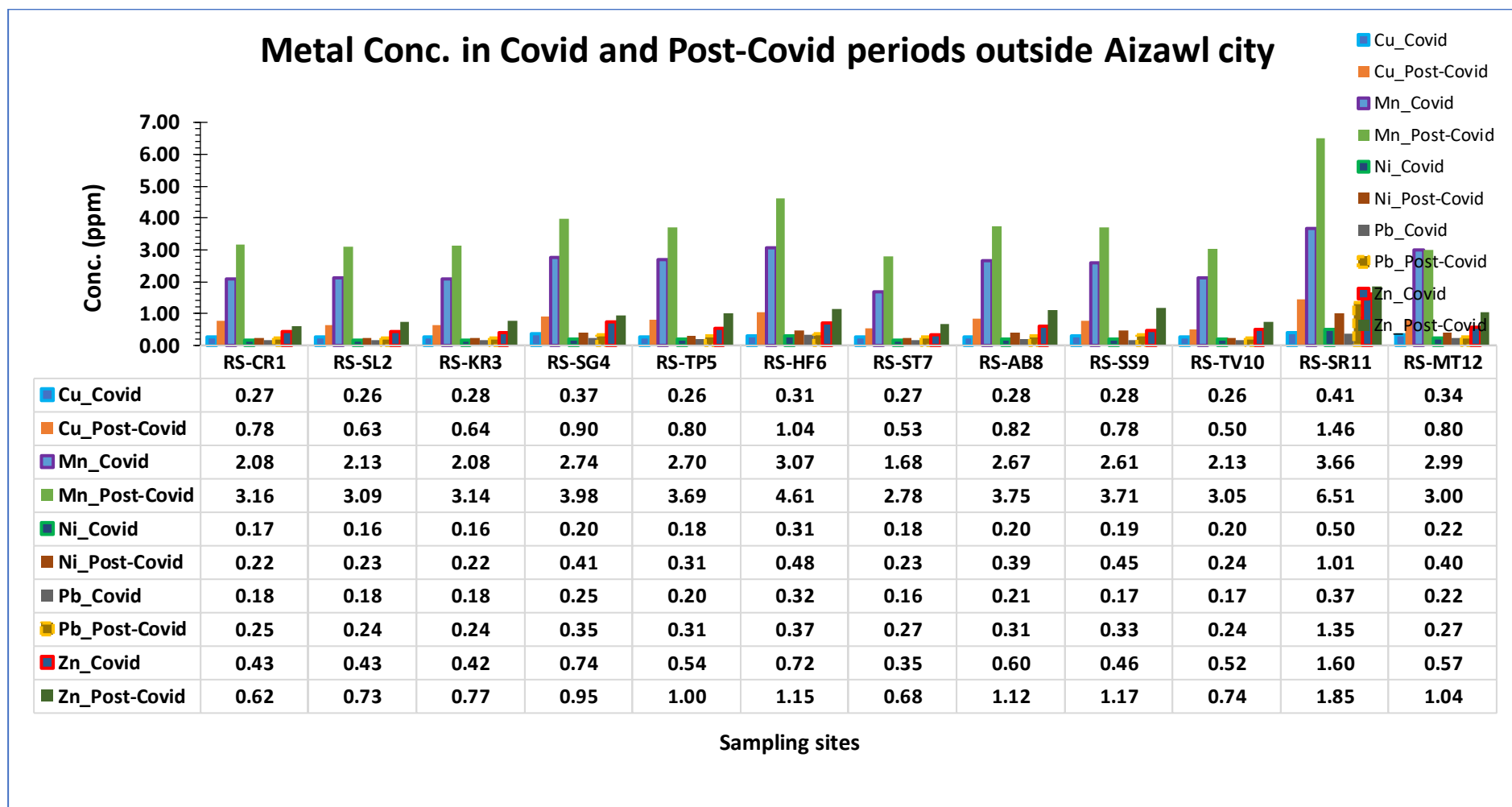


Fig. 4.2.7b. Metal concentration in Covid and Post-Covid periods outside Aizawl.

During the COVID-19 lockdown, Cu concentrations ranged from 0.26 to 0.41 ppm, reflecting minimal human activity. This is noteworthy because Cu is commonly emitted from vehicle brake pads and exhaust systems. In the post-COVID period, Cu levels increased to between 0.50 and 1.46 ppm across these sites, indicating a return of vehicles to the roads and emphasizing the impact of traffic on Cu accumulation. Similarly, Zn, which is associated with vehicular sources like tire wear and engine oil, showed an increase in concentration from 1.35 ppm during the COVID period to a significantly higher level of 2.10 ppm at one site. In the post-COVID period, Zn concentrations ranged from 0.62 to 1.85 ppm. The study by Kim and Park (2023) elaborates on how specific vehicle components, such as tires and brake pads, contribute to Cu and Zn emissions, particularly in areas where traffic resumed after periods of reduced activity. The presence of these metals in roadside soils underscores the significant role that even moderate vehicular movement plays in pollutant accumulation.

Notable variation is observed in Fe, with concentrations during the COVID lockdowns ranging from 12.92 to 21.21 ppm, which were already elevated due to natural soil composition and minor anthropogenic contributions. During post-COVID, iron levels increased further, reaching 18.73 to 35.23 ppm. This trend aligns with findings from Yang et al., (2021), whose study on urban dust in Xiamen Island, China, demonstrated that iron concentrations are heavily influenced by vehicular activity and road wear, even in less urbanized areas. They emphasize that iron contamination can be widespread in regions with moderate to high traffic, suggesting that even towns outside major urban centers can experience substantial iron accumulation with the return of regular traffic. Mn is another metal commonly linked to traffic and industrial emissions, and the concentration rose from 1.68–3.66 ppm during COVID to 2.49–6.51 ppm in the post-COVID period. A study by Umer et al., (2021) on urban soils in Faisalabad, Pakistan, also found a strong correlation between Mn levels and vehicle emissions as well as industrial processes. They explain that Mn is released from vehicle exhaust and metal components. The elevated levels of Mn observed post-

COVID in the town areas outside Aizawl reinforce the role of renewed vehicular activities in soil contamination, even outside the city center.

The level of Ni increased from 0.18–0.50 ppm to 0.22–1.01 ppm, and Pb from 0.16–0.37 ppm to 0.24–1.35 ppm for COVID and post-COVID periods, respectively. Ni is frequently added to the surroundings by fuel incineration and the abrasion of vehicles. While lead has been taken out of the gasoline, there are pathways for it to get into the soil from emissions of older vehicles and certain industrial activities. Research by Carrero et al., (2012) highlights that even residual sources, such as emissions from older vehicles, can also contribute to the accumulation of lead and nickel in soils, particularly in moderate industrialised regions. This report reinforces the fact that sparsely inhabited regions are not immune to the injurious effects of these pollutants and thus the monitoring must not be relaxed. Altogether, these findings reveal that not only such a small town like Aizawl, even towns other than Aizawl are not bio-metals contamination-free, particularly after the reemergence of traffic and other human activities after the COVID pandemic. The increasing levels of metals in this study are in agreement with overall studies which have reported lesser pollution in semi-urban region as compared to urban area still that is not a reason of lesser metal accumulation owing to anthropogenic factor. Such studies, like Deb et al., (2022) for Chattogram city of Bangladesh, and Jeong et al., (2022) focusing on peri-urban areas in South Korea), indicate that smaller towns experience significant pollution from traffic and industrial activity as well. This highlights the importance for environmental monitoring and management on a routine basis for both urban and semi-urban areas to minimize the threat imposed by the ecological and health risks of heavy metals.

4.3. The Heavy Metal Pollution Indices

4.3.1. EF

The EF values of heavy metals such as Cu, Fe, Mn, Ni, Pb, and Zn at different sampling sites within Aizawl and outside Aizawl city are shown in Fig. 5.3.1a and 5.3.1b. respectively. The EF is a measure used to assess the degree of anthropogenic impact on the concentration of metals in the environment, with values greater than 1 indicating enrichment relative to a baseline or reference value, often indicating human activities

as given by Beniwal and Sunda (2023) and Hu et al., (2013). Fe is not included in the figure as it is used as a reference element in the EF calculation. The EF values given for different heavy metals at various sites within Aizawl in Fig. 5.3.1a. show considerable variation. For Cu, the EF values range from 1.55 at RS-VK2 to 2.63 at RS-TS7, indicating minimal pollution to moderate pollution levels. The EF value of Mn was in the range of 1.28 (at RS-SK3 and RS-RN8) to 1.82 (RS-TS7), and Zn varies from 1.54 (at RS-SK3) to 1.83 (RS-KT12), indicating minimal enrichment. Ni shows the highest EF at RS-KK1 (2.16), and EF values of Pb at the sites such as RS-BK10 (2.00), RS-CO11 (2.12), and RS-KT12 (2.54) show also show moderate enrichment or pollution. All the other sites show EF values less than 2.00 for Ni and Pb. Barbieri et al., (2015) indicated that EF vales less than 2 are under the categories of minimal pollution for Ni and Pb.

Figure 5.3.1b shows the EF for selected HMs in some of the collected samples and also at some sites located across Aizawl. The EF of Cu, Mn, Zn are ranged from 1.12 to 1.72, 1.11 to 1.63 and 0.77 to 1.57, respectively, which showed low enrichment of these metals. The largest EF value: EF of Ni and Pb at site RS-SR11 is 2.23 and 2.40, respectively, pointing moderate enrichment. The Ni and Pb enrichment grades at all other sites are very low. The EF values indicate high anthropogenic impact within Aizawl, and relatively lower enrichment levels at the sites outside the city. This suggests that urbanization plays an important role in the pollution of HM in urban regions, which is consistent with the results that the contamination of urban soils is higher, mainly because the region is the center of human activities (Ayaz et al., 2023; Hu et al., 2013).

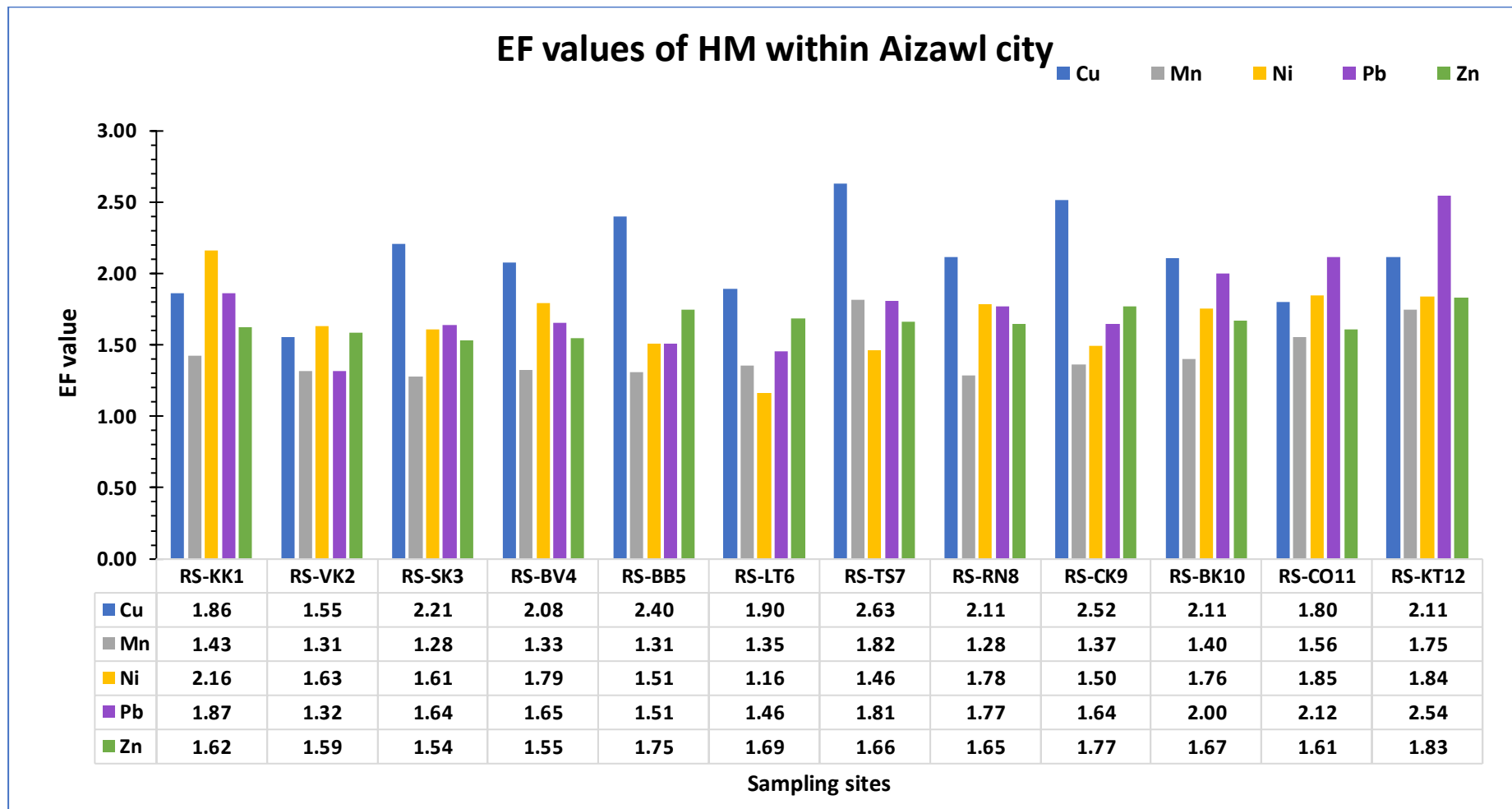


Fig. 4.3.1a. EF of HM in the roadside soil within Aizawl.

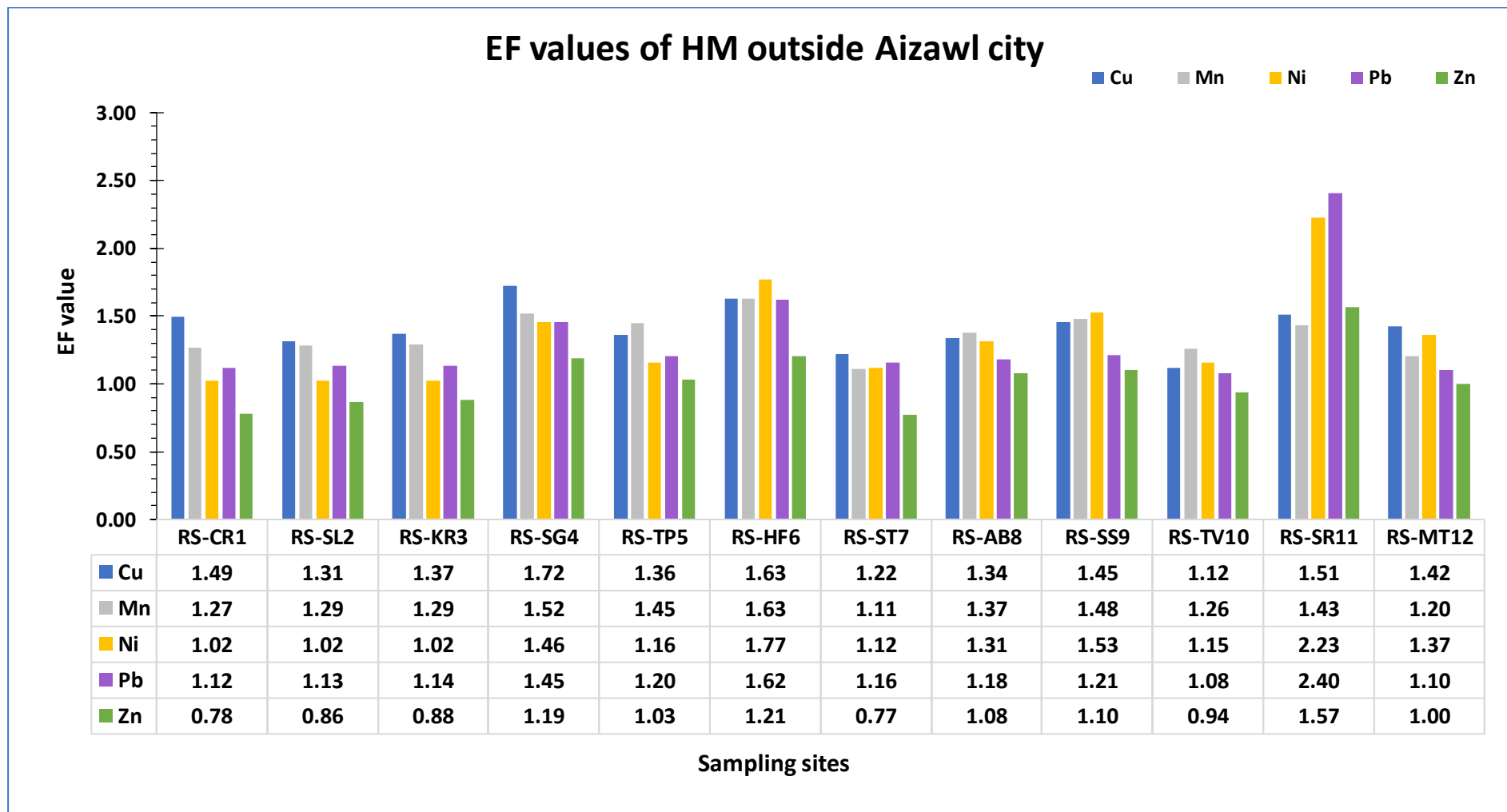


Fig. 4.3.1b. EF of HM in the roadside soil outside Aizawl.

4.3.2. CF

Fig. 4.3.2a. and 4.3.1b. depict the CF of heavy metals (Cu, Fe, Mn, Ni, Pb and Zn) in various sampling locations at Aizawl and beyond Aizawl, respectively. The contamination factor is a comparative ratio measure of the extent of contamination of metals by comparing inner concentration with the background or standard value.

In Fig. 5.3.2a, the CFs of heavy metals differ significantly among sites. The high CFs for several metals at different stations also reveal multi-origin contamination. It can be found that Cu has the highest CF value, varying from 3.27(at RS-VK2) to 5.19 (at RS-CK9), MI values are all smaller than 7, although all under considerable contamination degree. Fe has similar low and close CF values (1.96 at RS-KK12) through (2.11 at RS-CK9), indicating that it is less contaminated than other metals. The CF of Mn ranges between 2.59 (RS-SK3) to 3.97 (RS-TS7); Ni ranges between 2.41 (RS-SLT6) and 3.87 (RS-KK1), Pb varies from 2.55 (RS-VK2) and 4.72 (RS-KT12), and CF of Zn varies from 2.96 (RS-SK3) and 3.53 (RS-CK9). The CF in Mn, Ni, Pb and Zn are therefore considered in the category of moderate to high contamination which meant the sources of contamination are from traffic and anthropogenic activities in Aizawl. Akter et al., (2023) studied the CF of heavy metals containing Mn, Ni, Pb, and Zn in urban soils from Dhaka, Bangladesh. They discovered that between moderate and high levels of contamination caused mainly by traffic pollution and human behaviour. This is consistent with the example of Aizawl where again it was urban traffic-related pollution that caused significant contamination. Their results reveal the close relationships between urbanization, high density of traffic, and heavy metal pollution, and indicate that effective countermeasures of heavy metal pollution in a city should be enforced.

Fig. 4.3.2b. shows the CF values for heavy metals of the samples collected from outside the city Aizawl which seem to be lower and comparatively uniform in distribution compared to the city. Only some sites have significant contamination levels for certain of the heavy metals, such as CF values of 3.89 for Cu at RS-SR11, 3.19 for Mn at RS-SR11, 3.02 and 5.60 for Ni at RS-HF6 and RS-SR11 respectively and 3.63 and 3.96 for Pb at RS-SG4 and RS-HF6 respectively and 4.16 for Zn at RS-

SR11. In the present study, the CF value of 6.69 for Pb at RS-SR11 is extremely high and this exists in the very highly contaminated category.

Studies by Chen et al., (2024) in Jinan, China and Tripathi and Nema (2024) at Delhi, India have reported that road dust of this highly populated metropolis consists of high concentrations of metals like Pb, Cu, and Zn. These high levels are mainly due to vehicle emissions, which points out the importance of the traffic in the metal contamination in urban atmosphere. This trend is in close agreement with results from Aizawl where traffic is also an important source of HM in roadside soils.

The CFs are also important to evaluate the level of urban exposure. Research works such as Saha et al., (2017), Metals in particulates of outdoor air around a heavily trafficked round-about in Delhi – quantification, correlations and sources, 527th International workshop on total scattering data and applications in materials science and industry, In the case of Aizawl also, the metal CF values are high in central regions of the city, represents considerable contamination and in the peripheral part of the city (less urbanized), the CF values of the metals are low. The baseline values of essential metals, notably Fe, Zn, Cu, and Mn, in natural soils are illustrated by research work of Ashesh and Devi (2023) in Northeast India. Although normal components of the earth's crust, they can be rendered toxic in urban settings. It is in agreement with the findings in Aizawl, that anthropogenic activities have increased the concentrations of these metals above natural background concentration and have the potential to pose ecological risk. Furthermore, Efremova et al., (2020) in Moscow, Russia and by Ali et al., (2019) in Karachi, Pakistan, have reported the higher content of heavy metals (Pb and Ni) in urban soils due to vehicular emissions. These findings also highlight but the condition in Aizawl where the vehicular exhaust have a major role for the contamination of Pb and Ni in urban soils. This highlights the importance of controlling pollution in traffic-heavy areas.

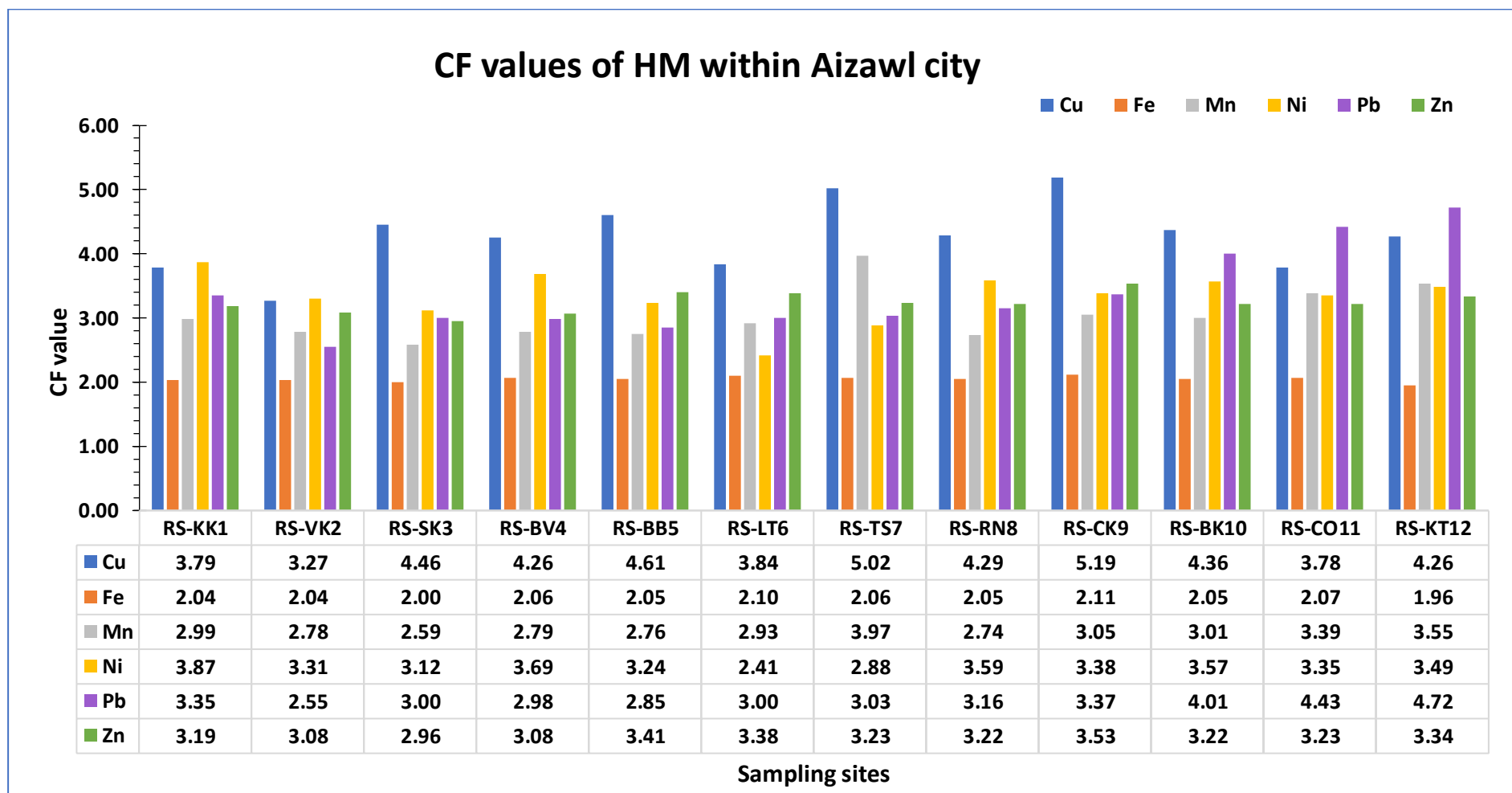


Fig. 4.3.2a. CF of HM in the roadside soil within Aizawl.

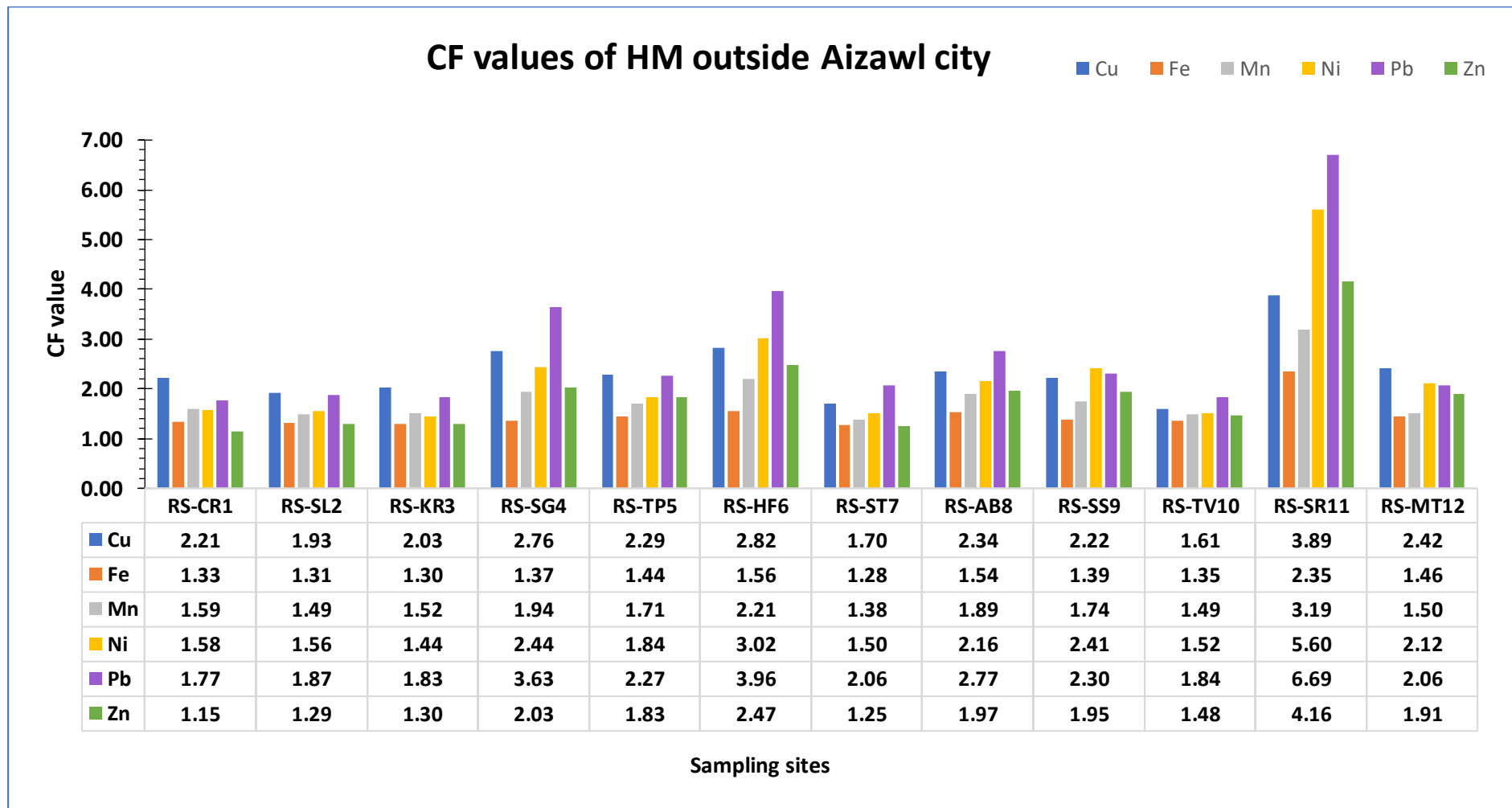


Fig. 4.3.2b. CF of HM in the roadside soil outside Aizawl.

4.3.3. Pollution Load Index (PLI)

Figure 4.3.3a and Figure 4.3.3b show the PLI of heavy metals (Cu, Fe, Mn, Ni, Pb, and Zn) for various sampling stations in the Aizawl and compared it with outside Aizawl. The PLI is an index created to assess the heavy metal pollution level in general. Fig. 5.3.3a. presents the PLI of the heavy metal for Aizawl. The figure also shows a significant temporal variation at each sampling site, influenced by local pollution sources. The PLI values of Cu are between 2.78 (RS-VK2) and 4.64 (RS-CK9) demonstrating moderate to high contamination of Cu. Fe has intermediate PLI values, from 1.94 in RS-KT12 to 2.03 in RS-BV4, indicating less contamination in comparison to other metals. The PLI for Mn varies from 2.50 (at RS-RN8) to 3.77 (at RS-TS7), for Ni, it varies from 2.22 (at RS-LT6) to 3.60 (at RS-KK1), for Pb it varies 2.37 (at RS-VK2) to 3.65 (at RS-KT12). In contrast, Zn PLI ranges from 2.90 at RS-SK3 to 3.52 at RS-CK9, indicating high sediment quality in some metals at various survey points.

Study by Kaushik et al., (2022) in Chandigarh, India for assessing contamination of heavy metals in urban soils and concentrating on metals Pb, Cu and Zn using the PLI. Their study found that PLI values greater than 1 at various urban sites indicated moderate to significant contamination, driven largely by traffic emissions and industrial activities. Specifically, PLI values above 2 were observed at some sites, reflecting substantial pollution levels and suggesting intensive human activity in these areas. This finding aligns closely with results from Aizawl, where similar PLI values often exceeding 1 and reaching above 2 in high-traffic zones underscore the impact of anthropogenic activities, especially vehicular emissions, on heavy metal pollution within the city.

Bali and Sidhu (2021) also worked on Ludhiana, India which is a metro-city with dense traffics, they utilized the Pollution Load Index for determining the soil contamination by Pb, Zn, and Cu. Their study revealed elevated PLI values across multiple sites, with values often greater than 1, indicating moderate pollution, and some exceeding 2, denoting considerable contamination associated with urbanization and high traffic flow. This pattern is comparable to the situation in Aizawl, where elevated PLI values

similarly indicate significant pollution loads in urban soils, particularly in traffic-heavy areas. These findings highlight the need for monitoring and management of metal pollution in densely populated regions, as high PLI values reflect the substantial influence of urban traffic and industrial activities on heavy metal accumulation.

Fig. 4.3.3b. displays the HM's PLI values in HM's concentrations sites outside Aizawl; the heavy metals' PLI are, in general, lower than inside the city which indicates relatively light contamination. The PLI of all metals studied was lower than 3.00, with the only exception at RS-SR11. The PLI of Cu, Fe, Mn, Ni, Pb, and Zn are 3.63, 2.32, 3.22, 5.22, 6.60, and 3.37, respectively indicating moderately polluted to an extremely highly polluted level at the RS-SR11. PLI values of Cu, Fe, Mn, Ni, Pb and Zn in other sites are ranged 1.51–2.51, 1.31–1.59, 1.34–2.41, 1.35–2.70, 1.46–2.35 and 1.03–1.84, respectively which all are also belonging to moderate polluted category. While the PLI values provide a quantitative measure of heavy metal pollution, it is crucial to consider the broader ecological and health impacts. Heavy metals, being non-biodegradable, pose significant risks to ecosystems and human health, affecting food safety and causing toxicological effects even at low concentrations. Therefore, comprehensive monitoring and strategic planning are essential to mitigate these risks and protect public health (Javaid et al., 2020).

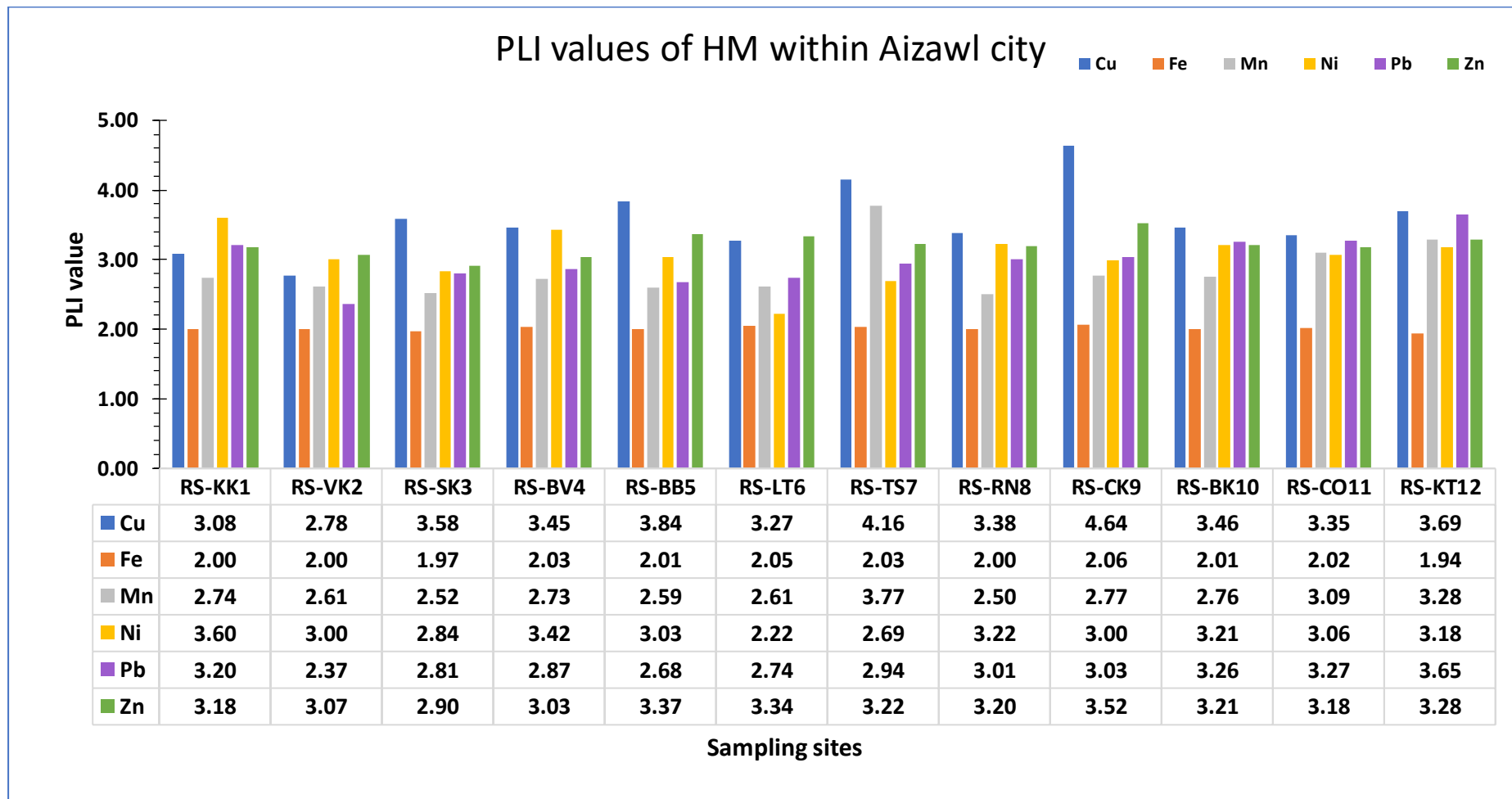


Fig. 4.3.3a. PLI of HM in the roadside soil within Aizawl.

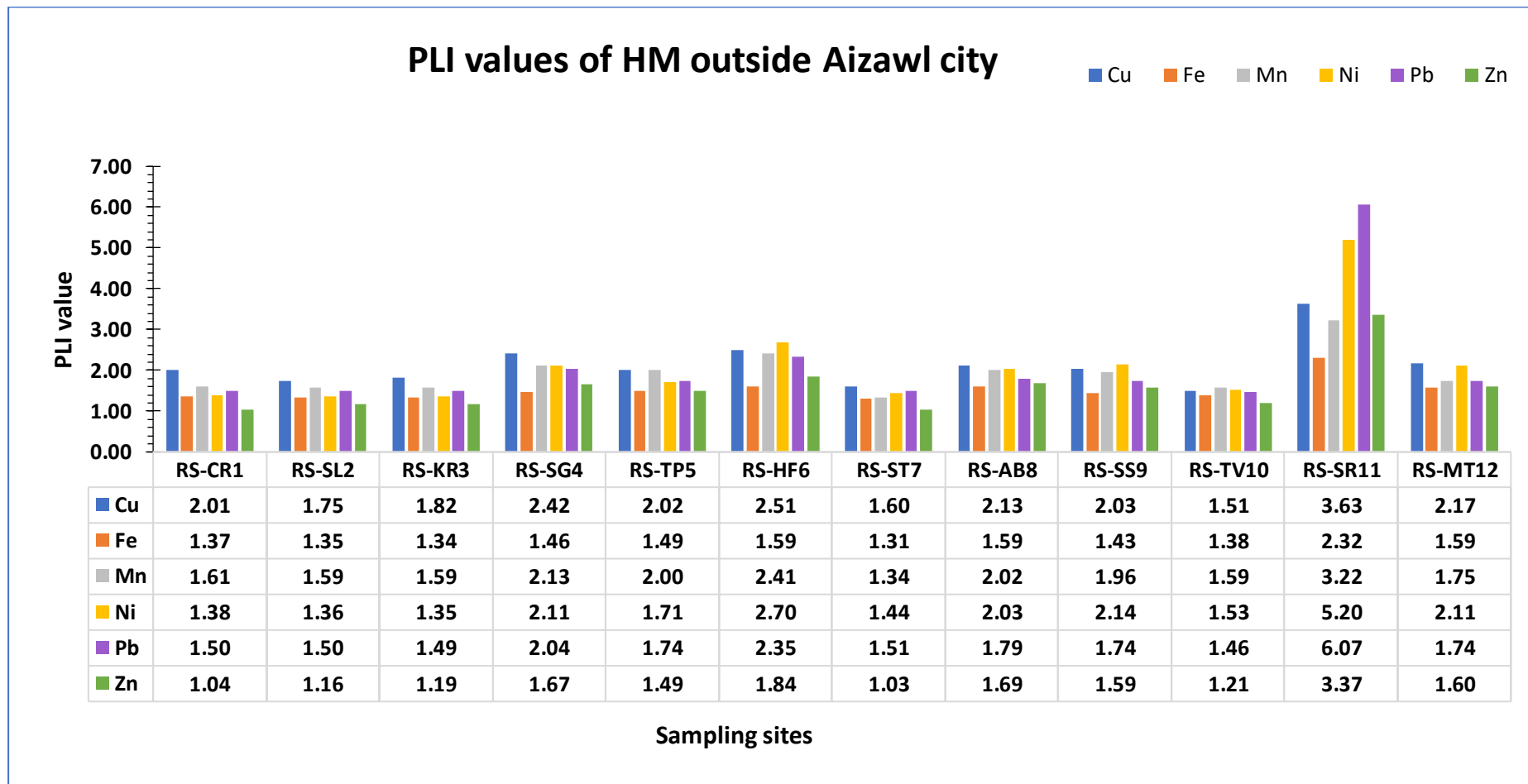


Fig. 4.3.3b. PLI of HM in the roadside soil outside Aizawl.

4.3.4. Geo-accumulation Index (Igeo)

Table 4.3.4a and 4.3.4b represent the Igeo values for the heavy metals analyzed in the study at different sampling points in Aizawl and outside Aizawl respectively. The Igeo is a useful measure to evaluate the contamination level of metals in sediments, which is based on a comparison between the current concentration to the pre-industrial one. Figure 5.3.4a. depict Igeo of heavy metals in roadside soils of Aizawl where the level of contamination is found to vary amongst the sampling locations. Cu presents medium pollution with Igeo values varying from 1.02 to 1.84 from RS-VK2 to RS-TS7. Iron strongly continues to produce low Igeo values that range from 0.40 at RS-KT12 to 0.50 at RS-LT6, indicating slight contamination. The Igeo values of Mn vary between 0.78 at RS-S3 and 1.26 at RS-TS7, indicative of moderate pollution in all the samples. Ni in the current work has Igeo values varying from 1.02 at site RS-V2 to 1.60 at site RS-R8, categorized as moderate contamination. The Pb Igeo varies from 0.84 (RS-VK2) to 1.45 (RS-KT12) and represents highly polluted conditions. The Zn has Igeo values ranging from 1.02 (RS-SK3) to 1.68 (RS-KT12), also representing moderate contamination. This classification is supported by Bali and Sidhu (2021) who classified Igeo values greater and less than 1.0 as moderate and low contamination, respectively, while values close to or greater than 1.5 were classified as considerable contamination, similar to trends observed here. Hanfi et al., (2020) have added more information to these levels, and showed that high Igeo values are closely related to urbanization and anthropogenic sources (including traffic and industrial sources), indicating their contribution to the enrichment of heavy metal pollution. The spatial variation in Igeo values in Aizawl indicates that urban expansion and anthropogenic activities play important roles in the accumulation of heavy metals, as stated by the Bali and Sidhu (2021) and Hanfi et al., (2020).

Fig. 4.3.4b the Igeo values of heavy metal in roadside soils in Aizawl, which is predominantly town areas than high dense urban areas. City sites, on the contrary, within Aizawl, generally exhibit higher levels of contamination compared to the suburban sites of the town areas having comparatively low traffic density and industries. The Igeo values for Cu vary between 0.18 (at site RS-SL2) and 1.10 at site RS-SR11 (Table 1), reflecting low to moderate pollution, with values closer to 1

indicating a low human influence. Igeo Fe is negative in all the sites, indicating zero contamination; the negative Igeo values means that there are no human-related influence. The Igeo of Mn ranges from 0.19 at RS-CR1 to 0.86 at RS-HF6, indicating crustal-derived or low-level pollution, which can be due to lower vehicular and human activities common to areas in town. Ni varies from -0.15 at RS-TS7 to 1.75 at RS-SR11 and those >1 especially >1.75 in our results indicate moderate pollution (at particular sampling sites), which could primarily be due to the influence of near source roadside or traffic activities. Igeo values for Pb range from 0.00 at RS-C1 to 1.76 at RS-S11, and values close to 1.76 represent a pronounced contamination, in particular in sites with higher traffic in the town. Zn exhibits values between -0.51 at RS-CK1 and 1.23 at RS-SR11, reflecting low to moderate contamination; concentrations higher than 1 are generally associated with traffic sources motorcycle tire and brake wear.

These Igeo values indicate that town sites greater than Aizawl have lower heavy metal accumulation, since the population density and sources of pollution are lower. Research by Hanfi et al., (2020) confirms that urbanisation anthropogenically contributes to metal contamination, which is in agreement with the higher pollution levels being recorded within the city limits of Aizawl. Similarly, Efremova et al. (2020) suggest that even medium-level heavy metal accumulation in soil may result in secondary pollution, so current monitoring and remediation efforts are necessary to control environmental and health risks in urban and town areas.

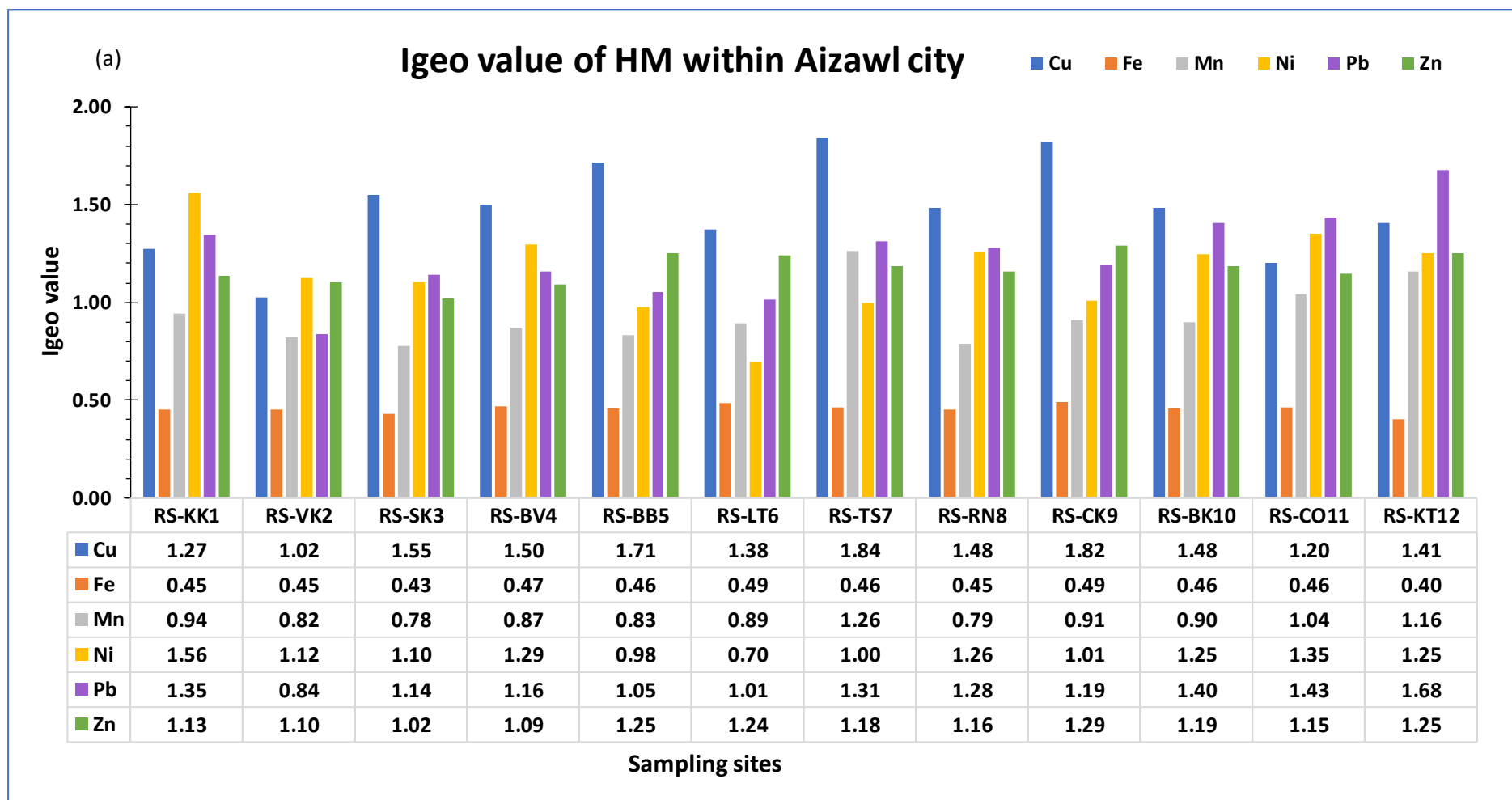


Fig. 4.3.4a. Igeo value of HM in the roadside soil within Aizawl.

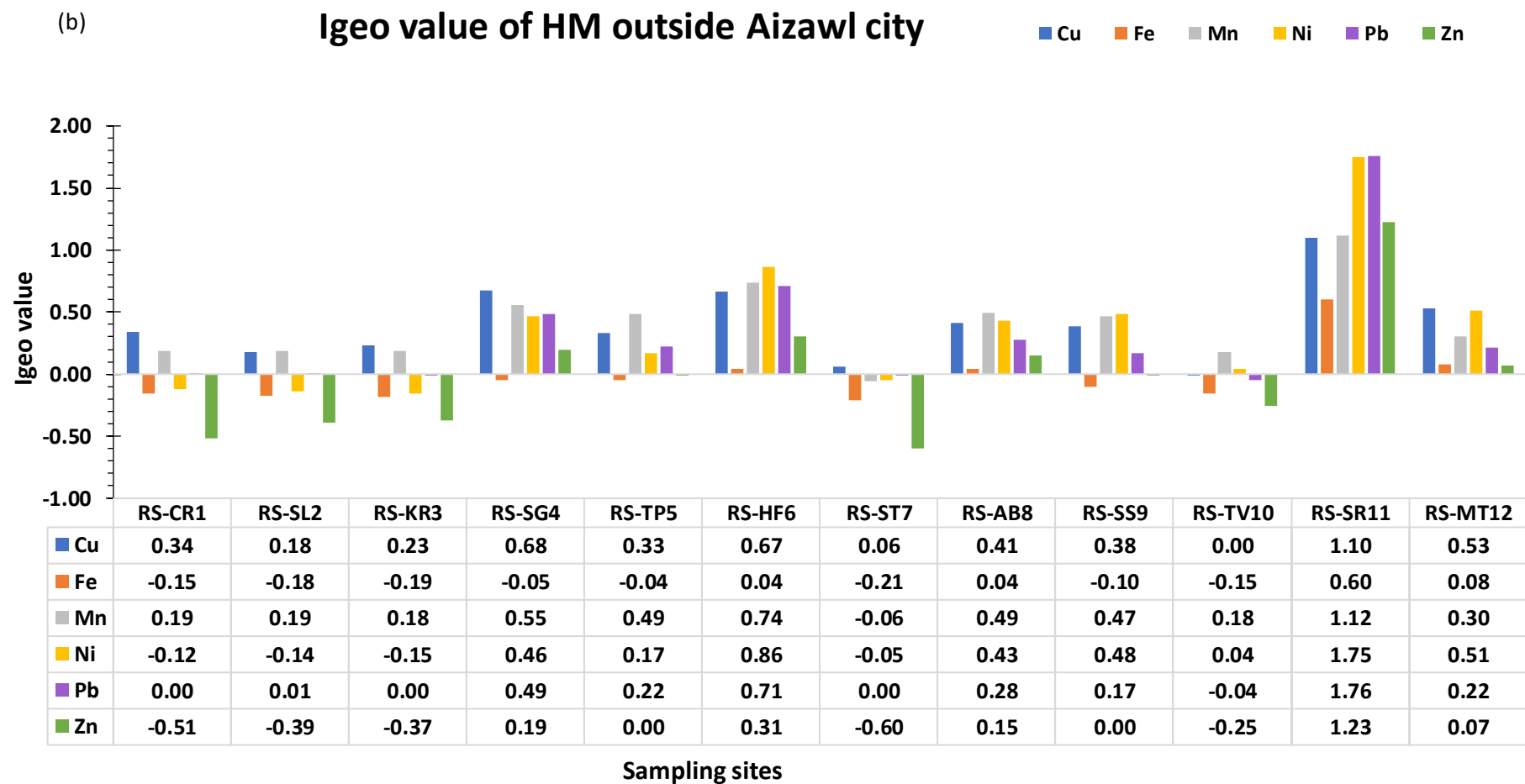


Fig. 4.3.4b. Igeo value of HM in the roadside soil outside Aizawl.

4.4. Heavy metal concentration in airborne particulate matter

The concentrations of heavy metals in airborne particulate matter (PM₁₀) from air samples collected at four sampling stations in Aizawl are detailed below. The data for each assessment year, spanning from October 2020 to September 2021 and from October 2021 to September 2022, has been categorized into three seasons: Pre-Monsoon (February to May), Monsoon (June to September), and Post-Monsoon (October to January). These findings are presented in the following sections. It is observed that the concentrations of the studied heavy metals are higher in the second assessment year compared to the first year. Among the selected sites, site A-DP recorded the highest levels of airborne heavy metal concentrations.

4.4.1 Cu

The Cu values of the sites during the period are depicted in Fig. 4.3.1a for all the sites in Aizawl city for the three seasons (pre-monsoon, monsoon, post-monsoon), respectively.

Cu also differed significantly between sites ($p < 0.001$) and between the seasons ($p < 0.002$). There was also a significant difference between the sites, and between the months ($p < 0.001$), (Table 4.3.1b., Table 4.3.1c). Amongst the 4, the maximum Cu concentration was recorded with $666.5 \pm 42.19 \text{ ng/m}^3$ in A-DP and a minimum of $298 \pm 22.87 \text{ ng/m}^3$ in A-KT.

The Cu concentration varies from 216.25 ng/m^3 at site A-BK in the first assessment year's monsoon season to 817.75 ng/m^3 at site A-DP in the second assessment year's pre-monsoon. On the whole, A-DP had the highest Cu content of the sampling sites in both of the two survey years, as well as in three seasons. Cu in the sites increases generally in the second year of the survey than the others possibly due to high accumulation of anthropogenic activities and vehicle movements after the ease of public movement restriction because of COVID-19. In the pre-monsoon phase, Cu concentrations are high at all sites, with A-DP always presenting the highest values. A number of factors can contribute to this increase, due to traffic, market activities, lower rainfall and the resuspension of copper-bearing dust to the air, leading to increased copper levels in particulate matter. Likewise, at sampling site A-LP in a high location

proximal to governmental buildings, there are relatively higher Cu concentration compared to A-BK and A-KT, amounting to 353.00 ng/m³ and 454.50 ng/m³ during the pre-monsoon in the 1st and 2nd years, respectively.

A research done by Salma et al., (2021), observed similar trends, indicating that Cu concentrations drop significantly during the monsoon season due to the washout effect of rainfall, which dilutes airborne particulate matter. Despite the high traffic volume in the area, the air sampler at A-BK is situated in a residential zone, slightly further from the road and at a higher elevation, which helps to reduce exposure to direct emissions. As a result, Cu levels at A-BK remain lower than those at A-DP. During the post-monsoon period, there are slightly higher metal concentrations than in the monsoon season across all sites, except for A-DP. Intermittent rainfall in the post-monsoon season could affect the heavy metal concentration in the particulate matter. Site A-DP, located in the central market area of the city, recorded the highest concentration of 734.75 ng/m³ during the post-monsoon season, reflecting contributions from vehicle emissions and market activities. As reported by Kumar et al., (2021), localized factors such as vegetation coverage and proximity to pollution sources can significantly influence air pollutant levels, even in densely populated urban areas.

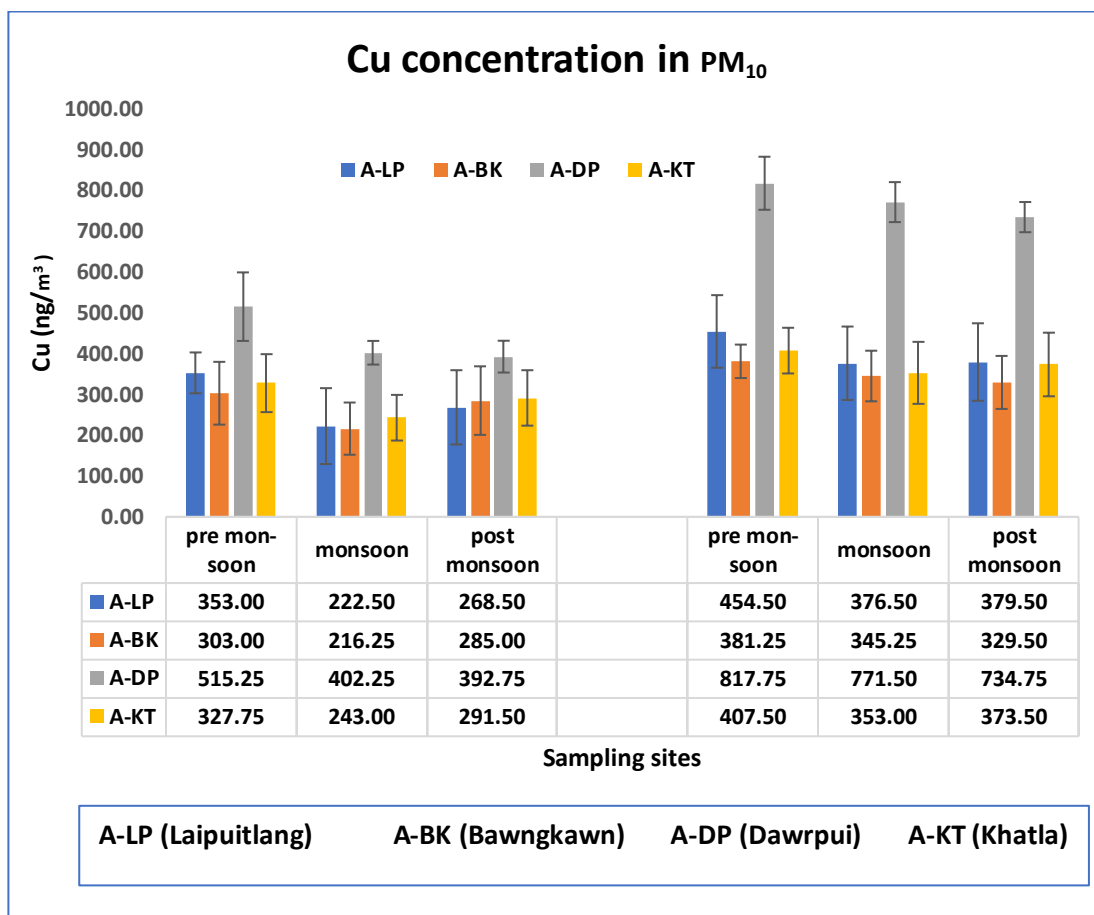


Fig. 4.4.1a. Cu concentration in airborne particulate matter within Aizawl.

Table 4.4.1a. Anova table showing significant variation of Cu within air sampling sites and season within Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	174694.8	3	58231.61	160.771	0.001	4.757
Between the seasons	13899.43	2	6949.715	19.187	0.002	5.143
Error	2173.206	6	362.201			
Total	190767.5	11				

Table 4.4.1b. Anova table showing significant variation of Cu within air sampling months and sites for 2years within Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the months	958298.3	23	41665.14	8.256	0.001	1.686
Between the sites	1396786	3	465595.3	92.261	0.001	2.737
Error	348205.5	69	5046.457			
Total	2703290	95				

Table 4.4.1c. Mean concentration of Cu (ng/m³) in air born particulate matter within Aizawl.

Sites	Pre - monsoon	Monsoon	Post- monsoon
A-LP (Laipuitlang)	403.75 ± 23.41	299.50 ± 12.81	324.00 ± 26.89
A-BK (Bawngkawn)	342.13 ± 31.23	280.75 ± 28.27	307.25 ± 33.78
A-DP (Dawrpui)	666.50 ± 42. 19	586.87 ± 24.29	563.75 ± 44.89
A-KT (Khatla)	367.63 ± 27.72	298.00 ± 22.87	332.50 ± 40.96

4.4.2. Fe

The Fe values of the selected sites during the study period 2020-2022 are plotted in Figures 4.3.2a for the different sites within Aizawl city for three seasons (pre-monsoon, monsoon, post-monsoon) respectively.

There was a substantial difference in Fe between sites, season and months ($P < 0.001$) as depicted in (Table 4.3.2b, Table 4.3.2c). Mean concentration at the its site 04 Maximum Fe at A-DP 2396.125±44.46 ng/m³ Minimum at A-KT 1896.75±23.28 ng/m³.

Seasonal average Fe concentrations during the period of study vary from 1633.50 ng/m³ at site A-KT in the post-monsoon of the initial year of the study to 2559.00 ng/m³ at site A-DP in the pre-monsoon of the second year. In general, Fe contents at the sampling stations are generally higher in the second year of monitoring than in the first one. This increase could result from the increased anthropogenic activity and vehicular movement following the relaxation of lockdown imposed by the COVID-19 pandemic. Fe (mg/m³) concentrations are higher during pre-monsoon period of the both assessment years, which may be attributed by wind, traffic movements, other human activities responsible for re-suspending of iron incorporated mobile particulate matters in the air under dry weather conditions. Values of Fe on the other hand are usually low during the post-monsoon period. A-DP has the maximum (2219.75 ng/m³ in the first years' monsoon to 2559.00 ng/m³ in the second years' pre-monsoon) Fe load over the taken sampling sites. Sites A-LP and A-BK also have high values, and this indicates that automobile exhaust and road dust are among contributors to Fe deposition, affecting also residential and office areas. The lowest values (1633.50 ng/m³ and 2321.25 ng/m³) are those recorded at A-KT, which is located in a government office site, probably because of such a lower direct exposure of the sampler to the sources of emission.

In the study by Nair et al., (2021), we also find that during the monsoon time of year, Fe levels at all sites decrease somewhat, primarily due to the wash-out effect of the rain that will dilute the air-borne particulate matter. In our study, Fe concentrations are lower during the monsoon period at all sites relative to the pre-monsoon season. This decline is largely due to rain scavenging of particulate material in the air. But the existence of relatively high Fe contents during the monsoon at stations A-DP (2219.75 ng/m³ and 2540.00 ng/m³ in the first and second years, respectively) may reflect continuous emissions, probably from vehicle activity, and the resuspension of road dust, especially in high-traffic areas and in the vicinity of ongoing construction activities. This indicates that the input from the Fe FPs may still have influenced the background metal levels even in the wet season. During post monsoon, Fe content continues to be marginally lesser with A-DP recording the highest Fe concentration both during 1st year and 2nd year (2052.50 ng/m³ and 2535.50 ng/m³ in 1st and 2nd

year, respectively). This is also consistent with A-LP and A-BK, which highlight the significant impact of local traffic, road dust and ongoing construction activity as the main sources of Fe pollution after stopping raining. Aggarwal et al., 2016 also suggest that post-monsoon Fe levels may increase during events where traffic and urban emissions rapidly bring off pollution levels back up to the pre-monsoon state. This illustrates how high traffic high construction urban areas get a spasmodic short-term decrease in Fe concentration when the monsoon washes them away, and then ping right back to high after everything has a chance to fall out of suspension and get back out into the atmosphere.

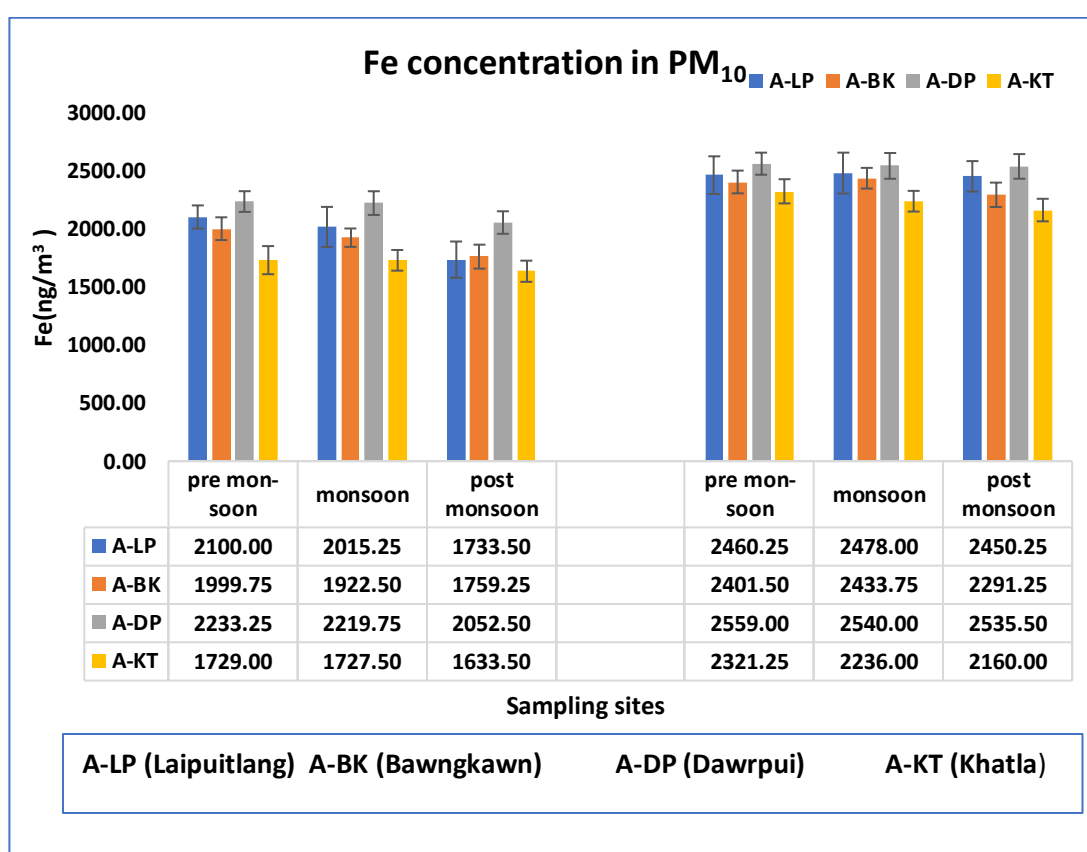


Fig. 4.4.2b. Fe concentration in airborne particulate matter within Aizawl.

Table 4.4.2a: Anova table showing significant variation of Fe within air sampling sites and season within Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	235020.6	3	78340.21	152.3471	0.001	4.757063
Between the seasons	48719.97	2	24359.99	47.37253	0.001	5.143253
Error	3085.331	6	514.2218			
Total	286825.9	11				

Table 4.4.2b: Anova table showing significant variation of Fe within air sampling months and sites outside Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f- crit</i>
Between the months	7245351	23	315015.3	17.380	0.001	1.686
Between the sites	1880165	3	626721.7	34.578	0.001	2.737
Error	1250605	69	18124.71			
Total	10376121	95				

Table 4.4.2c. Mean concentration of Fe in air born particulate matter within Aizawl.

Sites	Pre - monsoon	Monsoon	Post-monsoon
A-LP (Laipuitlang)	2280.125 ± 35. 78	2246.625 ± 29.21	2096.875 ± 42.12
A-BK (Bawngkawn)	2200.625 ± 36.81	2178.125 ± 27.12	2025.25 ± 44.38
A-DP (Dawrpui)	2396.125 ± 44.46	2379.875 31.91	2294.00 ± 38.16
A-KT (Khatla)	2025.125 ± 38.51	1981.75 ± 29.78	1896.75 ± 23.28

4.3.3. Mn

Mn values for the selected locations for the duration of the study period of 2020-2022 are illustrated in Figures 4.3.3a right from selected Aizawl city for 3 seasons (Pre-monsoon, Monsoon, post-monsoon).

Mn showed a wide variation between sites ($p < 0.001$) and between sites and months ($p < 0.001$) as presented in (Table 4.3.3b, Table 4.3.3c). Amongst all the other sites, site 4 recorded highest Fe concentration with maximum mean concentration on the site ($411.88 \pm 31.28 \text{ ng/m}^3$ and $316.25 \pm 23.27 \text{ ng/m}^3$ in A-DP and A-BK respectively).

The average concentrations of Mn in seasons during the study period vary between 279.75 and 496.25 ng/m^3 . Mn contents are more stable among all 4 sites, but the variation tendency in different seasons is a little bit irregular in comparison to other heavy metals. Both sites A-BK and A-LP have relatively lower Mn concentrations than those at sites A-DP and A-KT. The Mn concentrations in the first and second assessment block years are also not very different. According to Rai et al., (2021) vehicular emissions and brake wear are significant contributors to Mn pollution in the air. The elevated Mn concentrations in airborne particulate matter at specific sites may be due to vehicle movement and localized emission sources that contribute to airborne Mn in those areas. During the Pre-monsoon months, the level of Mn varies from 309.25 ng/m^3 to 411.75 ng/m^3 . During the monsoon, the concentrations of Mn range from 302.00 ng/m^3 to 438.25 ng/m^3 , while during the post-monsoon it ranges from 279.75 ng/m^3 (A-KT) to 496.25 ng/m^3 (A-DP). The decrease in Mn levels during the monsoon season at some sites could be attributed to the washout effect of rain,

which helps remove particulate matter from the atmosphere. A similar pattern was noted in a study by Pant et al., (2022), which found that Mn concentrations generally decrease during the monsoon season due to this washout effect. However, the elevated Mn levels at A-DP and A-KT observed during the monsoon season indicate that local emissions continue to contribute to the Mn load in airborne particulate matter, even during the rainy season.

The continued elevation of Mn at A-DP over the monitoring period indicates that vehicle emissions, less likely to be washed out by rain and other meteorological conditions, are a major source of PM₁₀ Mn, especially in high-traffic locations. The trends at other sites, showing only marginal changes in Mn concentrations during the monsoon, reflect the ongoing influence of vehicular activity even in rainy conditions, though the effect is less pronounced compared to A-DP. As conditions dry out in the post-monsoon period, Mn concentrations rise across all locations in the second assessment year. This increase can be attributed to the resumption of traffic, construction activity, and the re-suspension of particulate matter that had settled during the monsoon rains. Bhaskar et al., (2020) also found that with the arrival of dry season, sources like traffic and construction promptly revive ambient level of Mn to the pre-monsoon range because of enhanced resuspension of dust. Xie et al., (2022) also found that drier conditions are conducive to the re-suspension of Mn particle-bearing dust. The continuously higher Mn concentrations at A-DP compared to other sites underscore the strong influence of traffic emissions on atmospheric Mn pollution in crowded urban market areas where Mn emissions are concentrated. Gao et al. (2021) underscore the relevance of regional traffic emissions. This variation highlights the importance of proximity of emission sources and neighbouring activity patterns on Mn levels in different environments.

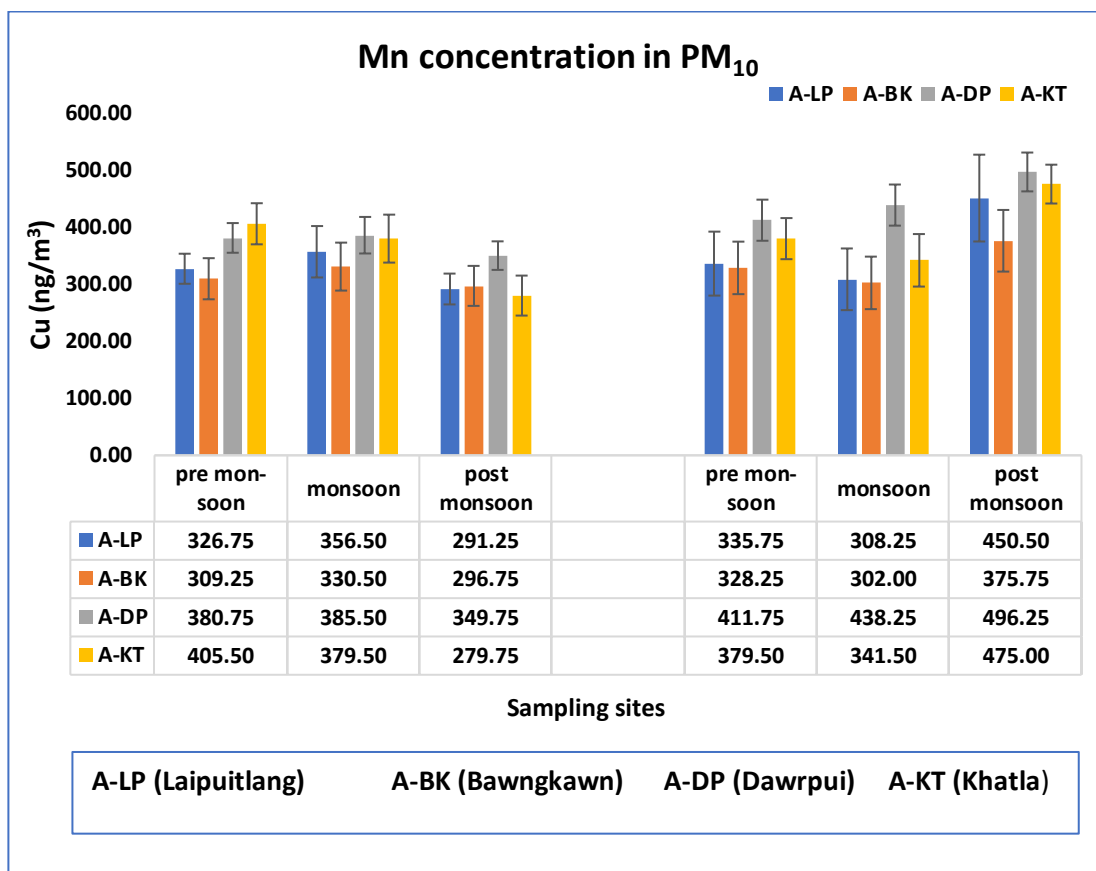


Fig. 4.4.3a. Mn concentration in airborne particulate matter within Aizawl.

Table 4.4.3a. Anova tables showing significant variation of Mn within air sampling sites and season within Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>f-crit</i>
Between the sites	12902.16	3	4300.718	23.732	0.001	4.757
Between the seasons	1045.828	2	522.914	2.885	0.132	5.143
Error	1087.3	6	181.216			
Total	15035.28	11				

Table 4.4.3b. Anova tables showing significant variation of Mn within air sampling months and sites for 2 years within Aizawl city.

Source of Variation	SS	df	MS	F	p-value	f-crit
Between the months	227147.2	23	9875.967	8.780931	0.001	1.686897
Between the sites	103214.5	3	34404.84	30.59008	0.001	2.737492
Error	77604.72	69	1124.706			
Total	407966.5	95				

Table 4.4.3c: Mean concentration of Mn in air born particulate matter within Aizawl.

Sites	Pre- monsoon	Monsoon	Post - monsoon
A-LP (Laipuitlang)	331.25 ± 27.89	332.38 ± 21.34	370.88 ± 23.21
A-BK (Bawngkawn)	318.75 ± 32.89	316.25 ± 23.27	336.25 ± 36.87
A-DP (Dawrpui)	396.25 ± 33.98	411.88 ± 31.28	423.00 ± 38.21
A-KT (Khatla)	392.5 ± 21.24	360.38 ± 27.26	377.38 ± 27.8

4.3.4. Ni

The Ni-values of the sites observed for the period of study (2020-2022) for Aizawl city are graphed in Figures 4.3.4 for three seasons (Pre-monsoon, monsoon, and post monsoon) where in both the sites selected in Aizawl city are shown.

Table 4.3.4a. the concentration of Mn differed significantly between sites (P and the increase was quite evident despite regular occurrences of rain. The presence of Ni could be related to the current anthropogenic activities in high-traffic market places, where commercial activities are the source of Ni pollutants. Ni levels were slightly higher in the monsoon season in the first year of evaluation, possibly as a result of atmospheric road dust resuspension and vehicular emissions. It is in line with the

trends found by Bernardina et al., (2022), who suggest that levels of Ni are still impacted by traffic and market activities despite seasonal rainfall.

During the post-monsoon, Ni concentrations are, however, slightly lower than during the monsoon season in most places. For example, the highest post-monsoon Ni concentration was 0.17 ng/m³ in A-DP and the lowest was 0.04 ng/m³ in A-LP. This is consistent with the findings from Parvez et al. (2023) who also reported decrease in the Ni concentration in their work for residential area of Kolkata, India. During all seasons A-DP showed highest Ni levels reflecting the effect of traffic jams and market traffic on particulate Ni. Conversely, sites A-LP and A-KT had lower concentrations and thus, probably less direct sources of pollution. This finding is in agreement with a report from Amato et al. (2020) in Barcelona, Spain, with government office areas and limited traffic impact. In hardcore-industrial and construction-rich areas of Sweden the study of Järup (2021), also underscore that road dust, construction and industrial emissions are ranges that contribute most to Ni pollution. This is consistent with A-DP, densely populated, as an urban density increases, it also results in high levels of pollutants.

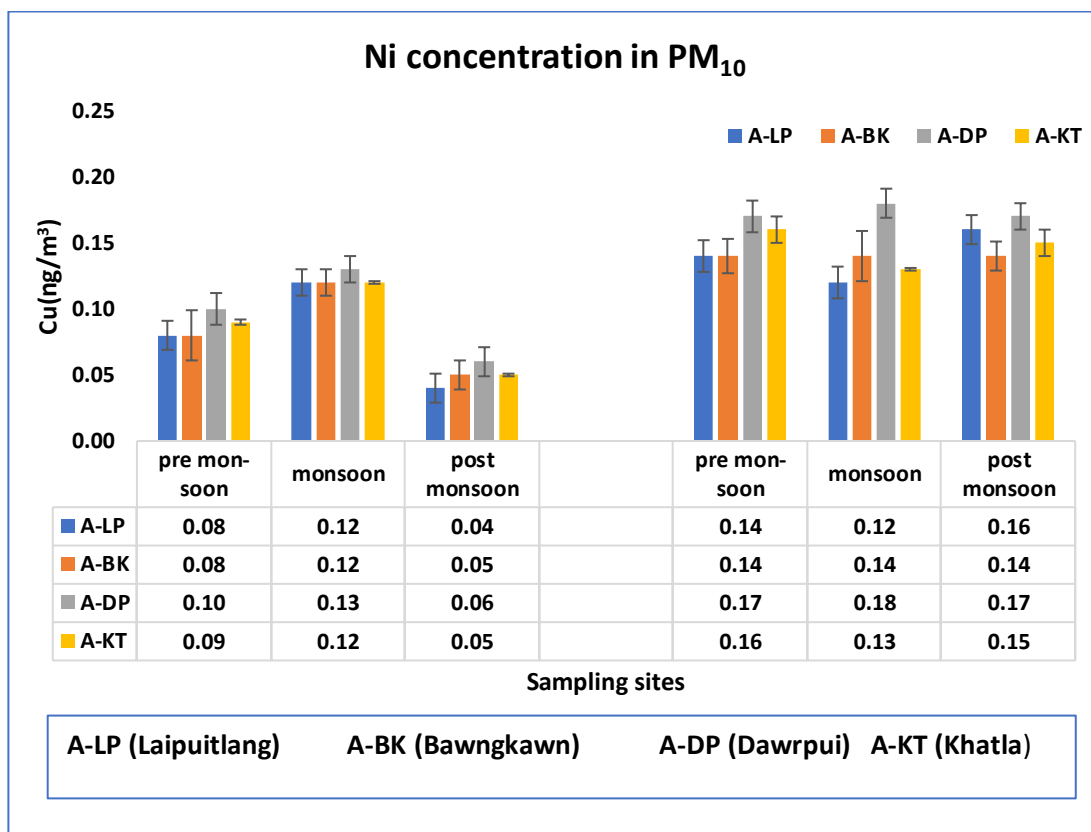


Fig. 4.4.4a. Ni concentration in airborne particulate matter within Aizawl.

Table 4.4.4a. Anova table showing significant variation of Ni within air sampling sites and season within Aizawl city.

Source of Variation	SS	df	MS	F	P-value	F crit
Between the sites	0.001065	3	0.000355	10.1868	0.009	4.757063
Between the season	0.001943	2	0.000971	27.87422	0.001	5.143253
Error	0.000209	6	3.49E-05			
Total	0.003217	11				

Table 4.4.4b Anova table showing significant variation of Ni within air sampling months and sites for 2nd years within Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between the months	0.151566	23	0.00659	42.11375	0.001	1.686897
Between the sites	0.009578	3	0.003193	20.40376	0.001	2.737492
Error	0.010797	69	0.000156			
Total	0.171941	95				

Table 4.4.4c. Mean concentration of Ni in air born particulate matter within Aizawl.

Sites	Pre- monsoon	Monsoon	Post- monsoon
A-LP (Lalpuitlang)	0.103 ± 27.38	0.116 ± 43.27	0.096 ± 24.21
A-BK (Bawngkawn)	0.106 ± 32.23	0.125 ± 31.26	0.095 ± 31.26
A-DP (Dawrpui)	0.121 ± 29.21	0.153 ± 28.31	0.114 ± 28.31
A-KT (Khatla)	0.114 ± 28.21	0.125 ± 23.28	0.090 ± 29.33

4.3.5. Pb

Fig. 4.3.5a for pre-monsoon, monsoon, post monsoon respectively during the study period 2020-2022 are depicted for the different sites of Aizawl city.

The difference in the Mn content among the sites ($P < 0.001$) and among the seasons was obvious ($P < 0.001$); as well as among the sites and the months ($P < 0.001$) as presented in (Table 4.3.5). b, Table 4.3.5. c). Highest mean concentration towards the site 4 with recorded maximum Fe concentration ($215.125 \pm 27.21 \text{ ng/m}^3$) in A-DP and minimum value of $135.25 \pm 27.34 \text{ ng/m}^3$ in A-LP.

The seasonal mean concentrations of Pb in the present work were approximately constant between years at a given site. Mean Pb concentration in the second block was larger than that in the first. The maximum Pb level were observed at site A-DP in entire monitoring period with a concentration varies from 119.75 ng/m^3 at site A-LP during post-monsoon of block first year to 244.50 ng/m^3 at site A-DP during pre-monsoon of block second year. Pb Pb levels in pre-monsoon Pb concentration was moderate in all the sites in the pre-monsoon period ranging from 123.50 ng/m^3 at A-LP to 244.50 ng/m^3 at A-DP. The higher Pb level in site A-DP can be attributed to the leaching of rain water into Pb containing materials, such as paints applied to surrounding urban structures units. These matter goes up into the air with the dryer days due to Wind, traffic and market activities are important sources causing urban airborne Pb pollution. These echoes were found in a report by Amato et al. (2020) conducted at Barcelona (Spain), in a moderately Pb contaminated situation in an urban environment strongly affected by vehicular emissions and resuscitated dust in pre-monsoon season.

Pb concentrations increased across all the sites during the monsoon season, with A-DP recording maximum values. This enhanced level of aspiration may be attributed to the washout of Pb particles that were reapportioned into air again. Parvez et al. (2023), investigating urban monsoon dynamics in Kolkata, India, and reported that although rainfall has a potential to dilute some pollutants it can also resuspend the heavier metals like Pb due to wet deposition. This means that the content of Pb found in the air is kept up not only by deposition but also resuspension in rainy season. This observation is consistent with the result obtained from the present study on roadsides soil where the

concentration of Pb dose increases in monsoon season rather than pre-monsoon and post-monsoon. In the post-monsoon season, Pb concentrations reduced at all sites, with A-DP still the most polluted site with a concentration of 241.45 ng/m³. Bernardina et al. (2022) also reported a decrease in Pb loads (Michigan, USA) as a result of lower emissions and traffic as noted by the trust, responsible for all reductions in Pb levels were observed in Michigan, USA that Pb levels were also remained high due to not control one source road dust and mobile sources. The Pb levels at A-DP was always lower which clearly indicates the influence of heavy traffic and local sources to Pb contamination in air. Such is result coincident with the research of Järup (2021) in industrial areas in Sweden, which points to the neighbouring traffic and human activity as the two most significant factors that affect the level of Pb with smaller traffic flow associated with lower concentrations.

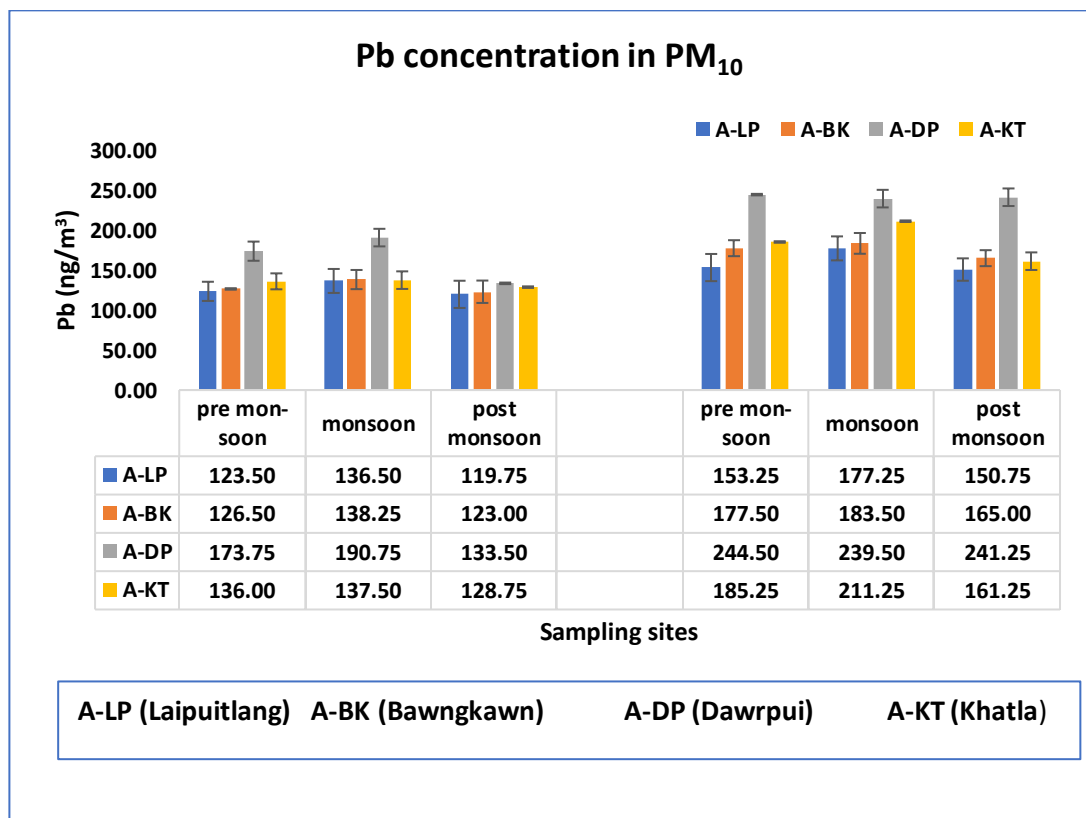


Fig. 4.4.5a. Pb concentration in airborne particulate matter within Aizawl

Table 4.4.5.a: Anova table showing significant variation of Pb within air sampling sites and season within Aizawl city.

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between the sites	6479.54	3	2159.847	98.923	0.001	4.757
Between the seasons	1143.216	2	571.608	26.180	0.001	5.143
Error	131.0015	6	21.833			
Total	7753.758	11				

Table 4.4.5b. Anova table showing significant variation of Pb within air sampling months and sites for 2 years within Aizawl city.

Source of Variation	SS	df	MS	F	P-value	F crit
Between the months	77158.33	23	3354.71	13.151	0.001	1.686
Between the sites	51839.75	3	17279.92	67.740	0.001	2.737
Error	17601.25	69	255.090			
Total	146599.3	95				

Table 4.4.5c. Mean concentration of Pb in air born particulate matter within Aizawl.

Sites	Pre- monsoon	Monsoon	Post- monsoon
A-LP (Laipuitlang)	138.38 ± 24.12	156.88 ± 29.31	135.25 ± 27.34
A-BK (Bawngkawn)	152 ± 28.28	160.875 ± 23.21	144 ± 34.32
A-DP (Dawrpui)	209.125 ± 32.12	215.125 ± 27.21	187.375 ± 31.12
A-KT (Khatla)	160.625 ± 39.12	174.375 ± 28.32	145 ± 28.12

4.3.6. Zn

The Zn values of the selected sites during the study period 2020-2022 are plotted in Figures 4.3.6a for the different sites within Aizawl city for three seasons (pre-monsoon, monsoon, post monsoon) respectively. There was a significant variation of Zn in between sites and seasons ($P < 0.001$) as well as between the sites and months ($P < 0.001$) as shown in (Table 4.3.5.b, Table 4.3.5.c). Taking the mean concentration from the 4 site, Fe concentration has maximum with $376.25 \pm 26.23 \text{ ng/m}^3$ in A-DP and minimum of $251.25 \pm 28.89 \text{ ng/m}^3$ in A-LP. The levels of Zn concentrations are consistent across different assessment years and sites. Zinc concentrations range from 236.25 ng/m^3 at A-LP to 368.75 ng/m^3 at A-DP in the pre-monsoon season, from 230.25 ng/m^3 at A-LP to 392.50 ng/m^3 at A-DP during the monsoon season, and from 216.50 ng/m^3 to 378.25 ng/m^3 at A-DP in the post-monsoon season. Thus, the concentrations of Zn are consistently higher at site A-DP across all seasons. Zn levels also peak at A-DP during the pre-monsoon period, likely due to heavy traffic and market activity in the area. Emissions from vehicles and the resuspension of road dust significantly contribute to the elevated Zn levels. Research has shown that non-exhaust emissions, such as tire wear and brake dust, are primary sources of zinc in urban environments. In contrast, government office areas like A-LP and A-KT exhibit lower zinc concentrations, which may result from reduced local pollution sources. This finding aligns with the work of Viana et al., (2020), which highlights the impact of traffic density on zinc pollution in urban settings. During the monsoon season, zinc concentrations increase slightly compared to other seasons, particularly at A-DP. This rise may be linked to the resuspension of zinc-containing dust from roadways and other surfaces. This phenomenon has been observed in urban studies, such as those reported by Thorpe and 199 Harrison (2008) in London, UK, where metal levels often remain elevated during rainy periods due to urban runoff and the redistribution of particles. This suggests that while rainfall can dilute certain pollutants, it may also result in higher zinc concentrations in airborne particulate matter due to resuspension in urban areas with high human activity. Post-monsoon concentrations of zinc decrease but remain significant, with A-DP still showing the highest concentration. Querol et al., (2020) found similar post-monsoon trends in their study of urban particulate matter,

where settled particles re-enter the atmosphere due to dry conditions and traffic movement. The consistently higher zinc levels at A-DP across all seasons indicate a strong influence from traffic and anthropogenic activities on zinc pollution, while lower concentrations at some sites reflect less congested conditions. Li et al., (2021), in their study of zinc pollution in Italian cities, attributed similar seasonal variations in zinc levels to vehicular activity, road dust resuspension, and localized emissions, reinforcing the idea that human activities contribute significantly to the presence of zinc in urban air throughout different seasonal conditions.

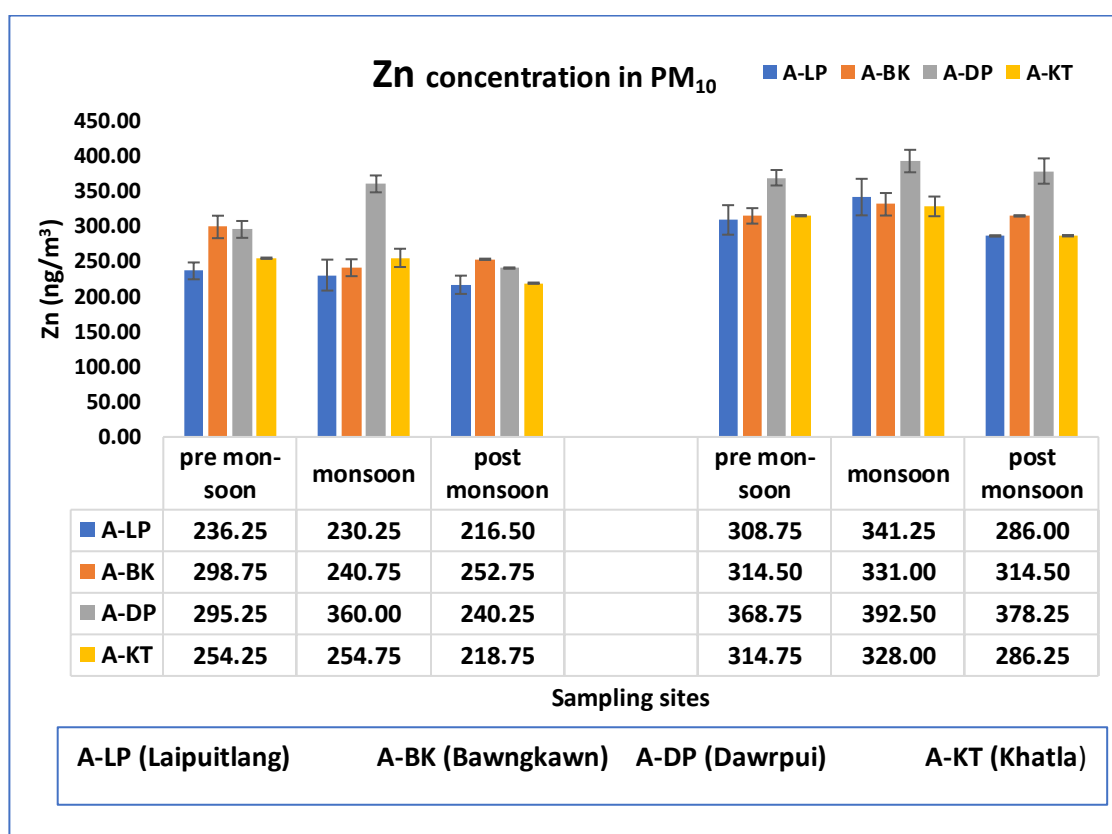


Fig. 4.4.6a. Zn concentration in airborne particulate matter within Aizawl

Table 4.4.6a. Anova table showing significant variation of Zn within air sampling sites and season within Aizawl city.

Source of Variation	SS	df	MS	F	P-value	F crit
Between the sites	8840.949	3	2946.983	12.28581	0.006	4.757063
Between the seasons	2670.658	2	1335.329	5.566911	0.043	5.143253
Error	1439.213	6	239.8689			
Total	12950.82	11				

Table 4.4.6b. Anova table showing significant variation of Zn within air sampling months and sites within Aizawl city

Source of Variation	SS	df	MS	F	P-value	F crit
Within months	161135.3	23	7005.884	11.7838	0.001	1.686897
Within sites	70729.58	3	23576.53	39.65541	0.001	2.737492
Error	41022.92	69	594.535			
Total	272887.8	95				

Table 4.4.6c. Mean concentration of Ni (ng/m³) in air born particulate matter within Aizawl

Sites	Pre- monsoon	Monsoon	Post- monsoon
A-LP (Laipuitlang)	272.5 ± 23.21	285.75 ± 25.31	251.25 ± 28.89
A-BK (Bawngkawn)	306.63 ± 29.21	285.88 ± 28.21	283.63 ± 24.21
A-DP (Dawrpui)	332 ± 23.21	376.25 ± 26.23	309.25 ± 25. 23
A-KT (Khatla)	284.5 ± 36.21	291.38 ± 24.31	252.5 ± 28.12

Table 4.4.6d. Correlation of heavy metals, rainfall and traffic activities present in particulate matter within Aizawl city (n=12).

	Rainfall	Traffic activities	Cu	Fe	Mn	Ni	Pb	Zn
Rainfall	1	0.97	-0.91	-0.52	-0.78	-0.48	0.89	-0.54
Traffic activities	-	1	0.98	0.76	0.47	0.99	0.99	0.98
Cu			1	0.67	0.93	0.73	-0.76	0.83
Fe				1	0.91	0.98	-0.61	0.99
Mn					1	0.77	-0.92	0.95
Ni						1	-0.61	0.99
Pb							1	-0.81
Zn								1

*:significant at $p < 0.05$; **: significant at $p < 0.01$

Further, the relationship between rainfall, traffic-related activities and the concentration of different HM (Cu, Fe, Mn, Ni, Pb, Zn) was determined by correlation matrix for particulates in Aizawl city. Wet only precipitation showed negative relationship with most of the heavy metals and among them particularly were copper ($r = -0.91$), manganese ($r = -0.78$) and zinc ($r = -0.54$). It means that precipitation probably reduces the ratio of these metals in the atmosphere by mechanisms including wet deposition or washout. In an interesting fashion, rainfall is a clear positively-correlated force on Pb at $r = 0.89$, indicating that lead stems from sources that are less weather-dependent sources (e.g. historic deposit, certain industrial outflows).

On the other hand, traffic activities present very strong positive correlations with almost all the heavy metals like Cu ($r=0.98$), Fe ($r=0.76$), Ni ($r=0.99$), Pb ($r=0.99$), and Zn ($r=0.98$), indicating that vehicular emissions accounted as major contributor to heavy metal pollution in the city. The relationship between traffic activities and Mn is also positive ($r=0.47$) but weak. These results distinctly demonstrate that traffic is a major source of atmospheric HM concentrations in Aizawl.

In addition, significant inter-metal correlations exist, such as Cu and Mn with $r=0.93$, Fe and Mn have $r=0.91$, and Zn and Ni with $r=0.99$, indicating they may have common sources, such as brake/tire wear or combustion of fuel. The opposite is true for lead, wherein the negative correlation is even stronger with Cu ($r=-0.76$), Mn ($r=-0.92$), and Zn ($r=-0.81$), suggesting that the sources or characteristics of particulate lead in the atmosphere are different from those of other metals. The matrix presented the remarkable combination of the complex mechanism between meteorological components and human activities with a view to trace the levels of heavy metals in urban air.

Chapter 5

SUMMARY AND CONCLUSION

5. SUMMARY AND CONCLUSION

Assessment of heavy metal pollution in roadside soil of Aizawl, Mizoram, India sheds light on the environmental degradation associated with urban and vehicular functions. Metal concentrations in different sampling sites in and around Aizawl city were studied and compared. The results showed uneven content of these metals; iron was the one found in the highest concentration. The higher than the ABVs of metal concentrations imply vehicular emissions and other anthropogenic activities as the dominant sources of pollution. The metal levels were also influenced by the change in season, notably in the lead level, which was higher during the monsoon, when the observed runoff occurs from urban surfaces.

Pollution evaluation by indices including the pollution PLI, Igeo, and EF showed that most of the studied sites were at moderate pollution. The findings accentuate the anthropogenic effect on metal distribution with traffic emissions, industrial sources, and population density being the major contributors. This pollution may be a risk to human health of the urban population, who are being exposed to roadside soils which is highlighted the requirement of its regular monitoring and importantly, the need of some suitable management remedial measures to minimize heavy metal exposure.

The specific results above can be summarized, as follows, with respect to physical properties and the heavy metal content of roadside soil and the airborne particle matter:

5.1. Physicochemical Properties of Roadside Soil

The pH of the road side soils of all the selected sites (either with-in or out-side Aizawl city) represented alkali nature as the range was from 7.34 ± 1.13 to 11.40 ± 0.67 . There were also pronounced seasonal and spatial differences. Monsoon month generally showed high pH (high leaching and dilution) because in raining season, leaching and dilution of acidic substances with rainfall take place and less acidic alluvial medium increases alkaline nature of soil. All season and site, averaged, the monsoon was the highest pH season. There was a positive correlation

between rainfall and pH at $r = 0.75$ in Aizawl city, and $r = 0.98$ outside Aizawl city. High pH values were observed in the urban zone (Aizawl city) compared to those in the rural zone, especially pH was higher in all the locations of Aizawl city, except in the post-monsoon season pH values were comparatively high in few rural sites. Overall comparison also indicated a more basic pH in Aizawl. The high alkalinity of the soils in the two zones is mainly the result of human activities and climate on account of reduced buffering capacity and leaching effect.

The SMC values differed temporally and spatially among different study sites i.e., both forest and cultivated land (inside and outskirts of Aizawl city) depending upon the season with the exception of values during monsoon season that had highest values generally attributed by increased rainfall and water infiltration. Estimated mean values of SMC across all sites and seasons varied between $5.21 \pm 0.04\%$ and $18.45 \pm 0.31\%$. In all seasons, the maximum SMC both inside and outside Aizawl were recorded during monsoon. This observation was also supported by the relationship between rainfall and SMC, as high positive correlation coefficients were obtained, $r = 0.99$ in Aizawl city and $r = 0.82$ outside Aizawl city. Both intra- and interseasonally, Aizawl city had significantly higher SMC compared to other sites (Table 3). This was because of urban nature of city, such as surface runoff and least permeability of the city, all of these could result in the low capacity of soil to hold water.

The SOC contents decreased in the monsoon season, which might be attributed to leaching effects owing to higher rainfall, and increased in the pre- and post-monsoon season. SOC varied from 1.02 to $18.45 \pm 0.31\%$ among all sites and seasons. SOC content decreased as a whole in monsoon season in Aizawl due possibly to high precipitation with increased leaching. The SOC outside Aizawl, however, was more stable among the seasons. Comparison of SOC in urban and rural areas showed a general trend of higher SOC in sites located outside Aizawl. However, higher values were also recorded for some urban sites, consistent with accumulation of organic material derived from the urban vegetation, waste, and less runoff. Besides, traffic and road-deposited sediments also affect the SOC spatial distribution.

Overall, at all the sites and the seasons, total nitrogen (TN) concentration showed a variation from $0.08 \pm 0.01\%$ to $1.80 \pm 0.14\%$ which was maximum during the monsoon season due to the wash off rain induced nitrogen deposition and runoff. Monsoon peak season had the highest general average of TN for the majority of sites. This pattern reflects higher N deposition and leaching during wet seasons, emphasizing the importance of wet periods for N fluxes. The association between rainfall and TN could further be supported by strong relationship between them, for seasonal averages ($r = 0.86$, $r = 0.99$). TN levels were higher significantly outside Aizawl city than within between urban and rural areas. Environmental factors, including pH and rain intensity, significantly affect nitrogen and pollution transportation in roadside sediment. These observations are especially applicable in a city such as Aizawl where these environmental fluctuations are known to be high and cause a large spatial variation in the nitrogen levels.

AP contents differed significantly among sites and seasons, varying between 0.11 ± 0.13 and 4.21 ± 0.78 kg/ha, and there were urban and rural contrasts. AP values are always stronger outside Aizawl city compared to within during all seasons. This difference observed in phosphorus retention reflects diverse land use influences, where urban lands have phosphorus losses by road deposited sediments and runoff, and rural lands remained phosphorous rich due to agricultural inputs and decomposition of organic matters. The correlation between rainfall and AP, based on the seasonal mean, illustrated a strong negative relationship ($r = -0.99$, $r = -0.82$), indicating that rainfall can dilute or leach phosphorus, especially in urban watersheds with stronger site water flow. In conclusion, statistical analysis revealed that APC was significantly higher in locations other than Aizawl city. These results indicate the effect of the environment and land-use practice on phosphorus availability across geographic areas.

In Aizawl city AK was widely varied between sites and seasons. The AK varied from 25.35 ± 3.04 kg/ha to 87.24 ± 9.55 kg/ha. Far from the city of Aizawl, AK values also exhibited spatial variability. The values varied from 54.37 ± 4.92 kg/ha to 100.89 ± 10.41 kg/ha and AK remained almost steady across the seasons for all the sites

inside the city and outside the city of Aizawl. However, there were few sites outside Aizawl (RS-SG4, RS-SR11, RS-MT12) where potassium contents were lower as compared to rest of the sites. Pomeranz, Y and Melton, J (ed): The highest potassium levels for all samples capped by RS-BV4 throughout the study period. The overall higher AK variances observed in sites located outside the Aizawl city were mainly due to the different soil properties and the types of land use affecting the K availability and retention. Potassium is found in the soil in various forms including water soluble, exchangeable, non-exchangeable and mineral bound, and these have implications on respectively the mobility and availability of K. The stable AK pools at Aizawl city indicate the dynamic equilibrium among these forms of AK under native soil factor and parent material. Correlation analysis of rainfall with AK values averaged over the three seasons was found positively correlated inside Aizawl city ($r = 0.68$) and weakly positively correlated [weak] outside Aizawl city ($r = 0.224$), suggesting that rainfall increased potassium availability more in urban area.

5.2. Heavy metal content in roadside soil

a. Concentration of Cu within Aizawl city differed significantly among sites and months. In comparison between the two years, there was generally higher concentration of Cu in 2021-22. High concentrations of Cu at some locations might be associated with greater traffic and greater urban activity, since the relationship between traffic volume and Cu concentrations was quite linear ($r = 0.97$). Elevated concentrations of Cu were observed in the season of pre-monsoon and the lowest in monsoon in both the sites within and outside Aizawl city. There is increased metal leaching during monsoon precipitation, in particular in urban sites with poor drainage (sites RS-CK9, RS-TS7, RS-BB5). Cu runoff and retention are jointly affected by urbanization and rainfall. Monsoon season increases metal runoff (due to poor drainage system) The dense urban impervious surface inevitably decreases infiltration and makes more water from the surface to be runoff. The feasibility of copper and problems of drainage lead to the increase of the effects. In general, the study indicates that Cu loading to the roadside soils is influenced by urbanisation,

climatic season and drain facilities, and high density of traffic is the primary contributor to the enhanced pollution of Cu in Aizawl city.

b. The Fe concentrations were higher the second year (2021–2022) compared to between years. High Fe in Aizawl city is closely associated with vehicular mobilization and traffic flow and there is a good positive correlation evident for the same ($r = 0.86$). Fe loading is due to abrasion of vehicle parts e.g. tires and brake and wear of road materials. Concentrations are generally lower and less variable outside of Aizawl city. The relatively low Fe concentrations in suburban areas may be indicative of less vehicular pollution and less urban activity. Fe and Zn concentrations in soils also increased with increasing road widths especially in urban roadside with greater vehicular traffic, more intricate street layout, and higher population density, resulting in greater Fe accumulation in soils.

c. Mn concentrations are positively correlated with traffic activity at both within and outside the Aizawl sites, indicating that traffic is a significant source of Mn pollution. High vehicle density and industrial activities are believed to be responsible for the high Mn levels in urban areas. Generally, the Mn content is lower outside of Aizawl city suggesting less influence by human activity. Mn content is highest in both within and outside the city during pre-monsoon season. Vehicle emissions and urban anthropogenic activities are major reasons for Mn pollution of Aizawl soils while climatic parameters affect pollutant dispersion.

d. Both concentrations of Ni and degree of traffic activity have a strong positive correlation both in and outside the Aizawl city ($r = 0.98$) showing traffic as one of the major contributory sources of Ni pollution. Seasonal variations indicate that Ni concentrations are greatest in the pre-monsoon with reduced dilution by rain and dry season atmospheric deposition enhancement.

e. There are good correlations Pb vs. Traffic ($r = 0.98$) and Pb vs. Rainfall ($r = 0.99$) and the result is positive significant between Pb and traffic and seasonal rainfalls.

f. Seasonal variations in Aizawl indicated that with exception of Pb concentrations that were maximal during the monsoon. The mean Pb concentration is greater inside Aizawl (pre-monsoon: 0.37 ppm, monsoon: 0.85 ppm, and post- monsoon: 0.36 ppm) than that outside (0.35 ppm in monsoon and 0.27 ppm for pre- and post-monsoon). The higher Pb levels during monsoon would be linked to a higher runoff and sediment movement, leading to mobilization of Pb-containing sources including building painting materials. In urban sites (RS-BK10, RS-CO11, RS-KT12) the high concentration reflects traffic burden and urbanization, and outside sites have lower but stable Pb due to lower human disturbance. Site RS-SR11 near Aizawl, beside National Highway, measured the highest Pb due to heavy flow traffic for which could be the main source of Pb. These findings emphasize the potential human health risk of Pb contamination in urban roadside soils and the importance of monitoring and controlling traffic-derived lead emissions.

g. Zn correlates strongly with traffic activity ($r = 0.98$) and negatively with rainfall ($r = -0.67$), indicating traffic as a major source and rainfall affecting dilution/removal. Seasonal trends reflect pre-monsoon, Zn peaks in dry seasons due to lesser wash-off and build-up from anthropogenic sources. Intervening monsoon rains redistribute and diminish Zn in sediments. Zn levels are usually highest around Aizawl, decreasing outside it, with a exception of RS-CO11, where the level of contamination is the highest (2.07 ppm pre- monsoon; 1.67 ppm monsoon; 1.44 ppm post-monsoon). The average Zn concentrations in the city (pre-monsoon: 1.81 ppm; monsoon: 1.56 ppm; post-monsoon: 1.62 ppm) are higher than those outside the city during the pre-monsoon seasons (0.94 ppm), monsoon (0.75 ppm), post-monsoon (0.71 ppm). Urbanization and the increased human involvement are the main causes of higher Zn pollution in city atmosphere.

h. Control of traffic emissions is important in urban environmental management. Promoting rain-induced mitigative mechanisms (e.g., green infrastructure, effective drainage) may be useful in reducing the urban atmospheric heavy metal pollution, particularly in cozy, high population density cities, such as Aizawl.

5.3 Impact of COVID-19 Lockdown on Metal Pollution

Heavy metal decreased significantly because of blocked traffic and human ceased activities under COVID-19 isolation, including Cu, Mn, Zn and Fe. In post-COVID, the load also increased as the traffic and normal life returned, and levels of Cu from a range of 46-0.92 ppm during COVID to 1.16-1.78 ppm during post-COVID, and Mn ranging from 2.82- 3.96 ppm to 8.57 ppm in sites of Aizawl. In the Aizawl district except Aizawl city, post-COVID rises were also noted.

5.4. Pollution Indices of heavy metals

5.4.1. EF

The EF value suggested that moderate pollution was found in the urban environment mainly for Cu, Mn and Zn further, Pb has highest in EF at RS-KT12 in Aizawl. The greatest EF in the Aizawl city was account at RS-KT12 for Pb with the moderate enrichment of 2.54. Apart from Aizawl, the highest EF was also recorded in RS-SR11 for Ni and Pb with average value indicative of moderate contamination 2.23 and 2.40 respectively.

5.4.2. CF

This CF values indicated significant urban contamination for Cu, Pb, and Zn, with the highest CF values for Cu and Pb in Aizawl. The maximum CF for Aizawl value was 5.19 for Cu in RS-CK9, showing severe contamination. The RS-SR11 showed the highest CF of 6.69 for Pb, which was very high in contaminations level outside Aizawl.

5.4.3. PLI

Aizawl was polluted influenced with moderate to high heavy metal contamination in urban sites as indicated by the PLI values and low in rural sites, generally less than 3.00. Maximum PLI value within Aizawl was 4.64 for Cu recorded at RS-CK9

indicating high contamination. The maximum PLI was recorded as 6.60 for Pb at RS-SR11 outside Aizawl and indicating the high contaminated condition.

5.4.4. Igeo

Igeo values for the heavy metals indicated that Cu, Pb, and Zn were in moderate polluted state in Aizawl. Levels were generally lower in Aizawl vicinity implying less anthropogenic influence. The highest Igeo in Aizawl was reported for Zn at RS-KT12 (1.68), showing moderate contamination. Highest Igeo for Pb was received at RS-SR11 with 1.76 located at Aizawl suburban indicating heavy pollution at the site.

5.5. Concentration of Heavy Metals Pollutants and Heavy Metals in Air particles

a. The highest Cu concentration was observed at Site A-DP (666.5 ± 42.19 ng/m³) and the lowest concentration was 298 ± 22.87 ng/m³ at Site A-KT. The Cu concentrations were generally higher during the second year, possibly as a result of an increased anthropogenic activity and vehicular movement consequent to the relaxation of the COVID-19 restriction to public movement. Cu concentrations were higher in all sites during pre-monsoon season, with site A-DP consistently having the highest values. This is due to reasons like traffic pressure, market operations, low precipitation and copper-laden dust turbid air lifting. Sampling site A-LP (hill top, near government offices) showed higher abundance of Cu compared to A-BK and A-KT during pre-monsoon, i.e., 353.00 ng/m³ (first year) and 454.50 ng/m³ (second year). Although high traffic density, the Cu levels in A-BK continued to be lower as a result of the air sampler being located in a more residential zone, slightly apart from road and at a more elevated position, thereby lesser direct emissions exposure. Variable retention of post-monsoon Cu concentrations, in respect to the monsoon pulse, was found in all the sites except A-DP (Table 1). A-DP exhibited the maximum post-monsoon concentration of 734.75 ng/m³ revealing the parked vehicle emission and market activities.

- b. The highest and lowest mean Fe concentrations were at site A-DP (2396.13 ± 44.46 ng/m³) and site A-KT (1896.75 ± 23.28 ng/m³), respectively. The seasonal average values of Fe were 1633.50 ng/m³ at A-KT (post-monsoon year one) to 2559.00 ng/m³ at A-DP (pre-monsoon year two). Fe occurred at relatively higher levels in the second year of assessment, which may be attributed to increased anthropogenic processes as well as vehicular traffic after relaxing COVID-19 lockdowns. Fe maxima in pre-monsoon season visited in both years, are believed to be due to suspension of iron-bearing particulate matter in the air during dry weather by wind, traffic movement and other human activities. During post-monsoon, the Fe concentrations were generally lower.
- c. The highest mean Mn concentration of 411.88 ± 31.28 ng/m³ was in site A-DP, whereas the lowest was of 316.25 ± 23.27 ng/m³ in site A-BK. The Mn contents of the first and second measurement years varied slightly. Vehicle exhausts and brake abrasion are the major sources of atmospheric Mn pollution. Higher Mn levels at some sampling points could reflect traffic influences and local pollution sources. The decline in Mn concentrations in the monsoon at certain locations is assumed as washout effect due to the removal of particulate matter by rainfall. Higher Mn at A-DP and A-KT during the monsoon suggests ongoing local sources of Mn and their contribution to Mn pollution despite the rainy season. The critical accumulation of Mn at A-DP throughout the study indicates that vehicle emissions, which are less susceptible to rain, should be the principal origin of atmospheric Mn, particularly in busy roads.
- d. All other sites reveal minor increase in the Mn during the monsoon season, indicating the influence of automobiles persisting, albeit, in a moderate form than A-DP. During the post-monsoon period of the second year, Mn concentrations increased at all sites with increased traffic, construction work, and re-suspension of particulate matter. The consistently higher Mn contents in A-DP further indicate the pronounced influence of traffic pollution in densely trafficked urban market.
- e. During monsoon deposits, higher levels of Ni were observed in all the samples and fluctuations were still smaller values i.e. 0.012 ng/m³ through a maximum average of

0.18 ng/m³ at A-DP at the second year of evaluation. The presence of Ni can be attributed to the anthropogenic activities in the high traffic market areas, where the commercial activities are the major source of Ni emission. Enhancement of Ni during monsoon in the first sampling year is due to road-dust resuspension and vehicular emission. In the post-monsoon, Ni concentrations were slightly lower than the monsoon Ones at most of the sites. A-DP had the highest post-monsoon Ni concentration of 0.17 ng/m³ and A-LP the lowest (0.04 ng/m³). Residual plots for A-DP displayed the highest Ni concentrations in all seasons, indicating the strong contribution of traffic and market related activities on air Ni pollution. On the other hand, sites such as A-LP and A-KT had lower concentrations indicating relatively low levels of direct emission sources.

f. Only site A-DP had a significantly different (highest) mean Pb concentration 215.125 ± 27.21 ng/m³, other sites with mean levels recorded were A-LP which had the lowest concentration 135.25 ± 27.34 ng/m³. The seasonal averages of the mean Pb concentration were quite similar in each site over the years, and they were higher the second year of recording than first year. It can be inferred that the higher concentration of Pb in A-DP may be associated with the resuspension of the Pb-containing materials (e.g., paints from urban structures) by the wind, traffic, and market activities in dry weather. Pb increased for all sites during monsoon season with the highest for A-DP again. That are washed and resuspended Pb particles, that prevents Pb outwash. The positive Pb anomaly during the monsoon over other seasons in the present study also supports these atmospheric conditions. Pb levels declined at most sites in the post monsoon season with A-DP having a higher level of 241.45 ng/m³. The higher products of Pb in A-DP reflect the strong contribution of heavy traffic and anthropogenic sources for Pb within the urban area.

g. Site A-DP had the highest average Zn concentration of 376.25 ± 26.23 ng/m³ and site A-LP had the lowest of the 251.25 ± 28.89 ng/m³. Average Zn concentrations were generally stable among years and sites. Site A-DP presented the highest Zn levels in all seasons, which could be attributed to the high traffic and market activities. Source contributions of Zn to the urban from non-exhaust (tire wear and

brake dust) is a main urban source of Zn. Zn concentrations increased slightly during the monsoon period compared to the non-monsoon period, particularly at A-DP, due to resuspension of zinc-bearing dust during rainfall. After monsoon Zn concentrations reduced, but were still significant, with A-DP still having the highest levels. Zn concentration remained higher at A-DP persistently in the rest of the seasons indicating the contribution of traffic and anthropogenic in zinc pollution in urban areas. The lower Zn levels at the other sites suggest less urbanised conditions.

h. The positive relationship of rainfall with almost all the heavy metals suggest that they are being removed from the atmosphere by washout (Hadi, 2006). Mn also shows strong negative correlation ($r=-0.78$). Because Pb shows a strong positive relationship with rainfall ($r=0.89$), it can be inferred that Pb concentrations may be prolonged in the rainy season or even increase sustained resuspension or in relationship with particular sources of emissions.

i. The correlation of traffic activity with most heavy metals supported the traffic as a significant source of airborne metal pollution. There is a strong correlation between Cu and traffic on the bridges ($r=0.98$). Strong relations among Ni, Pb, and Zn ($r = 0.99$, $r = 0.99$, and $r = 0.98$). Fe also correlates positively ($r=0.76$). Mn is moderately correlated positively with traffic ($r=0.47$).

j. The Inter-metal correlations indicate that they share common sources or atmospheric behavior (Cu and Mn: $r=0.93$, Fe and Mn: $r=0.91$, Ni and Zn: $r=0.99$). The correlation values between Pb and other elements as a sign that different sources or atmospheric processes would influence the results. Rainwater serves as a natural cleaning agent for all metals with the exception of Pb. Vehicular emissions contribute the most to airborne Cu, Fe, Ni, Pb and Zn.

k. The extensive analysis of roadside soils in and around the Aizawl city for two years signifies the substantial seasonal and spatial variations in soil physicochemical properties and heavy metal concentrations, the knowledge of which can significantly enlighten the impact of the natural and anthropogenic factors influencing soil health. Urban development status, traffic emissions, seasonal climatic conditions, and human

activities were identified as the primary factors affecting soil metals contamination, with significant differences of soil metal concentration patterns between urban and rural areas. The pH of urban soils in general was higher than that of rural soils because of the buffering of the rainwater and addition of materials of alkaline nature from human activities that are mixed with an acidic component. In contrast, rural soils, with less exposure to pollutants, had a more consistent pH over seasons. Monsoonal rains strongly contributed to reducing soil acidity at all sites, more in urban sites, where more alkaline material was added.

l. Seasonality was also observed in SMC with the peak values occurring during monsoon rainfall at both urban and rural samples sites. In urban soils there was less retained water compared to rural soils, as a result of the predictions of lower infiltration and higher runoff of impervious surfaces, while rural soils, with greater coverage from vegetation and higher permeability, exhibited a greater retention of moisture. Likewise, SOC levels were greater in urban soils because of organic accumulation by urban waste and decomposing plant material, but the seasonal variation was higher getting depleted during monsoon due leaching. Conversely, rural SOC contents were lower and experienced less variations, a result of lower exposure to collected organic inputs. Results indicated that TNC exhibited significant fluctuations at urban sites and attained the highest values during the monsoon, driven by nitrogen deposition, but decreased with natural vegetation and decayed organic matter in increased rural soils. Also both APC and AKC had different ranges. APC was higher in rural soils due to decomposed plant materials while KTC in urban soils varied due to the deposition of nutrients and leaching.

m. Heavy metal analysis indicates that urbanization exerts most considerable influence on roadside soils. Cu, Pb, Zn, Mn, and Ni were higher in urban soils, owing to vehicular emissions, industrial activity, and urban runoff. Seasonal pattern is observed, as the pre-monsoon showed high concentration due to accumulation of metal in dry conditions during pre-monsoon season monsoon event leading to washout by rainfall. There were higher distributions within urban hotspots for copper and zinc, presumably from vehicular, industrial and urban activities, and lower distributions within the rural

areas with the exception of localized pollution adjacent to highways. The lockdown owing to COVID-19 was unique and such conditions provided the opportunity to study the influence of reduced human activity which led to a significant drop in heavy metal concentration especially to Cu, Mn, and Zn. In the post lockdown levels increased to previous levels, indicating strong traffic and other anthropogenic impact.

n. In surface particulate matter, concentrations of heavy metals also varied seasonally and spatially and were highest at the urban sites (e.g., A-DP) due to heavy emissions of vehicular exhausts, market related activities, construction activities and also due to dust resuspension. The fraction of metals (Cu, Zn, Mn, and Fe), were strongly affected by brake wear, road dust, and non-exhaust vehicular traffic. Seasonal variation showed higher levels during pre-monsoon on account of dry condition favouring suspension and lower levels during monsoon attributed to washout by rain. Pb and Ni were still retained in the air even in wet weather, especially in urban hotspots, because emissions from wetted surfaces and urban activity took place. Administrative office locations A-LP and A-KT had lower levels, indicative of reduced exposure from direct pollution sources.

o. The areas of maximum pollution and a high concentration of metals in the Aizawl city are mostly attributed to RS-KK1, RS-BV4, RS-TS7, RS-CK9, and RS-KT1. They are marked by heavy traffic and intense anthropogenic influence, and active shift lasts till midnight. RS-HF6, RS-AB8, and RS-SR11 outside Aizawl also showed higher metal concentration. These clusters are mostly present along the nearby National Highway and also function as traffic nodes or urban centers and hence have high pollution levels, local hybrid as well as Gaussian estimates for urban nodes along the highway.

p. These results highlight the importance of monitoring and the development of an integrated environmental management, through the reduction emissions, an effective control of waste and stormwater management. Suitable intervention programs should be targeted to high stress urban areas to minimize the soil and air contamination burden for sustainable ecology and human health. The seasonal and spatial variations

indicate the need for more targeted actions to face up to the long-term challenges of urbanization and heavy metal pollution.

5.6. Remediation

Given the hilly terrains in Aizawl and limited fund as well as technologies, the following low-cost effective measures are suggested to mitigate heavy metal pollution from roadside soil and air in the town. These are to be affordable and effective and fit the city's specific environment and challenges.

Below is a longer, more detailed version of your strategies, adapted to Aizawl, Mizoram, with additional background and corrective action from the city's geological, climatic and societal peculiarities:

a. Public Awareness/Education Campaigns

Initiate city-wise environmental awareness campaign with visual aids (such as posters, leaflets in Mizo, etc), Radio programmes on local FM channels, various community awareness programme to demonstrate sources and risks of heavy metal pollutants shows on traffic, waste burning and construction. Focus on health hazards such as respiratory disease or skin conditions or long-term neurological problems brought on through exposure to heavy metals. Campaigns also should encourage preventive actions such as face masks and the use of air-purifying plants to improve indoor air quality and proper waste disposal.

b. Community Engagement and Participation Mechanism

Mobilize communities through neighbourhood level programs like "Soil Health Saturdays," in which citizens use low-cost testing kits to test their soil. Involve NGOs, youths' local groups and Self-Help groups of women to make the bottom-up approach. Brainstorm ways to inspire and collect valuable information from area residents and green-light ideas like asking them to report back on traffic density, instances of open dumping or patches of unhealthy soil.

c. School and Youth Programs

Include environmental education in the curriculum of schools as part of the Science or Social Studies on soil and air health made relevant to Aizawl's hilly ecosystem. Environmental responsibility will also be fostered through activities such as "Mini Soil Labs," planting native species, and interactive storytelling on pollution. Work together with Eco Clubs on field trips, workshops and competitions about environmental conservation.

d. Policy Advocacy and Low- Emission Zones

Collaborate with the Aizawl Municipal Corporation and the Mizoram State Pollution Control Board to pursue low-emission zones in proximity to sensitive areas such as schools, hospitals, elder care facilities, etc. Promote routine car checkup and the adoption of cleaner fuel such as LPG. To advocate the tightening of illegal dumping and construction dust on local bylaw amendment.

e. Vegetative Screens and Green Elements

Plant Baffle/Green Roadsides with locally available plant species such as Bamboo, Ficus, Bougainvillea, Vetiver grass etc. that trap dust and absorb metals like Pb, Zn, Ni. These green walls do not only regulate air and soil pollution, but also enhance visual aspects and biodiversity. Encourage rooftop/vertical gardens in urban homes.

f. Phytoremediation with Indigenous Plants

Employ phytoremediation with metal-collecting indigenous plants like *Saccharum spontaneum*, *Pennisetum purpureum* and *Parthenium hysterophorus*, which are already well suited to the soils of Mizoram. These plants can be cultivated in polluted hotspots and harvested without being consumed to extract metals from the biosphere in the long run. Add in public plantings drives, and a public ready move.

g. Methods for Controlling Dust

Approximate idealized controls that could be enforced on the dust sources in terms of water spraying at dusty roads, notably from November to March (the dry season when the air quality in the region is worsened). Use recycled water wherever

feasible. Provide temporary dust screens around construction area in high traffic zones such as Vaivakawn, Kulikawn and Zarkawt.

h. Runoff and Rainwater Management

Set up rainwater harvesting structures in schools, government buildings and residential colonies to prevent runoff that bring the heavy metals from road to the agricultural field and homes. Construct contour trenches, check dams, and terracing systems to decrease soil erosion important in Aizawl's steep and erosion-prone hillsides.

i. Capability & Knowledge Transfer

Train community leaders, schoolteachers and municipal workers regularly in managing soil health. Popularize bio-degradable receptacles for this waste (such earthen pots) and educate on the safe disposal. Collaborate with Mizoram University and NGOs for comprehensive mentoring and technology transfer.

j. Partnership for Technical Support

Work in partnership with schools, CSOs, and environmental NGOs like the Mizoram Pollution Control Board, the Green Mizoram movement and NEERI to offer monitoring equipment, data interpretation support and guidance for field-based remediation approaches.

k. Methods of Municipal Solid Waste Management

Raise the consciousness of the community on waste segregation and proper waste disposal. Establish such centres for collecting hazardous waste and promote home composting. Have the people of the municipalities be trained in operation and maintenance of sanitary land fill.

l. Air Quality Community-Lead Monitoring

Deploy low-cost air quality sensors at schools, traffic intersections, and near dumpsites to collect data on PM and the heavy metals associated with it, such as lead

and nickel. Data should flow through community notice boards or apps. Enact quarterly community air audits to pinpoint pollution highs and take rapid action.

m. Best Management Practices (BMPs)

Introduce soil conservation measures appropriate to the slopping nature of Aizawl such as vegetative hedges, bamboo fencing, and contour bunding. Encourage the use of bio-filters and silt traps in the drainage system to filter out contaminants before they reach surface water or gardens.

n. Continuous Evaluation and Improvement

Establish a community feedback cell through which local inhabitants can communicate their observations, complaints and suggestions. Increase the frequency of assessment as the implemented plans proceed; indicators include trends in hospital visits or visits to providers, results from air/soil testing, and photographs showing the degree of pollution. Monitor needs and adapt strategies.

o. Involvement of the Public in Soil Quality Monitoring

Capacity-building: Train community group members in simple soil testing and promote bi-annual monitoring with visual tools (color charts, pH strips). Create no frills logbooks where households could write down their results. This provides a platform for building awareness and also is a citizen-science database for Aizawl's environmental planning.

p. Targeted Remediation Through Decision Frameworks

Use plain methodologies such as MCDA in a community meeting to collectively select the most feasible and efficient remedial approaches. Costs, efficacy, community acceptance and time can all be openly debated with visuals.

q. Ethical and Inclusive Approaches

Arrange that marginalized groups such as tribal minorities, daily wages labors, women, and Youth are included in remediation planning and its execution. Give

them incentives, or recognitions for being part of them that they would appreciate and translate or have a verbal communication that can be understood no matter the educational level.

r. Resilience and Adaptation Planning

Set in place long-term strategies with like diversified agroforestry, erosion-proof crops and rotation planting to keep the soil healthy. Predict soil stress with climate projections for Mizoram and establish programs to help communities adjust agriculture and living systems.

s. Regular Feedback and Adaptive Management

Build a living environmental indicator database with quarterly updates and public input. This helps to keep the city's response to heavy metal contamination dynamic and neighbourhood-driven. For instances, mobile apps or WhatsApp groups for live updates, especially during extreme weather events.

5.7 CONCLUSION

This study provides a comprehensive overview of physicochemical properties and heavy metal contamination of roadside soil and air in Aizawl city and vicinity demonstrating clear spatial and seasonal trends that reflect the exposure to anthropogenic pressures in the environment of this hill town. The physicochemical characteristics, including pH, organic matter (OM), fluctuated widely across sites and among seasons, with higher pH values occurring during rainy months attributed to leaching and dilution. These fluctuations have an impact on the mobility and bio accessibility of heavy metals in soils. In Aizawl city, higher load of metals (Pb, Zn, Cu) were recorded over major traffic zones such as Vaivakawn and Zarkawt particularly in dry season implying vehicular discharge, construction dusts and inadequate management of waste as the sources. In the non-urban areas, metals were generally lower but some rural areas still exhibited high Fe and Mn concentrations, indicating localized pollution, potentially from farmland runoff or nearby roads.

Seasonal and spatial variations were also indicated in the air samples, with the higher concentrations of PM-bound metals such as Pb and Ni in the air being observed in

the dry winter season. This pattern is consistent with enhanced atmospheric dust and lower precipitation to quell particulate. The contamination indices such as PLI, Igeo and CF indicated moderate to high pollution in some sites, particularly the urban places, suggesting an urgency to the focus remediation.

Of particular interest was comparison with post-COVID data, where concentrations of heavy metals were seen to dip slightly during and immediately after lockdown periods, indicating the significant effect of human activities such as traffic and industrial work on pollution levels. The fact that contamination rebounds after limitations shows that short-term reductions do nothing without longer-term, sustained approaches.

Based on these findings, the study suggests a series of low-cost, applicable and location-specific community-based remediation activities which address the hilly and mountainous nature of Aizawl city and its poor infrastructure and socio-economic condition. These consists of environmental awareness program in Mizo, school programs, community soil-testing camp, and greening the bank with local plant species having phytoremediatory values. It also suggested infrastructure-based interventions such as rainwater-harvesting, dust control during the dry months and appropriate municipal solid waste management. Involvement of the institution with agencies such as the Mizoram Pollution Control Board, local NGOs, and academic institutions are important for sharing of information and capacity building. Inclusive participation of these particularly vulnerable groups, such as women, youth, and the marginalized, is very crucial as the interventions have to be sustainable and acceptable.

In summary, the study identifies the gravity and the complexity of heavy metal pollution of Aizawl's urban and peri-urban area and tentatively develops an action agenda that is evidence-based and context bound. Widespread adoption of the proposed cost-effective strategies, regular surveillance of water quality and community participation are central to risk reduction, ecological health and human well-being in the city of Aizawl. By working together and through adaptive management, the city can begin to achieve a cleaner, healthier

Appendix

Appendix 1. Soil properties with response to the different sampling sites within Aizawl city.

	RS-K1	RS-V2	RS-S3	RS-BV4	RS-BB5	RS-L6	RS-T7	RS-R8	RS-C9	RS-BK10	RS-C011	RS-KT12
pH	9.50	9.64	9.00	8.98	8.09	7.92	9.63	9.31	9.10	9.82	8.62	10.14
OC(%)	0.85	0.79	0.73	0.88	0.97	0.98	0.88	0.91	0.91	0.85	0.58	1.08
SMC(%)	8.49	8.24		8.28	8.56	8.60	8.43	8.49	8.39	8.46	8.49	8.45
(kg/ha)			8.39									
N(kg/ha)	0.49	1.07	1.27	1.00	0.73	1.63	1.23	0.80	0.60	1.00	1.01	1.00
P(kg/ha)	1.35	0.46	0.20	1.21	0.50	0.85	0.65	1.09	1.60	0.88	0.59	1.15
K (kg/ha)	55.28	48.13	49.59	86.95	40.54	38.41	33.68	36.76	37.44	47.22	45.46	61.31

	RS-C1	RS-S2	RS-K3	RS-S4	RS-T5	RS-H6	RS-S7	RS-A8	RS-S9	RS-T10	RS-S11	RS-M12
pH	8.20	8.15	8.16	10.00	8.52	8.82	8.11	8.57	8.14	9.15	9.11	8.47
OC(%)	0.77	0.64	0.78	0.51	0.90	0.71	0.95	0.86	0.91	0.77	0.61	0.63
SMC(%)	10.08	10.06	9.93	10.44	10.42	9.99	10.09	10.00	10.03	9.91	10.06	9.92
(kg/ha)												
N (kg/ha)	1.07	1.03	1.47	1.73	1.40	1.43	1.57	1.50	1.57	1.40	1.37	1.50
P(kg/ha)	3.24	3.97	4.08	0.87	3.84	1.23	3.99	3.28	4.11	3.88	2.12	1.92
K(kg/ha)	89.74	85.86	91.69	55.07	90.48	90.84	98.39	99.16	87.88	87.86	64.81	63.33

Appendix 2. Properties with response to the different sampling sites outside Aizawl city.

Appendix 3. Monthly Copper concentration on roadside soil within Aizawl City (2020-2022) in ppm.

	RS-K1	RS-V2	RS-S3	RS-BV4	RS-BB5	RS-L6	RS-T7	RS-R8	RS-C9	RS-BK10	RS-C011	RS-KT12
Aug-20	0.52	0.46	0.59	0.56	0.55	0.46	0.31	0.25	0.4	0.51	0.21	0.27
Sep-20	0.29	0.45	1.03	0.70	0.93	0.77	0.49	0.36	0.91	0.88	0.25	0.67
Oct-20	0.24	0.42	0.52	0.33	0.58	0.24	0.45	0.17	0.86	0.26	0.47	0.80
Nov-20	0.19	0.13	0.49	0.26	0.27	0.08	0.19	0.12	0.51	0.50	0.07	0.25
Dec-20	0.25	0.37	0.20	0.72	0.68	0.17	0.37	0.34	1.26	0.33	0.08	0.56
Jan-21	0.54	0.67	1.10	0.32	0.68	0.86	1.62	1.39	1.55	1.37	1.17	1.17
Feb-21	0.78	0.63	1.27	1.94	1.91	1.69	0.74	0.64	1.49	0.76	0.14	0.70

Mar-21	1.74	0.65	1.48	1.52	1.50	0.24	3.23	0.66	1.36	0.79	0.31	0.40
April-21	0.44	0.33	0.43	0.56	0.71	0.26	0.45	0.77	1.70	0.73	0.45	0.68
May-21	0.17	0.27	0.28	0.36	0.38	0.47	0.29	0.37	0.38	0.37	0.30	0.37
June-21	0.95	0.59	0.68	0.66	0.57	0.36	0.76	0.37	1.25	0.79	0.29	0.89
July-21	0.29	0.77	0.64	0.65	2.73	1.71	2.36	1.36	1.10	0.75	1.39	0.57
Aug-21	0.35	0.41	0.42	0.33	0.28	0.32	0.34	0.27	0.67	0.24	0.60	0.64
Sep-21	0.37	0.45	0.22	0.37	0.29	0.36	0.33	0.34	0.57	0.28	0.59	0.78
Oct-21	0.36	0.54	0.35	0.41	0.32	0.52	0.38	0.29	0.52	0.25	0.65	0.85
Nov-21	2.46	1.12	3.65	2.02	2.73	2.35	3.85	2.14	1.86	2.37	1.33	1.55
Dec-21	2.22	2.01	2.43	2.34	2.06	2.37	2.47	2.68	1.78	2.33	2.73	2.34

Jan-22	2.17	2.10	2.36	2.31	2.02	2.27	2.36	2.64	1.76	2.30	2.74	2.27
Feb-22	1.19	0.77	1.25	1.13	1.03	1.35	2.31	2.63	1.60	2.25	2.03	2.23
Mar-22	2.86	2.24	2.64	2.63	2.63	2.45	2.34	2.49	2.24	2.35	2.27	2.40
April-22	2.02	1.39	1.71	1.56	2.29	1.70	1.54	1.58	2.24	1.59	1.36	1.80
May-22	0.84	0.54	0.55	0.79	1.59	0.69	1.12	1.10	2.39	1.30	0.61	1.27
Jun-22	1.49	1.99	1.26	3.21	2.11	1.00	2.27	2.27	3.47	2.81	1.31	1.63
July-22	0.37	0.30	0.53	0.33	0.94	1.35	2.05	0.42	0.59	0.59	1.44	0.15

Appendix 4. Monthly Iron concentration on roadside soil within Aizawl City (2020-2022) in ppm.

	RS-K1	RS-V2	RS-S3	RS-BV4	RS-BB5	RS-L6	RS-T7	RS-R8	RS-C9	RS-BK10	RS-C011	RS-KT12
Aug-20	13.97	13.14	13.13	13.42	13.26	13.4	13.14	13.2	13.15	13.24	14.59	12.54
Sep-20	14.28	14.14	14.19	14.17	14.23	14.48	14.53	14.76	14.71	14.24	14.46	14.49
Oct-20	17.84	14.49	14.56	14.54	14.56	14.67	14.49	14.13	14.46	14.42	14.52	14.76
Nov-20	26.23	25.09	26.00	25.18	25.18	25.11	24.81	24.85	25.25	25.46	25.85	26.34
Dec-20	26.15	26.87	26.76	26.88	26.62	26.79	26.70	26.26	26.29	26.26	25.85	26.6
Jan-21	25.47	24.77	25.59	25.60	23.97	25.26	24.76	25.67	24.92	25.17	25.71	25.70
Feb-21	31.81	32.51	31.36	31.86	32.24	32.28	30.89	31.18	31.81	32.17	29.84	32.10

Mar-21	20.49	20.53	20.51	20.31	20.43	17.96	20.50	19.97	20.13	20.03	19.94	18.72
April-21	23.56	23.56	23.91	24.00	23.00	23.41	22.59	20.77	22.63	23.44	22.73	22.82
May-21	26.51	26.90	25.37	28.24	27.51	26.93	26.43	26.24	26.34	26.11	26.32	26.74
June-21	15.58	15.55	15.64	15.49	15.29	15.78	15.82	15.22	15.22	15.35	15.17	15.36
July-21	15.58	15.55	15.64	15.49	15.29	15.78	15.82	15.22	15.22	15.35	15.17	15.36
Aug-21	27.00	28.18	31.28	28.07	27.57	29.69	32.73	28.09	30.38	29.14	28.27	28.50
Sep-21	28.34	29.71	36.12	26.42	27.50	29.82	33.18	26.12	33.80	25.24	28.77	25.50
Oct-21	22.94	30.79	33.33	30.00	29.47	32.10	33.96	30.17	32.70	26.01	28.83	31.14
Nov-21	23.84	23.64	23.84	23.84	23.52	23.36	23.44	23.55	23.55	23.74	23.74	23.74
Dec-21	23.84	23.74	23.92	23.85	23.53	23.67	23.74	23.47	23.54	23.64	23.82	23.91

Jan-22	23.72	23.62	23.66	23.81	23.41	23.66	23.72	23.40	23.42	23.57	23.43	23.85
Feb-22	23.65	23.93	23.74	23.95	23.44	23.66	23.71	23.60	23.63	23.74	23.25	23.62
Mar-22	23.41	23.07	23.21	23.73	23.51	23.76	23.33	22.97	23.05	23.15	23.04	23.12
April-22	31.42	30.60	30.25	34.65	34.82	37.39	32.11	32.11	37.03	36.53	36.10	33.30
May-22	35.41	34.67	34.14	40.11	40.14	43.93	36.64	41.73	44.24	43.37	42.84	38.65
Jun-22	23.13	23.46	23.60	23.52	22.24	22.75	23.53	23.42	23.37	23.14	23.69	23.68
July-22	54.49	50.70	40.93	48.78	52.73	50.69	44.60	55.16	52.57	48.66	50.16	24.21

Appendix 5. Monthly Manganese concentration on roadside soil within Aizawl City (2020-2022) in ppm.

	RS-K1	RS-V2	RS-S3	RS-BV4	RS-BB5	RS-L6	RS-T7	RS-R8	RS-C9	RS-BK10	RS-C011	RS-KT12
Aug-20	4.48	2.63	2.63	3.48	2.67	2.97	3.10	2.35	3.23	2.15	2.28	2.09
Sep-20	2.37	3.12	3.45	4.28	3.41	3.74	3.43	2.79	3.33	2.94	2.81	4.80
Oct-20	2.47	3.13	2.44	2.51	2.57	2.57	3.30	2.03	2.58	2.59	2.70	2.27
Nov-20	3.01	2.67	2.92	2.84	2.84	2.27	3.14	1.90	2.60	2.61	2.74	2.48
Dec-20	2.81	2.96	3.12	2.91	3.71	4.78	4.72	3.10	3.17	2.82	3.26	4.07
Jan-21	3.65	3.20	3.98	3.41	2.5	3.24	3.38	3.87	2.69	2.76	3.48	3.81
Feb-21												

	3.10	2.88	3.25	3.24	3.27	3.22	2.92	2.68	2.47	3.93	2.15	3.73
Mar-21	3.78	2.94	3.74	3.08	3.26	0.63	4.11	3.05	3.03	3.21	5.00	5.00
April-21	3.65	3.68	3.78	3.83	3.34	2.88	3.65	3.60	3.29	3.83	2.53	3.86
May-21	2.71	2.70	3.56	4.32	4.12	2.44	3.68	2.49	2.56	2.35	3.16	4.21
June-21	4.17	2.67	3.02	3.25	2.65	3.01	3.61	2.55	2.65	2.78	3.30	2.98
July-21	1.57	1.24	3.81	1.73	1.28	1.91	1.89	1.83	1.98	1.25	1.25	1.89
Aug-21	2.27	2.47	5.42	3.35	2.20	1.93	5.18	2.06	2.34	1.87	2.17	3.29
Sep-21	1.71	2.31	4.04	3.76	2.85	2.05	6.55	2.22	2.40	2.37	2.73	3.29
Oct-21	2.04	3.08	2.88	2.89	2.34	2.86	2.68	1.82	1.69	2.80	3.49	6.12
Nov-21	5.67	5.06	6.45	5.32	6.35	6.35	6.92	7.75	9.05	7.56	7.77	10.52
Dec-21												

	9.25	6.85	5.97	7.04	7.55	10.94	11.44	5.91	7.84	9.12	9.33	7.06
Jan-22	9.19	6.92	5.92	6.10	6.55	10.11	10.42	4.84	6.87	8.86	8.90	7.03
Feb-22	8.21	6.78	5.67	6.06	6.46	9.10	8.43	4.64	6.82	8.11	8.39	6.12
Mar-22	7.49	5.70	5.19	7.45	5.06	5.10	9.25	6.23	6.24	7.81	8.26	6.30
April-22	6.26	5.56	5.13	6.01	8.48	8.19	12.06	7.64	9.42	8.38	11.42	12.20
May-22	5.68	5.63	5.10	4.57	7.71	10.33	13.18	7.74	11.05	8.46	13.01	15.43
Jun-22	6.42	5.19	4.71	5.96	3.32	3.49	8.96	5.42	5.80	6.72	8.15	7.63
July-22	7.08	11.63	2.08	4.16	6.05	4.08	7.79	10.98	7.17	4.27	5.29	3.39

Appendix 6. Monthly Nickel concentration on roadside soil within Aizawl City (2020-2022) in ppm.

	RS-K1	RS-V2	RS-S3	RS-BV4	RS-BB5	RS-L6	RS-T7	RS-R8	RS-C9	RS-BK10	RS-C011	RS-KT12
Aug-20	0.38	0.28	0.26	0.19	0.15	0.14	0.12	0.25	0.20	0.25	0.19	0.22
Sep-20	0.17	0.17	0.20	0.44	0.21	0.22	0.15	0.24	0.20	0.24	0.18	0.27
Oct-20	0.31	0.18	0.23	0.37	0.18	0.18	0.15	0.15	0.20	0.19	0.19	0.11
Nov-20	0.26	0.15	0.21	0.17	0.18	0.18	0.17	0.17	0.25	0.23	0.21	0.25
Dec-20	0.43	0.16	0.23	0.20	0.20	0.25	0.19	0.19	0.25	0.18	0.18	0.25
Jan-21	0.34	0.36	0.28	0.23	0.19	0.28	0.25	0.76	0.35	0.67	0.34	0.65
Feb-21	0.19	0.17	0.29	0.28	0.17	0.23	0.18	0.17	0.17	0.52	0.13	0.20

Mar-21	1.61	0.26	0.27	1.04	0.20	0.09	1.19	1.13	0.23	0.22	0.27	0.23
April-21	0.25	0.25	0.23	0.39	0.38	0.20	0.19	0.19	0.20	0.24	2.56	0.25
May-21	0.15	0.15	0.24	0.27	0.22	0.24	0.25	0.17	0.37	0.14	0.21	0.30
June-21	0.53	0.29	0.29	0.47	0.29	0.25	0.27	0.38	0.36	0.44	0.45	0.36
July-21	0.05	0.02	0.11	0.37	0.22	0.05	0.21	0.28	0.25	0.41	0.17	0.37
Aug-21	0.03	0.05	0.09	0.46	0.27	0.15	0.26	0.39	0.15	0.58	0.21	0.48
Sep-21	0.29	0.45	0.22	0.52	0.75	0.78	0.29	0.43	0.19	0.58	0.22	0.54
Oct-21	0.39	0.57	0.33	0.56	0.71	0.66	0.30	0.41	0.29	0.58	0.66	0.62
Nov-21	0.63	0.36	0.54	0.43	0.47	0.34	0.47	0.36	0.56	0.44	0.45	0.32
Dec-21	0.44	0.36	0.53	0.45	0.27	0.44	0.24	0.36	0.65	0.36	0.25	0.25

Jan-22	0.47	0.33	0.51	0.40	0.26	0.43	0.20	0.34	0.56	0.31	0.23	0.25
Feb-22	0.40	0.33	0.51	0.35	0.25	0.49	0.21	0.27	0.43	0.40	0.35	0.32
Mar-22	0.44	0.40	0.61	0.33	0.33	0.27	0.21	0.37	0.46	0.34	0.29	0.29
April-22	0.33	0.26	0.28	0.13	0.27	0.12	0.21	0.36	0.43	0.37	0.19	0.26
May-22	0.35	0.27	0.34	0.46	0.45	0.87	0.70	0.70	1.16	0.67	0.80	1.28
Jun-22	0.64	0.72	0.91	0.63	0.43	0.79	0.31	0.35	0.28	0.65	0.63	0.30
July-22	0.63	0.48	0.47	0.37	0.45	0.37	0.36	0.64	0.76	0.37	0.66	0.79

Appendix 7. Monthly Lead concentration on roadside soil within Aizawl City (2020-2022) in ppm.

	RS-K1	RS-V2	RS-S3	RS-BV4	RS-BB5	RS-L6	RS-T7	RS-R8	RS-C9	RS-BK10	RS-C011	RS-KT12
Aug-20	0.16	0.15	0.13	0.35	0.12	0.20	0.10	0.32	0.10	0.18	0.15	0.18
Sep-20	0.66	0.17	0.21	0.70	0.27	0.26	0.11	0.44	0.12	0.27	0.17	0.22
Oct-20	0.81	0.12	0.58	0.15	0.17	0.13	0.13	0.11	0.12	0.09	0.07	0.05
Nov-20	0.14	0.19	0.21	0.22	0.22	0.18	0.18	0.16	0.24	0.23	0.28	0.34
Dec-20	0.37	0.24	0.17	0.24	0.27	0.25	0.25	0.26	0.37	0.24	0.20	0.32
Jan-21	0.32	0.33	0.36	0.30	0.47	0.62	0.71	0.62	0.37	0.27	0.20	0.32
Feb-21	0.19	0.17	0.29	0.28	0.17	0.23	0.18	0.17	0.17	0.52	0.13	0.20

Mar-21	1.61	0.26	0.27	1.04	0.20	0.09	1.19	1.13	0.23	0.22	0.27	0.23
April-21	0.25	0.25	0.23	0.39	0.38	0.20	0.19	0.19	0.20	0.24	2.56	0.25
May-21	0.15	0.15	0.24	0.27	0.22	0.24	0.25	0.17	0.37	0.10	0.21	0.30
June-21	0.53	0.29	0.29	0.47	0.29	0.25	0.27	0.38	0.36	0.44	0.45	0.36
July-21	0.26	0.39	0.17	0.47	0.65	0.79	0.62	0.33	0.28	0.93	0.25	1.33
Aug-21	0.81	0.21	0.19	0.21	0.89	1.48	0.45	0.63	1.13	2.32	3.10	3.04
Sep-21	0.92	0.50	0.49	0.54	0.45	0.33	0.45	0.86	1.22	2.87	3.64	3.02
Oct-21	0.37	0.55	0.33	0.64	0.62	0.42	0.79	0.46	0.41	0.57	0.53	0.89
Nov-21	0.57	0.35	0.55	0.34	0.45	0.34	0.43	0.56	0.33	0.26	0.37	0.55
Dec-21	0.46	0.46	0.57	0.32	0.32	0.37	0.47	0.37	0.35	0.42	0.35	0.34

Jan-22	0.46	0.41	0.57	0.32	0.32	0.36	0.45	0.34	0.34	0.45	0.35	0.32
Feb-22	0.41	0.37	0.51	0.33	0.30	0.30	0.36	0.37	0.35	0.40	0.35	0.32
Mar-22	0.42	0.43	0.56	0.34	0.33	0.37	0.39	0.36	0.33	0.46	0.34	0.24
April-22	0.30	0.28	0.42	0.39	0.35	0.67	0.55	0.46	0.74	0.57	0.55	0.84
May-22	0.35	0.27	0.34	0.46	0.45	0.87	0.70	0.70	1.16	0.67	0.80	1.28
Jun-22	0.85	0.78	0.60	0.56	0.74	0.66	0.70	1.09	1.15	0.71	0.92	0.75
July-22	0.87	1.22	1.37	0.90	1.06	0.87	0.97	0.85	0.79	0.69	0.82	0.90

Appendix 8. Monthly Zinc concentration on roadside soil within Aizawl City (2020-2022) in ppm.

	RS-K1	RS-V2	RS-S3	RS-BV4	RS-BB5	RS-L6	RS-T7	RS-R8	RS-C9	RS-BK10	RS-C011	RS-KT12
Aug-20	0.49	0.48	0.60	0.62	0.31	0.31	0.22	0.37	0.45	0.30	0.39	0.36
Sep-20	1.08	1.04	1.41	1.44	1.50	1.51	1.27	1.49	1.5	0.66	1.36	1.51
Oct-20	1.12	0.83	0.96	0.89	0.84	1.08	0.90	0.85	1.12	0.84	0.89	0.60
Nov-20	2.15	0.86	1.32	1.55	1.33	1.49	1.23	1.06	1.45	1.56	0.73	1.93
Dec-20	2.12	1.66	1.52	0.53	1.57	0.70	1.77	1.7	2.17	1.71	0.77	2.33
Jan-21	1.89	2.55	2.46	2.18	2.64	2.67	2.26	2.59	2.28	2.61	1.96	2.59
Feb-21	2.00	2.41	2.24	2.17	2.20	2.09	1.90	2.06	2.76	2.27	0.86	3.08

Mar-21	1.90	1.87	1.85	1.27	1.82	1.13	1.90	1.46	1.80	1.81	1.67	1.86
April-21	1.79	1.54	1.62	1.75	2.02	1.94	1.88	1.84	1.97	1.90	2.08	2.07
May-21	1.54	1.67	1.69	1.97	2.02	2.06	2.09	1.63	2.06	1.93	2.10	2.17
June-21	1.74	1.81	1.62	1.81	1.69	1.79	1.72	1.71	1.84	1.78	1.58	1.82
July-21	1.45	1.65	1.25	1.70	1.82	1.80	1.80	1.81	1.86	1.81	1.86	1.80
Aug-21	1.45	1.45	0.92	1.19	2.18	2.33	2.17	1.87	2.02	1.95	2.26	2.21
Sep-21	1.35	1.61	1.03	1.20	2.26	2.73	2.19	2.45	1.98	1.93	2.15	2.16
Oct-21	1.45	1.52	0.94	1.22	1.65	1.63	1.83	1.80	1.82	1.76	1.71	1.75
Nov-21	1.77	1.76	1.76	1.77	1.66	1.76	1.64	1.81	1.81	1.76	1.73	1.78
Dec-21	1.83	1.76	1.74	1.77	1.73	1.79	1.76	1.62	1.77	1.74	1.77	1.65

Jan-22	1.80	1.71	1.70	1.56	1.52	1.71	1.68	1.57	1.66	1.72	1.74	1.61
Feb-22	1.76	1.72	1.71	1.50	1.53	1.63	1.62	1.55	1.72	1.75	1.76	1.55
Mar-22	1.92	1.83	1.82	1.84	1.75	1.56	1.66	1.53	1.80	1.76	1.80	1.68
April-22	1.77	1.75	1.71	1.76	1.72	2.24	1.65	1.57	1.73	1.68	1.71	1.61
May-22	1.56	1.64	1.56	1.58	1.63	2.62	1.63	1.62	1.63	1.61	1.62	1.62
Jun-22	1.53	1.64	1.57	1.60	1.65	1.63	1.63	1.64	1.63	1.63	1.64	1.61
July-22	1.28	1.20	0.85	2.82	3.05	1.71	1.77	1.88	2.30	1.76	3.58	0.65

Appendix 9. Monthly Copper concentration on roadside soil outside Aizawl City (2020-2022) in ppm.

	RS-CR1	RS-SL2	RS-KR3	RS-SG4	RS-TP5	RS-HF6	RS-ST7	RS-AB8	RS-SS9	RS-TV10	RS-SR11	RS-MT12
Aug-20	0.27	0.27	0.29	0.33	0.25	0.31	0.27	0.26	0.28	0.26	0.35	0.27
Sep-20	0.28	0.27	0.28	0.34	0.26	0.32	0.27	0.29	0.28	0.27	0.38	0.30
Oct-20	0.24	0.21	0.22	0.33	0.27	0.3	0.28	0.29	0.29	0.26	0.47	0.32
Nov-20	0.20	0.21	0.22	0.27	0.22	0.22	0.21	0.22	0.23	0.21	0.35	0.27
Dec-20	0.28	0.27	0.28	0.38	0.24	0.37	0.28	0.25	0.29	0.25	0.48	0.35
Jan-21	0.25	0.26	0.28	0.37	0.24	0.32	0.26	0.25	0.27	0.25	0.45	0.32
Feb-21	0.28	0.28	0.27	0.4	0.26	0.38	0.28	0.27	0.28	0.24	0.46	0.35

Mar-21	0.30	0.29	0.29	0.41	0.25	0.33	0.29	0.31	0.30	0.27	0.41	0.40
April-21	0.29	0.28	0.28	0.39	0.27	0.31	0.28	0.32	0.29	0.26	0.41	0.39
May-21	0.21	0.22	0.24	0.36	0.22	0.28	0.24	0.29	0.31	0.27	0.32	0.33
June-21	0.31	0.31	0.34	0.39	0.28	0.32	0.27	0.29	0.30	0.28	0.39	0.37
July-21	0.28	0.30	0.33	0.42	0.30	0.31	0.29	0.30	0.29	0.27	0.41	0.34
Aug-21	0.52	0.55	0.54	0.69	0.57	0.79	0.51	0.73	0.64	0.55	1.21	0.65
Sep-21	0.54	0.62	0.67	0.73	0.62	0.84	0.55	0.89	0.84	0.61	1.28	0.86
Oct-21	0.54	0.63	0.65	0.78	0.63	0.83	0.56	0.83	0.81	0.57	1.23	0.84
Nov-21	0.53	0.67	0.66	0.65	0.65	0.88	0.64	0.85	0.85	0.64	1.43	0.86
Dec-21	0.51	0.65	0.78	0.79	0.88	1.15	0.69	1.27	1.21	0.89	1.63	1.23

Jan-22	0.54	0.66	0.82	0.77	0.98	1.18	0.78	1.23	1.22	0.86	1.54	1.25
Feb-22	0.62	0.87	0.85	0.89	1.07	1.21	0.82	1.22	1.32	0.91	1.87	1.12
Mar-22	0.66	0.92	0.95	0.93	1.21	1.33	0.85	1.21	1.34	0.90	1.87	1.12
April-22	0.72	0.81	0.78	1.29	1.43	1.67	0.81	1.43	1.62	0.92	2.45	1.04
May-22	0.77	0.83	0.86	1.54	1.64	1.56	0.75	1.52	1.78	0.77	2.98	1.28
Jun-22	0.75	0.81	0.82	1.32	1.24	1.29	0.67	1.23	1.53	0.65	2.87	1.22
July-22	0.72	0.75	0.84	1.07	1.03	1.12	0.54	0.98	0.88	0.56	1.87	0.89

Appendix 10. Monthly Iron concentration on roadside soil outside Aizawl City (2020-2022) in ppm.

	RS-CR1	RS-SL2	RS-KR3	RS-SG4	RS-TP5	RS-HF6	RS-ST7	RS-AB8	RS-SS9	RS-TV10	RS-SR11	RS-MT12
Aug-20	12.11	12.13	12.11	12.23	12.12	12.17	12.09	12.06	12.1	12.09	13.26	12.25
Sep-20	12.31	12.28	12.25	12.31	12.22	12.29	12.23	12.31	12.24	12.2	13.28	12.41
Oct-20	13.21	13.24	13.24	14.3	14.12	14.27	13.27	14.12	14.19	13.29	14.52	14.34
Nov-20	13.34	13.37	13.31	15.27	13.21	13.69	13.31	14.24	13.59	13.31	21.12	14.92
Dec-20	13.67	13.42	13.41	16.21	15.22	14.41	13.54	15.25	14.26	13.32	25.12	19.12
Jan-21	13.56	13.4	13.37	15.98	14.89	14.27	13.21	14.56	14.12	13.32	26.21	18.21
Feb-21	13.42	13.33	13.12	15.46	14	14.72	13	14.61	14	13.02	21.21	18.05

Mar-21	14.21	14.12	14	15.91	14.2	15.12	13.25	14.93	14.11	13.23	23.24	19.29
April-21	14.51	14.13	14.11	16.1	14.32	15.22	13.5	15.17	14.21	13.67	24	21
May-21	14.71	14.42	14.31	16.39	14.52	15.51	13.2	15.5	14	13.5	27.08	22.22
June-21	13.1	12.89	12.43	14.12	13.12	14.12	12.42	14.24	13.12	12.47	24.27	14.16
July-21	12.29	12.31	12.21	12.33	12.34	13.11	12.06	12.71	12.32	12.35	21.18	13.04
Aug-21	15.01	14.92	14.41	18.21	18.55	21.12	14.01	20.12	19.89	18.22	31.02	21.01
Sep-21	16.29	16.21	15.92	21.02	25.01	25.01	15.34	21.21	21.10	21.03	33.04	20.08
Oct-21	19.12	18.22	18.96	21.2	23.07	25.21	17.21	25.01	20.99	20.74	35.01	21.02
Nov-21	20.02	19.93	19.89	20.01	23.00	24.02	19.21	26.11	21.00	20.87	33.21	20.17
Dec-21	20.87	20.01	20.06	20.67	23.21	24.65	19.52	27.03	21.22	20.45	35.11	23.62

Jan-22	20.85	20.05	19.97	20.67	23.41	25.78	19.21	26.89	21.06	20.64	33.52	20.78
Feb-22	20.19	20.03	20.05	20.43	23.34	23.66	19.54	25.01	21.22	20.45	35.11	23.62
Mar-22	20.23	20.13	20.07	21.05	23.47	23.76	20.12	24.89	21.12	20.34	34.17	23.12
April-22	22.12	21.22	20.25	22.24	23.54	25.21	20.23	25.12	21.08	20.42	34.78	23.87
May-22	22	21.27	20.21	22.32	23.31	26	20.34	25.22	21.25	20.67	43.21	24.12
Jun-22	19.02	19.19	19.16	20.12	21.23	25.56	20.12	23.42	21.12	19.87	39.12	22.78
July-22	19.21	18.87	19.12	19.89	20.05	21.23	19.87	21.16	20.08	17.93	36.77	21.15

Appendix 11. Monthly Manganese concentration on roadside soil outside Aizawl City (2020-2022) in ppm.

	RS-CR1	RS-SL2	RS-KR3	RS-SG4	RS-TP5	RS-HF6	RS-ST7	RS-AB8	RS-SS9	RS-TV10	RS-SR11	RS-MT12
Aug-20	1.57	1.24	1.02	1.73	1.28	1.89	1.25	1.83	1.45	1.28	1.99	1.82
Sep-20	1.66	1.62	1.71	2.02	2	2.41	1.69	2.12	2.01	1.94	2.81	2.31
Oct-20	1.72	1.73	1.64	2.51	2.53	2.63	1.72	2.03	2.21	1.62	2.87	2.66
Nov-20	1.91	1.89	1.77	2.59	2.62	2.71	1.73	2.22	2.34	1.78	3.21	2.87
Dec-20	2.21	2.32	2.3	3.24	3.27	3.45	1.73	3.17	3.16	2.57	4.11	3.73
Jan-21	2.38	2.41	2.45	3.41	3.4	3.78	1.95	3.31	3.27	2.76	4.21	3.81
Feb-21	2.24	2.32	2.3	3.24	3.27	3.45	1.73	3.17	3.16	2.57	4.11	3.73

Mar-21	2.51	2.63	2.61	3.31	3.42	3.62	1.82	3.21	3.2	2.61	4.41	3.82
April-21	2.68	2.99	2.94	3.49	3.52	4.02	1.88	3.53	3.29	2.78	4.9	3.86
May-21	2.32	2.7	2.62	3.01	3.1	3.67	1.76	3.07	3	2.35	4.76	3.58
June-21	2.20	2.30	2.23	2.78	2.61	3.01	1.32	2.55	2.65	2.11	3.56	2.98
July-21	1.61	1.38	1.42	1.83	1.43	2.01	1.37	1.93	1.51	1.42	3.07	2.01
Aug-21	1.06	1.12	1.09	2.01	1.78	2.12	01-Jan	1.89	1.54	1.21	2.36	1.27
Sep-21	1.21	1.19	1.22	2.22	2.18	2.24	1.02	2.02	1.87	1.33	4.32	1.31
Oct-21	1.34	1.28	1.31	2.45	2.21	2.54	1.01	1.82	1.91	1.35	3.78	1.33
Nov-21	1.83	1.88	1.89	2.22	2.23	2.89	1.12	1.98	2.01	1.68	5.32	1.35
Dec-21	3.12	3.08	3.11	4.28	3.23	4.76	2.89	4.84	4.31	3.25	7.12	2.01

Jan-22	3.12	3.08	3.11	4.28	3.23	4.76	2.89	4.84	4.31	3.25	7.12	2.01
Feb-22	3.89	3.67	3.91	4.89	4.34	5.61	3.42	4.64	4.12	3.36	7.89	3.22
Mar-22	4.34	4.23	4.34	5.18	5.01	5.88	4.21	4.71	5.12	4.11	7.91	3.12
April-22	4.12	4	3.97	5.12	4.89	6.11	4.1	4.66	5.01	4	7.34	3.08
May-22	4.27	4.26	4.21	5.01	4.78	5.93	4.13	4.26	5.05	4.21	7.89	3.23
Jun-22	4.89	1.54	4.53	5.24	5.17	6.21	4.27	4.89	5.13	4.89	8.26	4.39
July-22	5.12	5.21	5.19	5.65	5.23	7.01	4.18	5.28	5.12	4.91	8.98	4.12

Appendix 12. Monthly Nickel concentration on roadside soil outside Aizawl City (2020-2022) in ppm.

	RS-CR1	RS-SL2	RS-KR3	RS-SG4	RS-TP5	RS-HF6	RS-ST7	RS-AB8	RS-SS9	RS-TV10	RS-SR11	RS-MT12
Aug-20	0.11	0.1	0.12	0.14	0.12	0.17	0.11	0.14	0.12	0.12	0.28	0.13
Sep-20	0.12	0.11	0.11	0.16	0.12	0.21	0.12	0.16	0.13	0.15	0.31	0.16
Oct-20	0.14	0.13	0.14	0.15	0.14	0.21	0.14	0.15	0.14	0.17	0.39	0.17
Nov-20	0.14	0.14	0.13	0.16	0.15	0.23	0.16	0.21	0.2	0.21	0.44	0.21
Dec-20	0.17	0.15	0.16	0.21	0.18	0.31	0.17	0.21	0.2	0.22	0.49	0.25
Jan-21	0.16	0.14	0.15	0.23	0.19	34	0.21	0.22	0.19	0.25	0.51	0.27
Feb-21	0.16	0.17	0.16	0.21	0.21	0.33	0.19	0.24	0.21	0.23	0.55	0.31

Mar-21	0.21	0.19	0.2	0.2	0.23	0.35	0.22	0.23	0.22	0.21	0.59	0.33
April-21	0.2	0.21	0.21	0.23	0.24	0.36	0.22	0.24	0.2	0.22	0.62	0.25
May-21	0.18	0.17	0.19	0.22	0.22	0.41	0.21	0.21	0.23	0.21	0.62	0.21
June-21	0.2	0.19	0.17	0.25	0.19	0.38	0.2	0.22	0.21	0.2	0.61	0.2
July-21	0.22	0.21	0.18	0.27	0.21	0.37	0.19	0.21	0.22	0.19	0.56	0.19
Aug-21	0.21	0.22	0.24	0.32	0.28	0.35	0.21	0.31	0.32	0.26	0.89	0.29
Sep-21	0.24	0.21	0.22	0.34	0.3	0.35	0.22	0.3	0.33	0.25	0.95	0.23
Oct-21	0.23	0.22	0.23	0.33	0.31	0.38	0.21	0.28	0.31	0.24	0.95	0.21
Nov-21	0.24	0.23	0.23	0.35	0.33	0.41	0.23	0.3	0.32	0.22	1.04	0.21
Dec-21	0.24	0.23	0.25	0.36	0.35	0.48	0.25	0.42	0.53	0.25	1.21	0.37

Jan-22	0.24	0.25	0.23	0.45	0.37	0.51	0.26	0.58	0.82	0.23	1.12	0.42
Feb-22	0.21	0.23	0.22	0.61	0.33	66	0.26	0.58	0.82	0.23	1.2	0.52
Mar-22	0.21	0.24	0.23	0.59	0.31	0.72	0.25	0.66	0.76	0.21	1.23	0.48
April-22	0.22	0.25	0.24	0.68	0.34	0.69	0.24	0.62	0.64	0.24	1.21	0.67
May-22	0.21	0.23	0.22	0.45	0.35	0.44	0.23	0.42	0.54	0.22	1.18	0.59
Jun-22	0.2	0.19	0.17	0.25	0.19	0.37	0.2	0.22	0.21	0.2	0.56	0.52
July-22	0.21	0.22	0.19	0.24	0.2	0.36	0.2	0.21	0.23	0.21	0.54	0.32

Appendix 13. Monthly Lead concentration on roadside soil outside Aizawl City (2020-2022) in ppm.

	RS-CR1	RS-SL2	RS-KR3	RS-SG4	RS-TP5	RS-HF6	RS-ST7	RS-AB8	RS-SS9	RS-TV10	RS-SR11	RS-MT12
Aug-20	0.13	0.12	0.13	0.19	0.12	0.2	0.1	0.16	0.1	0.14	0.34	0.18
Sep-20	0.14	0.13	0.12	0.15	0.14	0.21	0.11	0.17	0.12	0.15	0.35	0.21
Oct-20	0.15	0.16	0.15	0.18	0.16	0.22	0.13	0.17	0.12	0.14	0.31	0.22
Nov-20	0.16	0.17	0.19	0.2	0.2	0.21	0.14	0.19	0.14	0.16	0.37	0.22
Dec-20	0.18	0.18	0.19	0.21	0.2	0.26	0.15	0.2	0.16	0.17	0.38	0.24
Jan-21	0.17	0.18	0.16	0.22	0.19	0.32	0.14	0.19	0.17	0.16	0.31	0.21
Feb-21	0.21	0.22	0.21	0.24	0.2	0.34	0.16	0.17	0.16	0.17	0.31	0.22

Mar-21	0.19	0.17	0.18	0.21	0.19	0.3	0.17	0.19	0.14	0.15	0.41	0.21
April-21	0.21	0.18	0.19	0.22	0.19	0.31	0.19	0.21	0.17	0.17	0.38	0.2
May-21	0.14	0.15	0.15	0.16	0.15	0.33	0.13	0.15	0.16	0.17	0.41	0.22
June-21	0.23	0.25	0.23	0.34	0.27	0.39	0.24	0.28	0.25	0.19	0.4	0.23
July-21	0.25	0.28	0.27	0.67	0.33	0.74	0.31	0.47	0.31	0.27	0.52	0.31
Aug-21	0.31	0.28	0.3	0.43	0.41	0.4	0.3	0.39	0.42	0.29	2.01	0.31
Sep-21	0.28	0.23	0.23	0.41	0.37	0.38	0.27	0.33	0.38	0.24	1.23	0.26
Oct-21	0.22	0.24	0.25	0.39	0.34	0.39	0.29	0.31	0.35	0.25	1.12	0.25
Nov-21	0.24	0.21	0.22	0.34	0.28	0.32	0.25	0.28	0.32	0.23	1.18	0.23
Dec-21	0.24	0.23	0.23	0.32	0.27	0.33	0.26	0.32	0.33	0.21	1.23	0.26

Jan-22	0.21	0.22	0.21	0.32	0.28	0.31	0.25	0.29	0.31	0.2	1.21	0.24
Feb-22	0.22	0.22	0.23	0.28	0.26	0.32	0.22	0.27	0.28	0.21	1.25	0.23
Mar-22	0.21	0.23	0.22	0.29	0.24	0.27	0.23	0.24	0.26	0.22	1.21	0.25
April-22	0.21	0.22	0.21	0.31	0.23	0.35	0.28	0.25	0.27	0.24	1.25	0.28
May-22	0.23	0.24	0.22	0.3	0.25	0.32	0.25	0.22	0.25	0.26	1.21	0.25
Jun-22	0.3	0.29	0.28	0.37	0.32	0.37	0.28	0.34	0.38	0.27	1.46	0.29
July-22	0.28	0.31	0.31	0.41	0.43	0.67	0.33	0.42	0.46	0.31	1.89	0.36

Appendix 14. Monthly Zinc concentration on roadside soil outside Aizawl City (2020-2022) in ppm.

	RS-CR1	RS-SL2	RS-KR3	RS-SG4	RS-TP5	RS-HF6	RS-ST7	RS-AB8	RS-SS9	RS-TV10	RS-SR11	RS-MT12
Aug-20	0.21	0.24	0.23	0.44	0.32	0.41	0.26	0.35	0.33	0.25	0.81	0.32
Sep-20	0.22	0.27	0.26	0.44	0.3	0.39	0.28	0.34	0.38	0.28	0.93	0.3
Oct-20	0.44	0.39	0.35	0.51	0.34	0.51	0.28	0.41	0.38	0.29	1.23	0.42
Nov-20	0.47	0.42	0.44	0.68	0.42	0.67	0.31	0.44	0.4	0.23	1.42	0.51
Dec-20	0.51	0.44	0.49	0.71	0.61	0.71	0.33	0.51	0.44	0.27	1.58	0.61
Jan-21	0.34	0.36	0.28	0.78	0.57	0.65	0.25	0.76	0.35	0.67	1.49	0.65
Feb-21	0.36	0.39	0.37	0.78	0.54	0.67	0.28	0.68	0.24	0.59	1.56	0.58

Mar-21	0.49	0.48	0.51	0.81	0.58	0.73	0.31	0.74	0.38	0.63	1.64	0.61
April-21	0.54	0.53	0.55	0.85	0.61	0.75	0.38	0.72	0.59	0.72	2.08	0.63
May-21	0.51	0.5	0.49	0.89	0.68	0.81	0.42	0.67	0.61	0.78	2.1	0.67
June-21	0.55	0.59	0.54	0.94	0.73	1.02	0.53	0.75	0.68	0.79	2.15	0.75
July-21	0.51	0.53	0.51	1.04	0.8	1.27	0.54	0.81	0.74	0.71	2.23	0.83
Aug-21	0.52	0.55	0.54	0.69	0.57	0.79	0.51	0.73	0.64	0.55	1.21	0.65
Sep-21	0.54	0.62	0.67	0.73	0.62	0.84	0.55	0.89	0.84	0.61	1.28	0.86
Oct-21	0.54	0.63	0.65	0.78	0.63	0.83	0.56	0.83	0.81	0.57	1.23	0.84
Nov-21	0.53	0.67	0.66	0.65	0.65	0.88	0.64	0.85	0.85	0.64	1.43	0.86
Dec-21	0.51	0.65	0.78	0.79	0.88	1.15	0.69	1.27	1.21	0.89	1.63	1.23

Jan-22	0.54	0.66	0.82	0.77	0.98	1.18	0.78	1.23	1.22	0.86	1.54	1.25
Feb-22	0.62	0.87	0.85	0.89	1.07	1.21	0.82	1.22	1.32	0.91	1.87	1.12
Mar-22	0.66	0.92	0.95	0.93	1.21	1.33	0.85	1.21	1.34	0.9	1.85	1.21
April-22	0.72	0.81	0.78	1.29	1.43	1.67	0.81	1.43	1.62	0.92	2.45	1.04
May-22	0.77	0.83	0.86	1.54	1.64	1.56	0.75	1.52	1.78	0.77	2.98	1.28
Jun-22	0.75	0.81	0.82	1.32	1.24	1.29	0.67	1.23	1.53	0.65	2.87	1.22
July-22	0.72	0.75	0.84	1.07	1.03	1.12	0.54	0.98	0.88	0.56	1.87	0.89

Appendix 15. Monthly Cupper concentration on roadside soil in Aizawl (2020-2022) in ng/m³

Months	A-LP	A-BK	A-DP	A-KT		Months	A-LP	A-BK	A-DP	A-KT
Oct-20	0.00	231	339	229		Oct-21	317	289	548	338
Nov-20	230	248	358	281		Nov-21	382	291	762	351
Dec-20	320	342	442	332		Dec-21	428	382	942	438
Jan-21	312	319	432	324		Jan-22	391.00	356	687	367
Feb-21	251	278	429	267		Feb-22	362	339	763	349
Mar-21	423	342	561	329		Mar- 22	532	431	832	447
April-21	457	321	629	421		Apr-22	543	427	882	482
May-21	281	271	442	294		May-22	381	328	794	352
June-21	234	219	389	257		Jun-22	354	317	721	327
July-21	232	227	391	267		Jul-22	372	337	755	312
Aug-21	197	201	372	213		Aug-22	362	345	753	345
Sep-21	227	218	457	235		Sep-22	418	382	857	428

Appendix 16. Monthly Iron concentration on roadside soil in Aizawl (2020-2022) in ng/m³

Months	A-LP	A-BK	A-DP	A-KT		Months	A-LP	A-BK	A-DP	A-KT
Oct-20	0.00	1332	1782	1267		Oct-21	2328	2217	2314	2092
Nov-20	1723	1789	1824	2347		Nov-21	2568	2234	2627	2129
Dec-20	1993	2024	2283	1438		Dec-21	2617	2431	2783	2227
Jan-21	1876	1892	2321	1482		Jan-22	2328	2283	2418	2192
Feb-21	1852	1872	2248	1657		Feb-22	2437	2320	2534	2231
Mar-21	2129	1987	2192	1638		Mar- 22	2451	2378	2567	2342
April-21	2192	2012	2232	1724		Apr-22	2471	2456	2543	2341
May-21	2227	2128	2261	1897		May-22	2482	2452	2592	2371
June-21	1992	1835	2198	1654		Jun-22	2443	2419	2458	2218
July-21	1913	1835	2216	1568		Jul-22	2467	2420	2542	2297
Aug-21	1937	1892	2234	1561		Aug-22	2459	2437	2518	2195
Sep-21	2219	2128	2231	2127		Sep-22	2543	2459	2642	2234

Appendix 17. Monthly Mn concentration on roadside soil in Aizawl (2020-2022) in ng/m³

Months	A-LP	A-BK	A-DP	A-KT		Months	A-LP	A-BK	A-DP	A-KT
Oct-20	271	267	312	261		Oct-21	472	387	482	463
Nov-20	284	281	332	296		Nov-21	426	354	491	493
Dec-20	319	321	373	317		Dec-21	483	389	521	512
Jan-21	291	318	382	245		Jan-22	421	373	491	432
Feb-21	286	291	412	382		Feb-22	342	324	483	419
Mar-21	328	283	386	374		Mar- 22	291	318	372	392
April- 21	342	328	342	423		Apr-22	321	319	364	326
May-21	351	335	383	443		May-22	389	352	428	381
June-21	329	321	338	381		Jun-22	260	281	452	392
July-21	317	291	364	362		Jul-22	314	319	482	367
Aug-21	352	327	389	348		Aug-22	331	327	391	316
Sep-21	428	383	451	426		Sep-22	328	281	428	291

Appendix 18. Monthly Nickel concentration on roadside soil in Aizawl (2020-2022) in ng/m³

Months	A-LP	A-BK	A-DP	A-KT		Months	A-LP	A-BK	A-DP	A-KT
Oct-20	0.03	0.57	0.05	0.04		Oct-21	0.16	0.15	0.17	0.15
Nov-20	0.03	0.04	0.06	0.05		Nov-21	0.14	0.13	0.18	0.13
Dec-20	0.05	0.06	0.07	0.04		Dec-21	0.17	0.15	0.16	0.14
Jan-21	0.06	0.07	0.06	0.05		Jan-22	0.15	0.14	0.18	0.16
Feb-21	0.06	0.06	0.07	0.07		Feb-22	0.14	0.15	0.17	0.14
Mar-21	0.07	0.08	0.09	0.08		Mar- 22	0.14	0.13	0.16	0.17
April-21	0.08	0.07	0.07	0.09		Apr-22	0.15	0.16	0.18	0.16
May-21	0.11	0.12	0.15	0.11		May-22	0.12	0.13	0.17	0.15
June-21	0.1	0.11	0.11	0.12		Jun-22	0.1	0.12	0.15	0.13
July-21	0.12	0.12	0.12	0.11		Jul-22	0.12	0.11	0.16	0.13
Aug-21	0.11	0.11	0.13	0.13		Aug-22	0.14	0.16	0.19	0.13
Sep-21	0.13	0.12	0.16	0.12		Sep-22	0.13	0.15	0.21	0.14

Appendix 19. Monthly Lead concentration on roadside soil in Aizawl (2020-2022) in ng/m³

Months	A-LP	A-BK	A-DP	A-KT		Months	A-LP	A-BK	A-DP	A-KT
Oct-20	112	0.00	132	121		Oct-21	153	151	235	152
Nov-20	121	123	129	128		Nov-21	148	167	231	142
Dec-20	124	127	138	132		Dec-21	159	175	245	179
Jan-21	122	121	135	134		Jan-22	143	167	254	172
Feb-21	126	128	185	138		Feb-22	145	172	267	185
Mar-21	124	123	160	126		Mar- 22	147	178	212	183
April- 21	121	126	172	139		Apr-22	148	169	265	172
May-21	123	129	178	141		May-22	173	191	234	201
June-21	132	131	168	139		Jun-22	174	178	229	212
July-21	135	142	187	142		Jul-22	172	175	234	197
Aug-21	134	137	192	148		Aug-22	182	192	231	217
Sep-21	145	143	216	121		Sep-22	181	189	264	219

Appendix 21. Monthly Zinc concentration on roadside soil in Aizawl (2020-2022) in ng/m³

Months	A-LP	A-BK	A-DP	A-KT		Months	A-LP	A-BK	A-DP	A-KT
Oct-20	0.00	227	234	198		Oct-21	245	281	376	275
Nov-20	223	231	242	212		Nov-21	286	299	365	298
Dec-20	213	275	244	223		Dec-21	312	324	387	281
Jan-21	218	278	241	242		Jan-22	301.00	354	385	291
Feb-21	223	283	256	245		Feb-22	311	323	356	312
Mar-21	237	312	262	253		Mar- 22	291	298	363	311
April- 21	242	311	321	263		Apr-22	321	312	367	324
May-21	243	289	342	256		May-22	312	325	389	312
June-21	221	226	351	245		Jun-22	324	312	392	321
July-21	231	242	355	253		Jul-22	325	326	402	322
Aug-21	238	241	378	256		Aug-22	354	332	378	324
Sep-21	231	254	356	265		Sep-22	362	354	398	345

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Sl. No	Name of Examination	Year of Passing	Name of Board/University	Percentage/Grade
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2.	Higher secondary school leaving certificate (HSSLC)	2014	MBSE	68 %
3.	Bachelor of Science (Environmental Science)	2017	Mizoram University	66 %
4.	Master of Science (Environmental Science)	2019	Mizoram University	82 %

LIST OF PRESENTATION IN CONFERENCE/SYMPOSIUM/SEMINAR

1. “Effect of Anthropogenic Activity on the Physico-chemical Characteristics of Roadside Soil and Dust in Aizawl City” in the 2nd Annual Convention of North East (India) Academy of Science and Technology (NEAST) and International Seminar on Recent Advances in Science and Technology (IRSRAST) during 16th -18th November 2020 organized by NEAST, Mizoram University, Aizawl-796004, Mizoram(India)
2. “Analysis of Heavy Metal Concentration in roadside soil within Aizawl City- Mizoram, India” in the 4th Mizoram Science Congress. Jointly organized by Mizoram science, Technology, and Innovation Council (MISTIC) at Aizawl Club, Aizawl on 24-25th November, 2022.
3. “Covid- Effect on the metal concentration on roadside soil within Aizawl District, Mizoram India” in the PUC Research Conclave 2023 (An International workshop on Research and Project Development) at Pachhunga University College, Aizawl from 24th – 25th January, 2023. Organized by Research and Development Cell, Pachhunga University College.
4. “Quantifying Heavy Metal Contamination in Air Particulate Matters within Aizawl City, Mizoram” in the International Conference on Current trends in Green and Sustainable Chemistry (ICCTGSC-2023) held on 11th -12th May, 2023 at Pachhunga University College, Aizawl, Mizoram.
5. “Assessment of Heavy Metal such as Cu, Ni, Pb and Zn Elements presents at particulate matter in Air Sampler” in the National Seminar on Environmental Management: Issues and Challenges in North East India (NSEMICNEI, 2023) held on 1st – 2nd June, 2023 at the Department of Environmental Science, Pachhunga University College.
6. “Assessing Soil Pollution: An In-depth Investigation into Heavy Metal Concentrations Along Roadside Environments in Aizawl, Northeastern, India” in the International Conference on Recent Advances in Mathematical, Physical and Chemical Sciences (ICRAMPC, 2024) held 20th – 24th February, 2024 at Mizoram University.

7. “Assessment of Heavy Metal Concentration in Roadside Soil within Aizawl City, Mizoram, India” at the 9th International Conference on Environmental Pollution, Treatment and Protection (ICEPTP’24) held on 14th -16th April, 2024 at Imperial College, London.

Awards:

Best Paper Presenter at the 9th International Conference on Environmental Pollution, Treatment and Protection (ICEPTP’24) held on 14th -16th April, 2024 at Imperial College, London on the topic of “Assessment of Heavy Metal Concentration in Roadside Soil within Aizawl City, Mizoram, India”.

LIST OF SEMINAR/SYMPOSIUM/CONFERENCE/WORKSHOP ATTENDED

1. “Instrumentation and Applications of ICP-OES, GF-AAS and Electron Microscopy” held at Sophisticated Analytical Instrument Facility (SAIF), NEHU, Shillong from 28th April to 4th May, 2022 in collaboration with Project Management Unit NIT Agartala, under Synergistic Training Program Utilizing the Scientific & Technological Infrastructure (STUTI) of DST, New Delhi.
2. “Two – day National Workshop on Biodiversity Loss and Climate Change” held at Seminar Hall, Pachhunga University College from 9th – 10th February 2021. Jointly organized by Department of Environmental Science, Pachhunga University College and Rajiv Gandhi National Institute of Youth Development Program (YLSDP) in Higher Educational Institutions.

PAPER PUBLICATION

1. A Synoptic Review Of Heavy Metal Accumulation In Soils Along Urban Roadsides (2024). *African Journal of Biological Sciences*, 6(8): 3160-1672.
2. Heavy Metal Concentrations In Particulate Matter In The Air: Toxicity, Health Risks And Sustainable Mitigation (2024). *Journal of Applied Bionalysis*. 10(2): 143-154
3. Assessment of Heavy Metal Contaminations of Roadside Soil in Aizawl, Mizoram (India)2024: An In-Depth Analysis Utilizing Advanced Scientific Methodologies. *Asian Journal of Water, Environment and Pollution*. 21(5): 37-47.
4. Assessing Soil Pollution: An Investigation into Heavy Metal Contaminations in Roadside Soil in Aizawl, Northeast India (2024), *Science and Technology Journal*. 12(2), 2321-3388
5. Assessment of Heavy Metal Concentrations in Roadside soil within Aizawl City, Mizoram, India.
Proceedings of the 9th World Congress on Civil, Structural and Environmental Engineering (CSEE 2024). ICEPTP 139.

Assessing Soil Pollution: An Investigation into Heavy Metal Contaminations in Roadside Soil in Aizawl, Northeast India

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Abstract— The study investigates the heavy metal contamination in the roadside soils of Aizawl, located in Northeast India, where the roadside soil is vulnerable to heavy metal pollution due to vehicular traffic and human activities. A systematic analysis was conducted at twelve sampling sites throughout the city from August 2020 to July 2021, with three replicates taken at each location. Metal concentrations were measured using atomic absorption spectrophotometry after acid digestion, following the USEPA 3050B method. The heavy metals analysed include copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn). The mean metal concentrations at the selected sites range from 0.46 – 0.99 for Cu, 0.25 - 0.54 for Ni, 0.29 - 0.50 for Pb, and 1.35 – 1.84 for Zn. All measured metal concentrations exceeded the local average background values (ABVs), but they generally fall within the safe limits established by the Canadian and Chinese soil quality standards for residential areas. While all contamination levels fall within the moderately contaminated category based on the geo-accumulation index (Igeo), the pollution load index (PLI) indicated moderate to high levels of contamination by Cu at site S9 (Chanmari) and by Zn at sites S1 (Kulikawn), S5 (Bazar Bungkawn), S9 (Chanmari), and S12 (Khatla). The Pearson correlation analysis revealed a moderate positive correlation between copper and zinc, indicating a common source of pollution. Effect of monsoon Pb and Zn is also observed. The findings revealed varying metal concentrations at the different sites, with variations in the different sampling periods due to the influence of urbanization, human activities, vehicular traffic, and weather.

Keywords: Contamination, anthropogenic, vehicular traffic, contamination factor, pollution load index, geo-accumulation index.

INTRODUCTION

Environmental pollution is a major concern globally, with heavy metal contamination posing a significant threat to ecosystems and human health (Wang 1998). The widespread release of heavy metals into the environment, mainly through industrial activities and transportation, has led to the degradation of soil quality (Chowdhury *et al.* 2021). Soil pollution has become a growing environmental concern in both developed and developing countries. The presence of heavy metals in soils poses a particular threat to human health and the integrity of natural ecosystems,

as these contaminants can accumulate through the food chain and have detrimental effects on wildlife and the overall functioning of terrestrial environments (Dhokpande *et al.* 2024; Wan *et al.* 2024). Soil, as a major sink for the accumulation of different contaminants, such as heavy metals released through human activities, requires immediate attention (Keshavarzi *et al.* 2021).

Roadside soil and dust can be exposed to significant levels of heavy metals due to the accumulation of heavy metals in soils, which can be attributed to a range of human activities,

including automobile emissions, industrial activities, and land use practices (Abdullahi *et al.* 2023; Huang *et al.* 2022). It has been observed that roadside soil is highly contaminated with various heavy metals, namely Cu, Ni, Pb, and Zn, which poses a significant environmental concern with potential implications for human health and ecological systems (Chen *et al.* 2022; Arora *et al.* 2023). Thus, understanding the impact of heavy metal concentration on roadside soil is crucial for implementing effective mitigation strategies and safeguarding the environment (Kaur *et al.* 2022). Many studies have been conducted to explore the spatial distribution of heavy metal pollution in roadside soils (Wang *et al.* 2017; Kaur *et al.* 2022; Ayaz *et al.* 2023; Ma *et al.* 2023).

Human activities are the main cause of heavy metal pollution (Liu *et al.* 2024). The level of heavy metal contamination of soils depends on its type, climate, human activity, and atmospheric conditions, including wind direction and speed, type of precipitation, type of terrain, and type of vegetation (Skorbiłowicz *et al.* 2021). The surface layer of roadside soil near roads with heavy traffic in urban areas is a good indicator of heavy metal pollution, and heavy metals are released through different parts of vehicles. Metals such as Cu, Pd, and Zn enter the environment through the consumption of brake pads, lubricating and industrial oils, while Ni enters through the wear of metal parts and Ni-plated accessories (Altaf *et al.* 2021; Skorbiłowicz *et al.* 2021). Moreover, heavy metal content in soils along the road is strongly related to traffic and decreases with distance from the road and traffic volume (Arslan and Gizir 2006; Duong and Lee 2011). Therefore, soil contamination caused by vehicular transport has received much scientific attention in recent years and should be monitored to preserve environmental quality and prevent degradation (Wan *et al.* 2024; Kaur *et al.* 2022).

Given the environmental and public health implications of heavy metal pollution in urban soils, it is crucial to conduct comprehensive assessments of the spatial patterns and underlying factors contributing to soil contamination, particularly in rapidly developing regions (Feng *et al.* 2024). Rapid urbanization and industrial growth have placed significant pressure on delicate ecological systems (Ma *et al.* 2023). Aizawl, the capital city of Mizoram state, Northeast India, which is situated in hilly terrains, presents a unique geographic context for understanding the spatial distribution of heavy metal pollution. In a rapidly growing city like Aizawl, there is potential for roadside environments to accumulate heavy metals from vehicular emissions,

industrial activities, and other human sources. This study aims to assess the extent of heavy metal contamination in roadside soils in Aizawl, addressing the level of pollution, the effect of monsoon, and highlighting the possible factors contributing to the pollution.

MATERIALS AND METHODS

SAMPLE COLLECTION AND ANALYSIS

Samples were collected monthly from 12 different sites within Aizawl City from August 2020 to July 2021, with three replicates at each site, maintaining at least 10-meter spacing between the replicates. The soil samples collected also contain sediments and dust most of the time. Sampling sites were carefully chosen, avoiding the sites where ongoing buildings and road construction were nearby. The sampling was conducted during the Covid-19 pandemic when the public activities and vehicular movements were restricted due to the imposed lockdowns the Mizoram state government during these periods. Pristine soil samples were also collected from the undisturbed sites of Pachhunga University College campus and ITI Veng area, Aizawl, for comparison. Soil from each site was transferred to air-tight polythene bags and taken to the laboratory. Samples were processed for metal concentration analysis using the USEPA 3050B acid digestion method. In brief, unwanted and larger particles were removed, and drying was done at 75°C for 12 hours, followed by sieving through a 150-micron mesh. For digestion, 1 g of soil was mixed with 10 ml of 8.5 M nitric acid, heated, and again treated with nitric acid, hydrogen peroxide, and hydrochloric acid. After cooling, the samples were filtered and diluted to 100 ml with deionized water (USEPA 1996; Nnodum *et al.* 2022). All reagents were obtained from HiMedia, India. The contents of heavy metals such as Cu, Ni, Pb Zn were measured using an atomic absorption spectrophotometer (Shimadzu, AA-7000F).

POLLUTION INDICES

The pollution load index (PLI) serves as valuable tools for establishing simple but comparative means for assessing pollution levels while the geo-accumulation index (Igeo) evaluates pollution status and quantifies the influence of human activities, and the PLI and Igeo were assessed as detailed in previous literature (Chen *et al.* 2015; Mafuyai *et al.* 2015; Kaur *et al.* 2022). The Pollution load index (PLI) for the entire sampling site was determined as the nth root of the product of the n CF, i.e., $PLI = (CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n)^{1/n}$, where CF is the ratio of the metal concentration in the sample to the metal concentration in background.

This empirical index provides a simple, comparative means for assessing the level of heavy metal pollution. The PLI is classified as either background concentration ($PLI = 0$), unpolluted ($PLI \leq 1$), unpolluted to moderately polluted ($PLI \leq 2$), moderately polluted ($PLI \leq 3$), moderately to highly polluted ($PLI \leq 4$), highly polluted ($PLI \leq 5$), or very highly polluted ($PLI > 5$) to indicate the degree of contamination. Igeo is a geochemical criterion to evaluate pollution levels. It was calculated using the formula, $I_{geo} = \log_2 (C_n / 1.5B_n)$, where C_n is the measured concentration of metal in soils or sediments and B_n is the geochemical background value of the corresponding metal and 1.5 is a constant. The Igeo consists of 7 classes: Igeo value of < 0 , practically unpolluted; $> 0-1$, unpolluted to moderately polluted; $> 1-2$, moderately polluted; $> 2-3$, moderately to strongly polluted; $3-4$, strongly polluted; $4-5$, strongly polluted to extremely polluted > 5 extremely polluted.

RESULTS AND DISCUSSION

MEAN HEAVY METAL CONCENTRATIONS

Table 1 shows the mean of heavy metal concentrations in roadside soil samples at different selected sites within Aizawl City during August 2020 to July 2021. Significant variations

in the concentrations of Cu, Ni, Pb, and Zn are observed in different sampling periods at each site. The concentrations Zn are the highest, and the Cu concentrations are also higher than Ni and Pb in all the sites. Due to the absence of specific Indian soil guidelines, both the Canadian and the China soil guidelines for residential sites are utilized to assess the safety levels of contamination. The heavy metal concentrations are mostly higher than the average background values (ABVs), but they still fall within safe limits when compared with the soil guidelines of China and Canada (Teng *et al.* 2014; CCME 2023). The surface layer of roadside soil in urban areas is a good indicator of heavy metal pollution. It was reported that heavy metal pollution in urban areas primarily arose from anthropogenic activities, including vehicular emissions, construction activities, and improper waste disposal. Vehicles contributed significantly through emissions, tire and brake wear, and the deposition of lead and zinc from fuels and paints (Altaf *et al.* 2021; Skorbiłowicz *et al.* 2021). Additionally, improper waste management, including the disposal of electronic waste and batteries, added to heavy metal contamination in urban environments (Ali-Taleshi *et al.* 2022; Motuzova *et al.* 2014).

Table 1: Mean Metal Concentration at the Study Site in Aizawl (in ppm).

Site	Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
S1 (Kulikawn)	0.54±0.45	0.54±0.59	0.50±0.40	1.61±0.50
S2 (Vaivakawn)	0.46±0.20	0.31±0.27	0.29±0.27	1.53±0.63
S3 (Sikulpuikawn)	0.77±0.37	0.34±0.35	0.40±0.42	1.55±0.51
S4 (Bethlehem Vengthlang)	0.71±0.51	0.38±0.24	0.49±0.37	1.49±0.56
S5 (Bazar Bungkawn)	0.92±0.76	0.25±0.14	0.36±0.39	1.65±0.62
S6 (Laipuitlang)	0.63±0.55	0.25±0.18	0.31±0.23	1.55±0.66
S7 (Temple Square)	0.94±0.96	0.31±0.31	0.49±0.52	1.58±0.58
S8 (Ramhlun)	0.64±0.46	0.34±0.30	0.44±0.46	1.55±0.58
S9 (Chanmari)	0.99±0.49	0.26±0.07	0.33±0.27	1.77±0.59
S10 (Bawngkawn)	0.65±0.34	0.35±0.24	0.36±0.36	1.60±0.67
S11 (MINECO)	0.47±0.41	0.43±0.68	0.32±0.34	1.35±0.60
S12 (Khatla)	0.61±0.27	0.37±0.33	0.43±0.52	1.84±0.76
ABVs in Aizawl	0.24	0.14	0.14	0.49
China soil guidelines	100	50	300	250
Canada soil guidelines	64	50	140	200

ASSESSMENT OF CONTAMINATION LEVEL USING POLLUTION INDICES

Pollution Load Index

The PLI was used to assess the contamination levels and the PLI value is depicted in Figure 1. The figure reveals notable fluctuations in heavy metal contamination among various sampling locations, showcasing discernible variations in the concentrations of the studied heavy metals. The site S1 displays the highest PLI for Pb (2.67). S1, S4, S10, and S11 are classified as moderately polluted, while all other sites are categorized as unpolluted to moderately polluted. The highest PLI for Zn (3.34) is observed at site S9. S1, S5,

and S12 are also under moderate to highly polluted levels with respect to Zn, like site S9, and the rest are under the moderately polluted category. Site S9 demonstrates the highest, with a moderate to highly polluted PLI for Cu (3.55), while seven sites fall under the moderately polluted category. Site S1 exhibits the highest PLI for Ni with a value of 2.67, indicating a moderately polluted environment. Three sites (S4, S10, and S12) exhibit moderately polluted levels, while most of the sites (PLI 1.58 – 1.99) fall under unpolluted to moderately polluted levels. These observations imply that local activities or emissions have a notable impact on each site, contributing to heightened pollution levels (Kozáková *et al.* 2019; Comber *et al.* 2022).

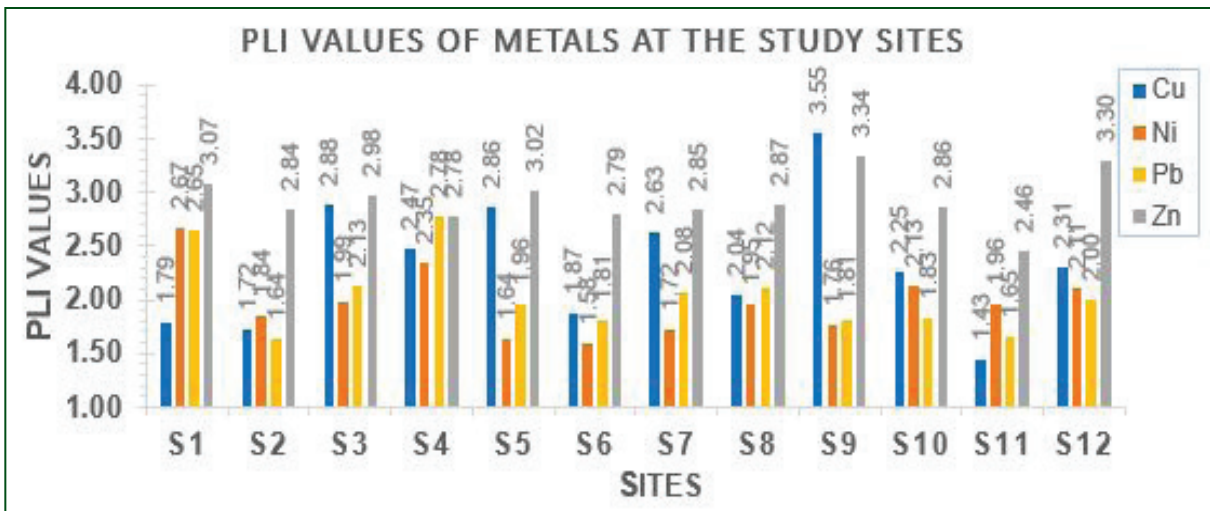


Fig. 1: PLI Values of Metals at the Study Site.

Geo-accumulation Index (Igeo)

The Igeo values calculated from the mean concentrations of metals at different months are presented in Figure 2 and it provides a comprehensive assessment of heavy metal contamination. Sites S1, S5, S7, and S9 exhibit higher Igeo values of 1.10, 1.35, 1.38, and 1.45, respectively, for Cu, indicating unpolluted to moderately polluted levels. The Igeo for Cu showed values ranging from 0.37 at S2 to 1.45 at site S9, from unpolluted to moderate pollution levels, suggesting localized pollution sources and varying degrees of anthropogenic impact at different sites (Ayaz *et al.* 2023). For Ni, Igeo values ranged from 0.26 (S5) to 1.26 (S1), indicating localized pollution sources and varying degrees of anthropogenic impact (Ali-Taleshi *et al.* 2022). The Igeo for Pb showed values ranging from 0.47 (at S2) to 1.26 (at S1),

suggesting unpolluted to moderate contamination. Zn contamination was moderately high across all sites, with Igeo values ranging from 0.88 at site S11 to 1.33 at site S12. Notably, some sites displayed higher contamination at least for some of the studied heavy metals, emphasizing their vulnerability to heavy metal pollution. The Igeo values for Cu, Ni, Pb, and Zn across various sites highlight the distribution of these metals, suggesting localized sources such as human activities, vehicular traffic activities, or construction work (Kaur *et al.* 2022). Anthropogenic activities such as vehicular traffic, industrial activities, rusting and degradation of metallic structures and materials bearing these metals could affect the contamination levels (Abdullahi *et al.* 2023; Dhaliwal *et al.* 2021).

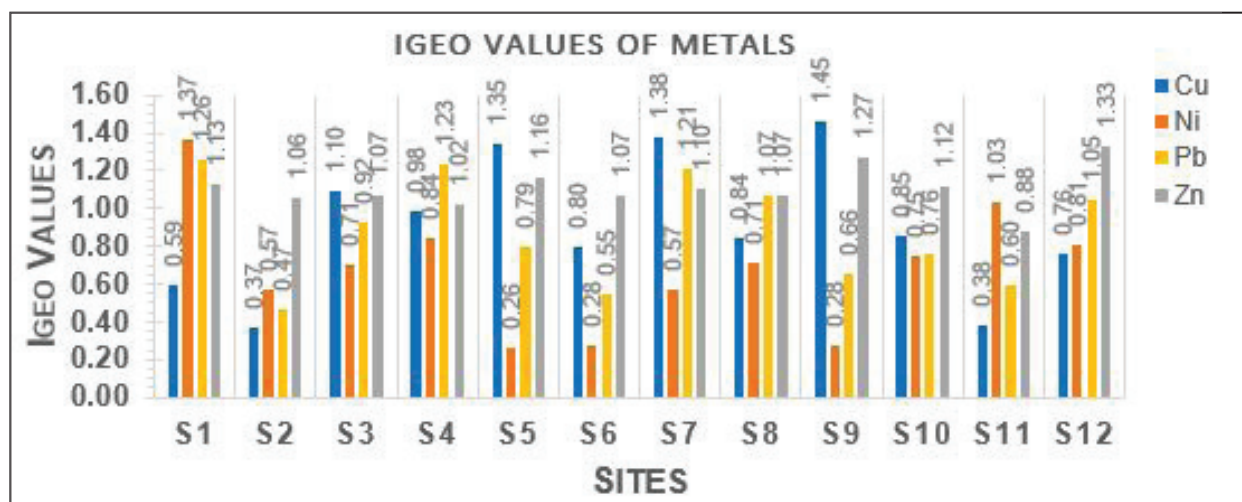


Fig. 2: Igeo Values of Metals at the Study Site.

Pearson Correlation

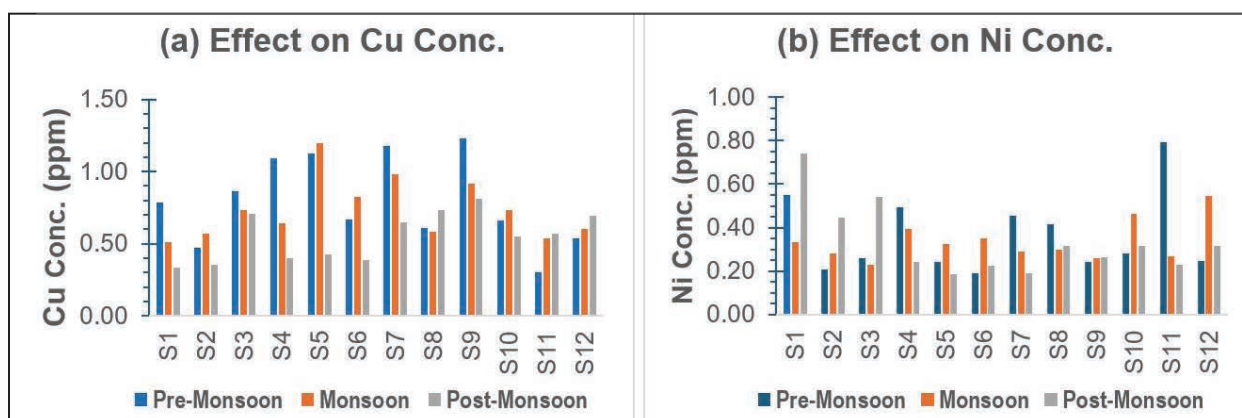
The Pearson correlation matrix represented in Table 2 provides insights into relationships between heavy metals, suggesting the common or distinct sources of pollution. A moderate positive correlation (0.361) between Cu and Zn suggests shared common sources like industrial activities or vehicular traffic-related pollution, as explained by Motuzova *et al.* (2014). Weak positive correlations between Ni and Zn (0.244); and Pb and Zn (0.229) indicate mixed sources, while Cu and Ni (0.122) have very weak correlations. In contrast, weak negative correlations between Cu and Pb (-0.201) and Ni and Pb (-0.224) imply different sources (Lu *et al.* 2014). These findings highlight the complex nature of factors influencing heavy metal contamination, emphasizing the need for more comprehensive source apportionment studies.

Table 2: Pearson Correlation Matrix for Metals.

Metals	Cu	Ni	Pb	Zn
Cu	1.000	0.122	-0.201	0.361
Ni	0.122	1.000	-0.224	0.244
Pb	-0.201	-0.224	1.000	0.229
Zn	0.361	0.244	0.229	1.000

EFFECT OF MONSOON ON THE VARIATIONS OF HEAVY METAL CONCENTRATIONS

The effect of monsoon on the variations of heavy metal concentrations is shown in Figure 3. The level of heavy metal contamination of soils can be affected by the atmospheric conditions, including wind direction and speed, type and level of precipitation, and the type of terrain and the soil physicochemical characteristics (Wang *et al.* 2017. Wang and Zhang 2018). The heavy metal contamination of soil can be influenced by variable factors.



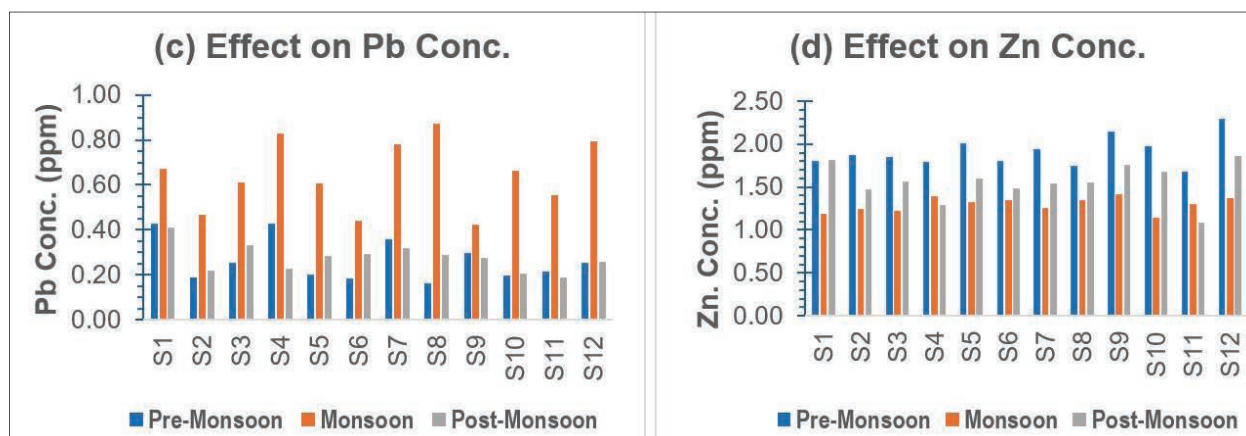


Fig. 3: Effect of Monsoon on the Variations of (a) Cu, (b) Ni, (c) Pb and (d) Zn.

It was observed from the figure that Pb concentrations reach a peak during the monsoon compared to pre-monsoon and post-monsoon, possibly due to rain washing lead-containing paints or leaching from other lead-containing materials. Previously, Schwarz (2016) reported that rain washed lead from old painted surfaces leached into the soil and exacerbating contamination. Zn exhibited the highest concentration in pre-monsoon, with a notable decrease during the monsoon and a slight increase in post-monsoon at most of the sites. The decrease in Zn concentration during the monsoon season could be due to the dilution effect by rainfall and diminished atmospheric deposition. It was reported previously that the heavy metal contamination of the dumpsite soil samples contained lowered in which revealed higher Fe, Cr and Cd levels in pre-monsoon than in post-monsoon (Guthula *et al.* 2018). Notable effect of monsoon on the change of concentrations of Cu and Ni was not observed. This could indicate that there could be many factors which govern the local contamination levels of these heavy metals.

CONCLUSION

This research thoroughly examined the extent of heavy metal contamination in roadside soils within Aizawl, Northeast India, focussing on the concentrations of Cu, Ni, Pb and Zn across twelve discrete sampling sites. The sampling was conducted during the Covid-19 pandemic. The public activities and vehicular movements were restricted since the Mizoram state government-imposed lockdowns during these periods. The data indicated marked spatial and temporal discrepancies in metal concentrations among the sampled sites, with Zn levels the highest, and Cu levels

significantly exceeding those of Ni and Pb. The mean metal concentrations ranged from 0.46 (at S2) to 0.99 (at S9) for Cu, 0.25 (at S5) to 0.54 (at S1) for Ni, 0.29 (at S2) to 0.50 (at S1) for Pb, and 1.35 (at S11) to 1.84 (at S12) for Zn. Although the concentrations of heavy metals were observed to be elevated relative to the average background levels in the vicinity, they were generally found to be within acceptable limits when assessed against the soil quality standards established by Canada and China. Site S9 demonstrates the highest, with a moderate to highly polluted PLI value for Cu (3.55), while the sites S1, S5, S9 and S12 showed 3.07, 3.02, 3.34 and 3.34 for Zn respectively. The highest Igeo values for Cu, Ni, Pb, Zn observed are 1.45, 1.37, 1.26, 1.33 respectively and all these falls within the moderately contaminated category. Furthermore, the Pearson correlation analysis elucidated a moderate positive correlation (0.361) between Cu and Zn which suggests shared common sources like industrial activities or vehicular traffic-related pollution. The study noted decrease in Zn concentrations during the monsoon season likely because of dilution effects from rainfall. The increase in Pb levels during the monsoon could be due to rain-induced runoff from lead-based paints and lead containing materials. This seasonal variability indicates the dynamic characteristics of heavy metal pollution in Aizawl. The results highlight the widespread occurrence of heavy metal contamination, primarily resulting from anthropogenic activities such as vehicular emissions, industrial operations, and localized activities. The study underscores the necessity for ongoing monitoring and systematic evaluation of soil contamination to protect the environment and public health.

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Assessment of the Heavy Metal Contaminations of Roadside Soil in Aizawl, Mizoram (India): An In-Depth Analysis Utilising Advanced Scientific Methodologies

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Abstract: The study was conducted to evaluate the heavy metal contamination levels in the roadside soil of Aizawl, Mizoram (India). Twelve sites were sampled monthly from August 2020 to July 2021, and concentrations of copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) were analyzed using atomic absorption spectrometer. The concentrations of heavy metals at the twelve studied sites varied widely from 0.43-1.06, 20.54-21.21, 2.69-3.41, 0.25-0.54, 0.31-0.49 and 1.35-1.77 for Cu, Fe, Mn, Ni, Pb, and Zn respectively. Pollution assessment tools such as the pollution load index, geo-accumulation index, and enrichment factor indicated moderate pollution levels. The study also observed fluctuations in the contamination levels due to the monsoon rainfall and the COVID-19 pandemic lockdown. Principal component analysis identified vehicular emissions, industrial activities, and atmospheric deposition as the potential sources of heavy metal contamination, with varying patterns observed at each site. While the observed heavy metal concentrations generally met permissible limits, the elevated levels suggested anthropogenic influences. It is crucial to continuously monitor and manage heavy metal contamination to mitigate potential health risks associated with heavy metal exposure.

Key words: Heavy metals, roadside soil, pollution, Aizawl, pollution load index, geo-accumulation index, enrichment factor, principal component analysis.

Introduction

Roadside soil is one of the environments that is most vulnerable to heavy metal pollution. The deposition of heavy metals from vehicle emissions, brake and tire wear, and other anthropogenic activities can lead to an increase in the concentration of heavy metals in roadside soil. Heavy metal pollution has become a global issue in recent years, with numerous negative effects on human health (Briffa et al., 2020). With rapid development,

intensive anthropogenic activities have resulted in a significant number of pollutants being discharged into the urban environment. Intense anthropogenic activities with a large number of heavy metal sources and high pollution density are more common in cities than in urban regions, causing significant health concerns for humans (Yan et al., 2018).

Earlier, soil contamination was not considered as serious as air and water pollution because soil contamination has a wider range and is more difficult

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to control and manage than air and water pollution (Ashraf et al., 2014). However, several studies on the concentration, distribution, and sources of heavy metals in roadside soils have been conducted in recent years revealing the current trends of soil contamination in developing countries. As a result, addressing soil contamination from heavy metals in roadside areas has become a hot topic of environmental concern worldwide (Su et al., 2014). Roadside soil serves as an important reservoir for pollution from various sources and can easily come into contact with pedestrians and people living near roads, either through suspended dust or direct contact (Mafuyai et al., 2015).

Many recent studies have assessed heavy metal concentrations in roadside soil due to the escalating industrialisation, urbanisation, and transportation activities. Anthropogenic influences significantly impact metal levels in roadside soils, with road transportation identified as a major source of heavy metal pollution and a key player in trace metal biochemical cycles. This study, the first of its kind in Mizoram, focusses on evaluating Cu, Fe, Mn, Ni, Pb, and Zn concentrations in the roadside soil of Aizawl City, aiming to identify the level of contamination and their sources.

Materials and Methods

Study Area

Aizawl, the capital of Mizoram state in northeastern India, is situated on steep hilly terrain at an elevation

of 974 meters above sea level. Roads are constructed by cutting through the steep slopes. The cityscape is characterised by narrow and small roads winding through the hilly landscape, often surrounded by buildings. Although there is no large factory in Aizawl and its vicinity, the city is expected to have significant pollution levels, given its high human population density, and is the vibrant center of administrative and economic activities in the state.

Sample Collection and Analysis

The sampling sites are situated between 21°56'N and 23°75'N latitudes and include important road intersections and national highways (Figure 1). The hilly landscape and buildings constructed very close to the narrow roads on both sides inhibit the collection of roadside soils at different distances from *the edge of the main road*. Nevertheless, roadside soil samples were collected at the roadside *within 2 m of the road edge at the designated 12 sampling sites*, collecting three replications every month. A total of 432 samples were collected from August 2020 to July 2021. The collected roadside soil was placed in a plastic bag and taken to the laboratory. The acid digestion method was employed for sample digestion, and the heavy metal analysis was done by using atomic absorption spectroscopy (AAS, AA-7000F). Metal contamination was avoided as far as possible throughout the sampling and digestion procedures.

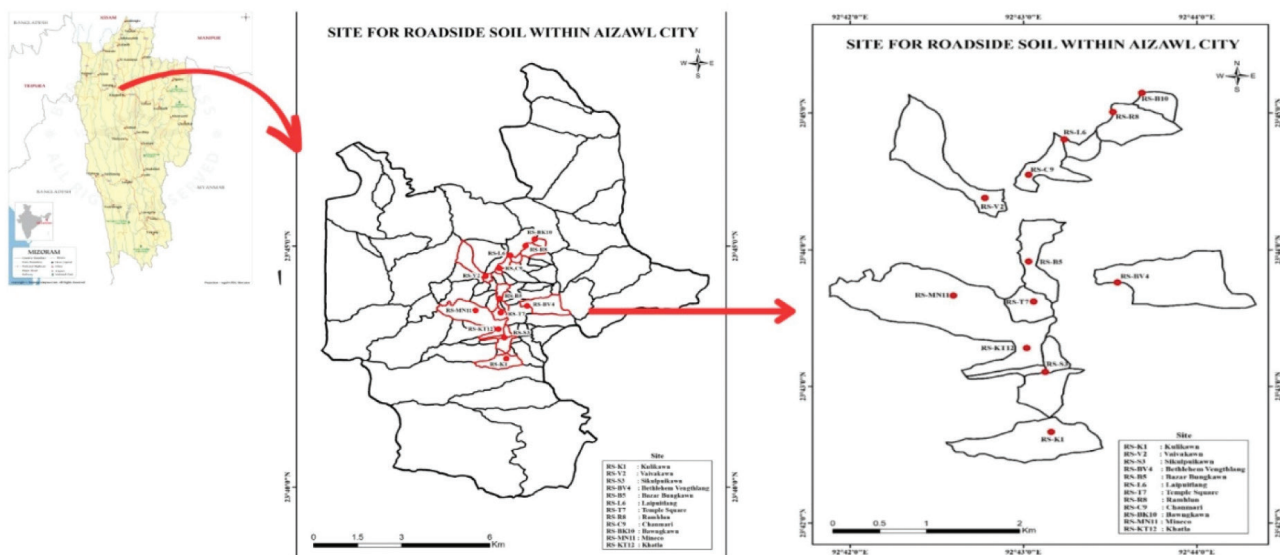


Figure 1: Distribution of sampling sites and location of the study area (Aizawl city).

Pollution Indicators

The pollution index can be used to provide a relative ranking of contamination levels. On the other hand, geochemical approaches, including the geo-accumulation index, pollution load index, enrichment factor, and principal component analysis, can be employed to assess the pollution status and to estimate the impact of anthropogenic activities (Lee et al., 2006).

Enrichment Factor (EF)

To quantify the degree of heavy metal enrichment and estimate the relative contribution of each metal generated from natural and anthropogenic activities, an EF approach was used (Yan et al., 2018). The EF is defined mathematically as:

$$EF_i = (C_i/C_R)_{\text{soil}} / (C_i/C_R)_{\text{background}}$$

where EF_i is the enrichment factor of trace metal, C_i is the metal concentration of metal in the sample, and C_R is the concentration of the reference metal. An EF value of <1.5 indicates that the metal was obtained primarily from the parent material. A larger EF indicates that anthropogenic loading contributes more than natural resources (Yan et al., 2018).

Geo-Accumulation Index (I_{geo})

The I_{geo} is a geochemical criterion for evaluating pollution levels and has been used since the late 1960s. It can be calculated using:

$$I_{\text{geo}} = \log_2 (C_n/1.5B_n)$$

where C_n is the measured concentration of metal n in soils or sediments and B_n is the geochemical background value of the corresponding metal.

Pollution Load Index (PLI)

The PLI of the metals was calculated according to the following formula,

$$PLI = (CF_1 \times CF_2 \times \dots \times CF_n)^{1/n}$$

where CF is the concentration of a specific heavy element in the soil sample and n is the number of heavy metals (Lu et al., 2014).

Statistical Analysis

Statistical analysis was performed with the statistical software package SPSS version 22.0 (IBM, Chicago, IL). Identification of the possible sources of heavy metals was performed using principal component analysis (PCA) (Wen et al., 2017).

Results and Discussion

The mean concentrations of heavy metals in roadside soil samples collected from Aizawl City are shown in Table 1. Heavy metals such as Cu, Fe, Mn, Ni, Pb, and Zn at the twelve studied sites varied widely from 0.43-1.06, 20.54-21.21, 2.69-3.41, 0.25-0.54, 0.31-0.49 and 1.35-1.77, respectively, showing that the mean concentrations of heavy metals at all the selected sites within Aizawl city were mostly higher than their

Table 1: Summary of the mean heavy metal concentrations in Aizawl City, Mizoram (in ppm)

Site	Cu	Fe	Mn	Ni	Pb	Zn
RS-K1	0.53	21.20	3.15	0.54	0.49	1.61
RS-V2	0.48	20.96	2.82	0.31	0.29	1.53
RS-S3	0.73	20.83	3.06	0.34	0.40	1.55
RS-BV4	0.72	21.21	3.24	0.38	0.49	1.49
RS-B5	0.96	20.82	2.97	0.25	0.36	1.65
RS-L6	0.61	20.91	2.81	0.25	0.31	1.55
RS-T7	0.94	20.76	3.41	0.31	0.49	1.58
RS-R8	0.57	20.54	2.69	0.34	0.44	1.55
RS-C9	1.06	20.70	2.80	0.26	0.33	1.77
RS-BK10	0.67	20.90	2.77	0.36	0.36	1.60
RS -MN11	0.43	20.74	2.89	0.43	0.32	1.35
RS-KT12	0.70	20.87	2.96	0.34	0.39	1.57
ABVs in Aizawl	0.41	13.27	1.95	0.13	0.15	0.87
China soil guidelines	100	-	-	50	300	250
Canada soil guidelines	64	-	-	50	140	200

corresponding average background values (ABVs). Fe exhibited the highest concentration (20.54 to 21.21 ppm) suggesting a strong association with vehicle pollutants (Skorbiłowicz et al., 2021), followed by Mn (2.69-3.41 ppm).

The distribution of heavy metals in roadside soil samples fluctuated in all twelve sites. Various activities, such as industries, traffic, and human activities, all contribute to metal contamination (Rødland et al., 2023). However, during the monsoon season, Pb concentrations rise at numerous locations, indicating that rainfall washes away building paints, resulting in greater Pb levels (Turner & Lewis, 2018). In the post-monsoon, metal concentration rises in areas with high anthropogenic and traffic activities. I_{geo} and PLI show moderate pollution levels for the studied metals. EF index indicates moderate to high pollution, with no data on extremely contaminated or very polluted classes as shown in Table 2.

Pollution Assessment of Roadside Soil Metals Using Geochemical Indicators

Figure 2 shows boxplots illustrating the monthly PLI values for heavy metals in Aizawl City from August 2020 to July 2021. Throughout the sampling period, Cu

displayed the greatest variability, except in the months of May and July 2021. Conversely, Fe consistently exhibited low variability each month. Moreover, the levels of metals such as Mn, Pb, and Zn fluctuated across the different months. High variability indicates significant fluctuations or changes in PLI values from one month to another. The heightened variability of Cu throughout most of the months suggests notable variations in copper concentrations in the study area over the specified period, potentially influenced by factors such as land use patterns, environmental conditions, human activities, or natural processes (Chen et al., 2015).

The comparison of mean heavy metal concentrations across twelve sites during the pre-monsoon, monsoon, and post-monsoon seasons in Graph 1 revealed higher PLI values for Pb and Zn at most sites. Table 2(b) showed that PLI values indicated primarily low to moderate pollution levels for all heavy metals, suggesting anthropogenic influence with varying impacts. The EF indices in Figure 3 demonstrated average EFs for Cu, Fe, Mn, Ni, Pb, and Zn at 3.49, 1.55, 1.23, 2.19, 3.98, and 4.67, respectively. These values reflected varying degrees of enrichment relative to natural background levels, with Cu, Pb, and Zn exceeding the threshold of

Table 2: The percentage of class distribution for pollution assessment of heavy metals in Aizawl roadside soils using (a) I_{geo} , (b) PLI, and (c) EF

<i>Class</i>	<i>Cu</i>	<i>Fe</i>	<i>Mn</i>	<i>Ni</i>	<i>Pb</i>	<i>Zn</i>
(a)	-	-	-	16.67%	-	-
Uncontaminated	75%	100%	100%	58.33%	58.33%	58.33%
Uncontaminated to moderately contaminated	25%	-	-	55%	41.67%	41.67%
Moderately contaminated	-	-	-	-	-	-
Moderate to heavily contaminated	-	-	-	-	-	-
Heavily contaminated	-	-	-	-	-	-
Extremely contaminated	-	-	-	-	-	-
(b)						
Low pollution	8.33%	8.33%	-	8.33%	-	-
Moderate pollution	66.67%	75%	100%	91.67%	75%	75%
High pollution	25%	16.67%	-	-	25%	25%
Very High pollution	-	-	-	-	-	-
(c)						
Depletion to minimal pollution	16.67%	66.67%	100%	50%	41.67%	8.33%
Moderate pollution	58.33%	33.33%	-	50%	41.67%	41.67%
Significant pollution	25%	-	-	-	16.66%	50%
Very strong pollution	-	-	-	-	-	-
Extreme pollution	-	-	-	-	-	-

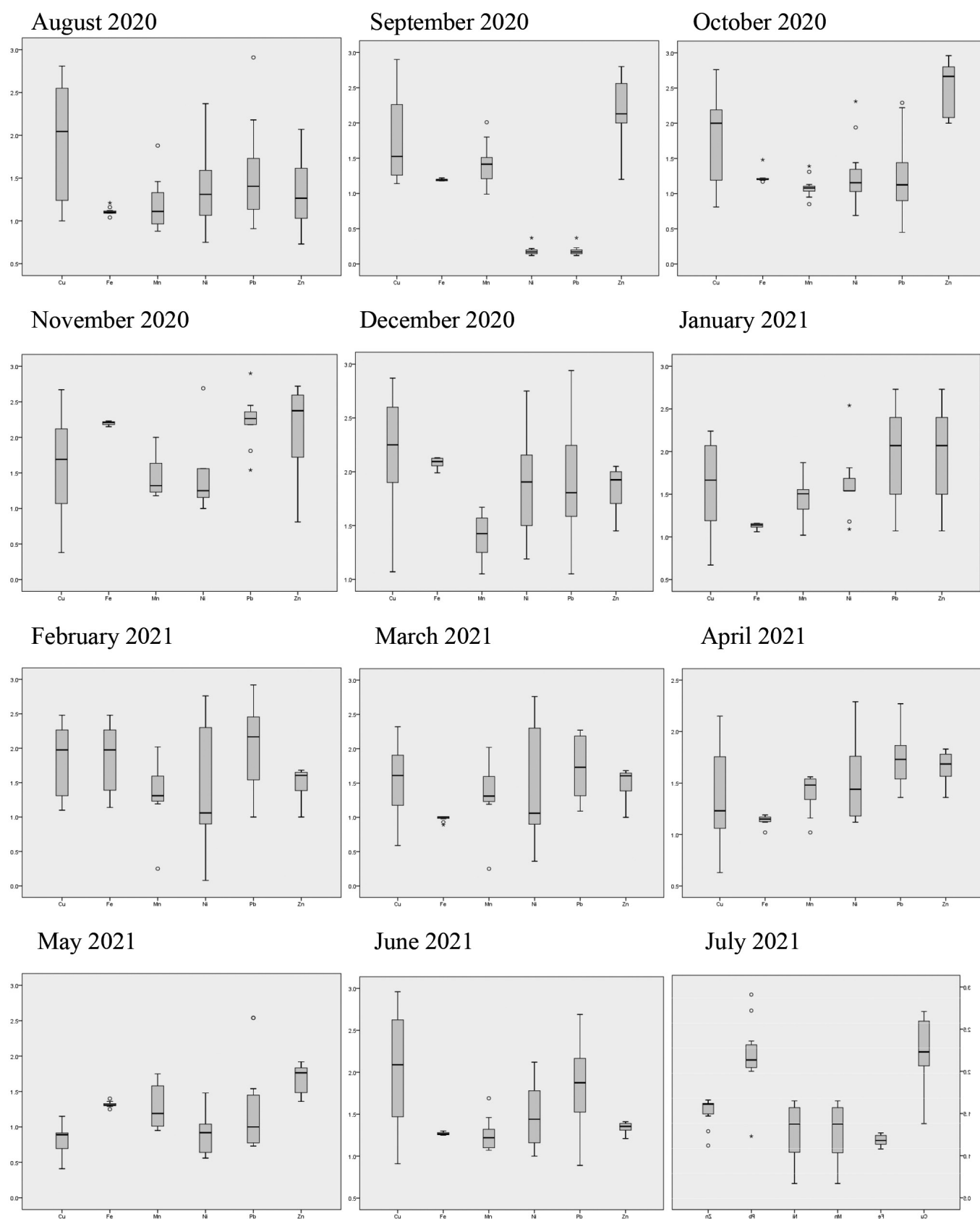


Figure 2: Boxplots of the PLI of heavy metal in the roadside soils of Aizawl from August 2020 to July 2021.

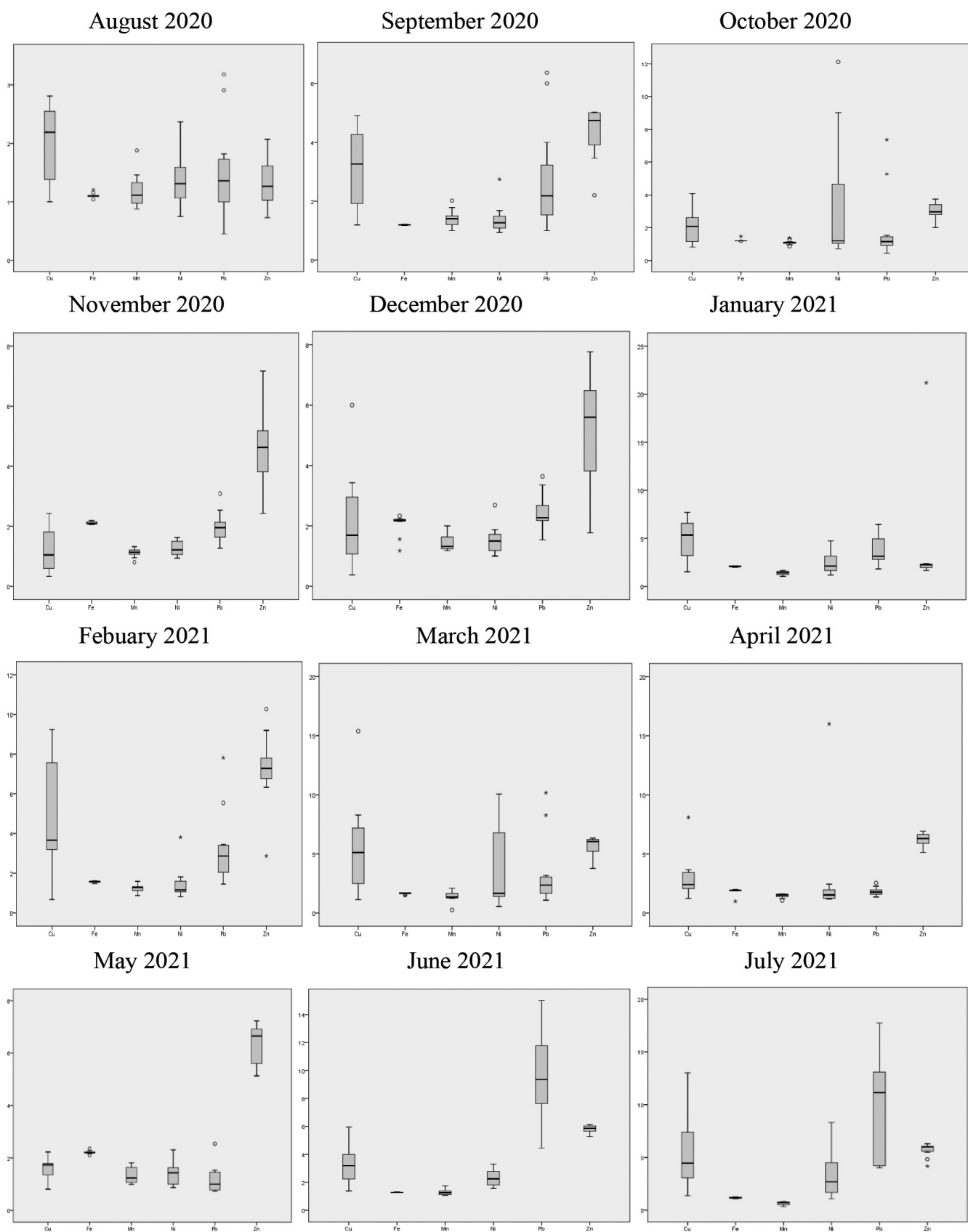


Figure 3: Boxplots of the EFs of heavy metals in roadside soil in Aizawl from August 2020 to July 2021.

1.5, indicating the notable anthropogenic influence on metal concentrations in roadside soil (Chen et al., 2015).

Graph 2 illustrates overlapping metal concentrations across seasons, with Pb showing the highest enrichment

post-monsoon at RS-S3. Table 2(c) indicates minimal to moderate pollution levels based on the Enrichment Factor (EF) for heavy metals. Aizawl's roadside soil exceeded ABVs, with Cu dominating the contamination.

Table 3: Matrix of principal component analysis loadings for trace metal concentrations in roadside soil

<i>Site</i>	<i>Metals</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>	<i>Site</i>	<i>Metals</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>
RS-K1	Cu	0.943	-	-	RS-T7	Ni	0.971	-	-
	Ni	0.897	-	-		Cu	0.951	-	-
	Pb	0.788	-	-		Fe	-	0.901	-
	Mn	0.654	-	-		Zn	-	0.879	-
	Fe	-	0.938	-		Mn	-	-	0.872
	Zn	-	0.878	-		Pb	-	-	0.863
% of Variance explain		47.739	36.856	-	% of Variance explain		41.429	31.185	19.295
RS-V2	Cu	0.818	-	-	RS-R8	Zn	0.850	-	-
	Ni	0.801	-	-		Cu	0.839	-	-
	Pb	0.721	-	-		Mn	0.717	-	-
	Fe	-	0.868	-		Ni	0.634	-	-
	Zn	-	0.863	-		Pb	-	0.826	-
	Mn	-	0.643	-		Fe	-	0.779	-
% of Variance explain		43.727	28.542	-	% of Variance explain		43.019	27.292	-
RS-S3	Zn	0.767	-	-	RS-C9	Fe	0.871	-	-
	Cu	0.719	-	-		Zn	0.869	-	-
	Pb	0.695	-	-		Cu	0.717	-	-
	Mn	-	0.792	-		Mn	-	0.776	-
	Ni	-	0.702	-		Pb	-	0.687	-
	Fe	-	0.686	-		Ni	-	0.685	-
% of Variance explain		43.061	21.875	-	% of Variance explain		45.345	20.262	-
RS-BV4	Zn	0.937	-	-	RS-BK10	Ni	0.965	-	-
	Cu	0.845	-	-		Pb	0.798	-	-
	Pb	-0.666	-	0.600		Cu	0.674	-	-
	Mn	-	0.805	-		Fe	-	0.878	-
	Ni	-	0.804	-		Mn	-	0.798	-
	Fe	-	-	0.879		Zn	-	0.760	-
% of Variance explain		37.286	26.811	17.785	% of Variance explain		42.215	36.808	-
RS-B55	Pb	0.955	-	-	RS-MN11	Zn	0.861	-	-
	Ni	0.910	-	-		Ni	0.807	-	-
	Cu	0.805	-	-		Cu	0.619	-	-
	Mn	-0.804	-	-		Pb	-	0.843	-
	Zn	-	0.912	-		Mn	-	0.752	-
	Fe	-	0.799	-		Fe	-	-0.617	-
% of Variance explain		54.383	26.765	-	% of Variance explain		40.0882	28.968	-
RS-L6	Ni	0.814	-	-	RS-KT12	Ni	0.969	-	-
	Pb	0.753	-	-		Pb	0.947	-	-
	Cu	0.721	-	-		Fe	-	0.956	-
	Fe	-	0.933	-		Zn	-	0.922	-
	Zn	-	0.715	-		Cu	-	-	0.874
	Mn	-	-	0.934		Mn	-	-	0.656
% of Variance explain		72.269	43.727	47.738	% of Variance explain		38.664	32.845	16.682

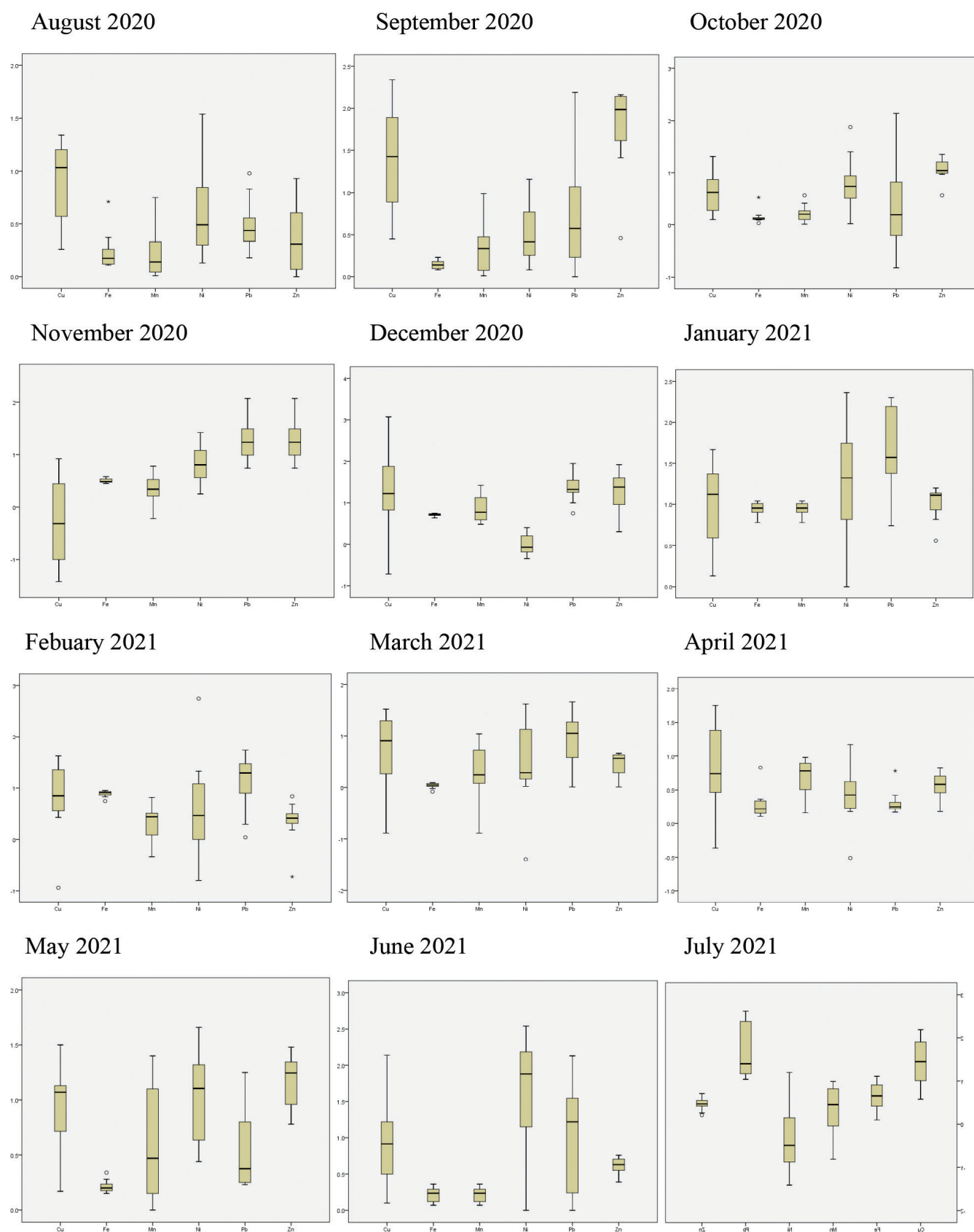
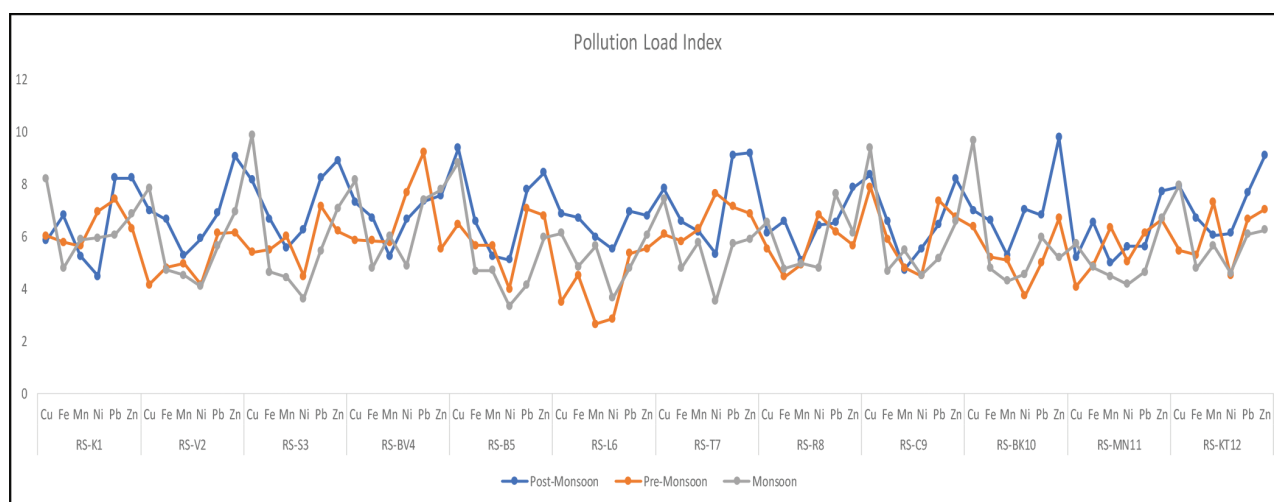
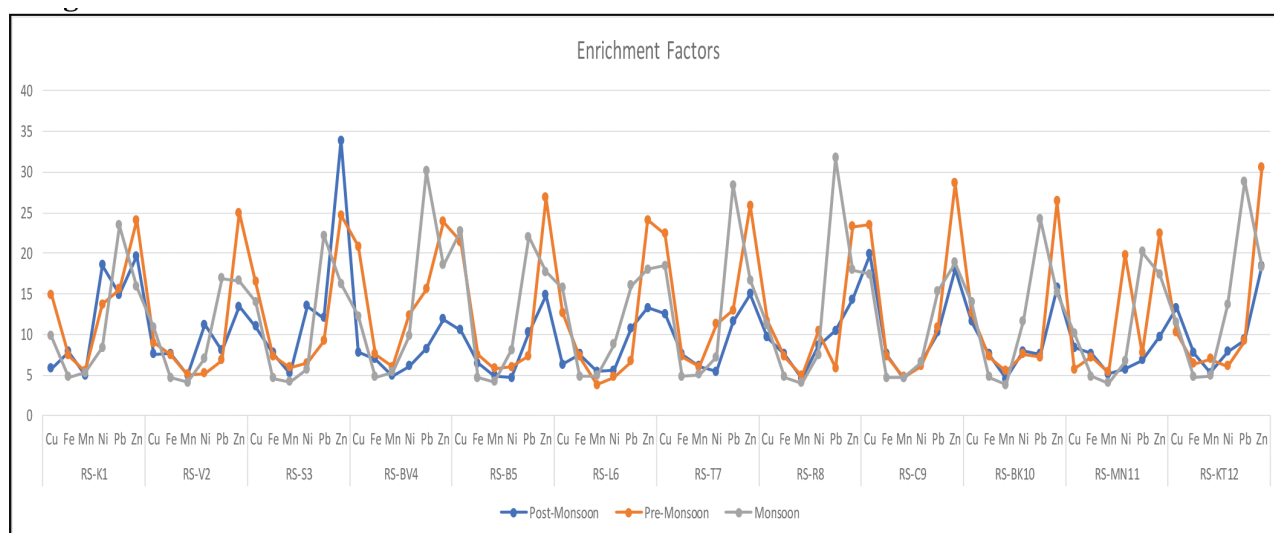


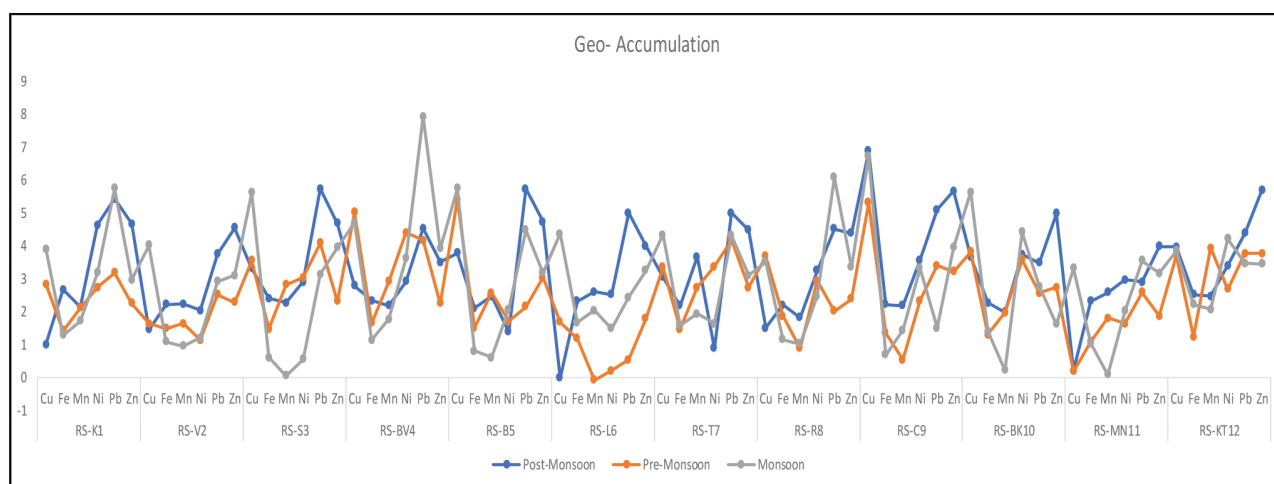
Figure 4: Boxplots of the I_{geo} values for heavy metals in Aizawl roadside soils from August 2020 to July 2021.



Graph 1: Influence of monsoon in the variation of heavy metals concentrations on selected sites using PLI



Graph 2: Influence of monsoon in the variation of heavy metals concentrations on selected sites using EFs.



Graph 3: Influence of monsoon in the variation in heavy metals concentrations on selected sites using the I_{geo} .

I_{geo} analysis in Graph 3 highlighted higher concentrations during the monsoon, notably in RS-BV4. Most metals fell into the uncontaminated to moderately contaminated category, as indicated in Table 2(a). The box plot in Figure 4 illustrates the heavy metal pollution levels, highlighting the impact of monsoon rainfall and variations at specific locations.

Identification of Pollution Sources

Principal component analysis (PCA) classified metals into groups based on their concentrations. Two and three rotated principal components (PCs) were derived, collectively explaining dataset variability. At RS-K1, trace metals were separated into two components, accounting for 84.590% of data variability. Component 1, led by copper, nickel, lead, and magnesium, explained 47.738% of the variance, while Component 2, featuring iron and zinc, explained 36.856%. Similar patterns were observed at other sites, with distinct metal dominance in specific components. For instance, RS-T7 displayed three components, collectively explaining 91.910% of the variability. Each component reveals unique metal patterns, with vehicular emissions influencing Cu and Ni, and industrial activities potentially impacting Fe and Zn (Åström et al., 2017). The concentration of Pb suggests a possible link to traffic-related activities, emphasising the diverse anthropogenic sources contributing to pollution in various roadside soils (Kaur et al., 2022) (Table 3). The study focusses on quantifying heavy metals in roadside soils, with vehicular emissions as the main source of lead pollution. Contamination factor and PCA are used to assess metal pollution, emphasising Zn, Pb, and Cu from traffic-related sources. Elevated metal contamination in street dust is impacted by vehicle traffic and industrial operations, with lead, zinc, and copper detected in fine particles (Lee et al., 2021).

The study conducted in Aizawl City identified specific sites with varying concentrations of heavy metals in roadside soils. Among these sites, RS-C9 exhibited the highest Cu concentration (1.06 ppm) which could be influenced by intense human and vehicular activities, while RS-MN11 showed the lowest Cu contamination (0.43 ppm). For Fe, RS-BV4 had the highest mean concentration (21.21 ppm), which could be attributed to heavy traffic, and human activity (Skorbiłowicz et al., 2021). Mn levels were the highest at RS-T7 (3.41 ppm), possibly due to road maintenance activities nearby. Ni concentrations were the highest at RS-K1 (0.54 ppm) and RS-MN11 (0.43 ppm), reflecting the impact of vehicle emissions and intense human activities. Pb concentrations varied widely with

RS-BV4, RS-K1, and RS-T7, identified as the most contaminated sites. RS-V2, where the sampling site has a steep slope, and RS-L6, which is situated at the hilltop with a higher elevation, had lower Pb levels. Zn concentrations were the highest at RS-C9 (1.77 ppm), probably due to railing construction works nearby and vehicular emissions. These findings highlight the spatial variability of heavy metal contamination in roadside soils across different sites in Aizawl City, emphasising the need for continued monitoring efforts to mitigate environmental and health risks associated with heavy metal pollution.

The heavy metal concentrations in the roadside soil samples collected within Aizawl City ranged from 0.1 to 5ppm for the selected metals as represented in Table 1. The distribution of heavy metals on roadside soils fluctuates over time, which could be because all of these studies were conducted during the global COVID-19 pandemic, when the Mizoram government frequently imposed total lockdowns, resulting in a decrease in public movement. The SED (2020) report indicated that the average number of LMV movements per day in October 2020 ranges between 1000 to 1120, while bus and truck movements average approximately 100 per day, which can have a significant impact on metal concentrations on roadside soil. Heavy metal concentrations were greater at most of the sites from November 2020 to January 2021, possibly because the movement of people and vehicles increased in a raid form as the government lifted the lockdown during these months. On the other hand, it is festival season and there is higher traffic, with approximately 2000 two-wheeler movements alone per day observed in most locations.

Conclusion

This study conducted in Aizawl, the capital city of Mizoram (India), offers profound insights into scenarios of heavy metals in roadside soil. Focussing on six pivotal heavy metals such as Cu, Fe, Mn, Ni, Pb, and Zn that are commonly associated with vehicular emissions, road-related activities, anthropogenic activities, and industrial processes. The study unveiled varying levels of heavy metal contamination, and the highest of the mean metal concentrations observed are in the order: $Fe > Mn > Zn > Cu > Ni > Pb$. Elevated concentrations of heavy metals were observed at specific sites such as RS-K1, RS-BV4, and RS-C9, underscoring the spatial variability influenced by metal types and their respective sources. Temporal fluctuations in heavy metal

concentrations, influenced by vehicular and human activities like festivals and by the lockdown due to the COVID-19 pandemic, were observed. Pollution assessments using indicators like PLI, EF, and I_{geo} indicated moderate to high pollution levels in roadside soil, mainly from anthropogenic sources. PCA identified distinct metal dominance patterns, with vehicular emissions, industrial activities, and urbanization as primary contributors. Close monitoring of heavy metals in roadside soils is crucial for environmental protection and public health.

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PARTICULARS OF THE CANDIDATE

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DEGREE	: DOCTOR OF PHILOSOPHY
DEPARTMENT	: Environmental Science
TITLE OF THESIS	: Study On Heavy Metal Contamination Of Soil And Air Particulate Matter Along The Roadside Of Aizawl District, Mizoram
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Extension (if any)	: NIL

Head

Department of Environmental Science

ABSTRACT

STUDY ON HEAVY METAL CONTAMINATION OF SOIL AND AIR PARTICULATE MATTER ALONG THE ROADSIDE OF AIZAWL DISTRICT, MIZORAM

**AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY**

GOSPEL LALLAWMZUALI

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**DEPARTMENT OF ENVIRONMENTAL SCIENCE
SCHOOL OF EARTH SCIENCE & NATURAL RESOURCE
MANAGEMENT
JULY, 2025**

**STUDY ON HEAVY METAL CONTAMINATION OF SOIL AND
AIR PARTICULATE MATTER ALONG THE ROADSIDE OF
AIZAWL DISTRICT, MIZORAM**

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Submitted
In partial fulfillment of the requirement of the Degree of Doctor of Philosophy
in Environmental Science of Mizoram University, Aizawl.

Environmental contamination by heavy metals has attracted world-wide attention. Environmental contamination with toxic heavy metals such as those used in batteries and electronic equipment due to fast industrialization etc., vehicular and other life style emissions and improper disposal of goods has posed the threat to eco system and human health. In addition, road transportation is a major contributor to heavy metal into soil and fine particulate in the atmosphere. In several studies worldwide, high concentrations of metals including copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), manganese (Mn), and iron (Fe) have been discovered in topsoil as well as airborne particles near highways and city streets.

Distance from pollution sources is of great importance in determining heavy metal concentration and speciation in environmental matrix. Compared with remote area soil, heavy metal at road soils is generally higher and directly deposited, and enriched from the dust pollution. On high-traffic roads, heavy metals are enriched in fine inhalable particles, mainly PM₁₀. They are predominantly due to motor exhaust and resuspension of road dust, which occurs more frequently in dense centers. Such long term exposure to these polluted atmospheres may suggest the bioaccumulation of such toxic metals that resulted in various health disturbance.

The problem of heavy metal pollution is a serious concern in urban roadsides of India—due to rapid growth of transport system and its intensity and presence of commercial and industrial corridors in cities. Even with the change to unleaded gasoline, there remain tiny levels of metals such as Ni and Pb, which are present and released during fuel burning. Moreover, non-exhaust emissions including lubricating oils, tire abrasion and braking systems also contribute to heavy metal pollution in roads. These pollutants also influenced by several components including different type of land-use, such as roadside greenbelt, distance from the traffic lane, traffic flow rate, and local meteorological, dispersion and deposition patterns. While much of the work carried out in India has been concerned with topsoil contamination, airborne PM trace metal concentration is not well documented, particularly in the North-Eastern region, where wet deposition through precipitation is an important pathway for the introduction of environmental contamination. The interpretation of

these concentrations is highly important for risk assessment in public health and the environment.

Aizawl, the capital of Mizoram had lots more population as well as number of registered vehicle increasing rapidly, leading to the bulky traffic and pollution is also increasing. The city is also located on the hilly land, which may cause problems for the high humidity and potential heavy rain for the ecology at the area. There is also a paucity of data due to monitoring of air and soil quality in smaller towns of North-East India, including Aizawl, limiting efforts to study the air and soil pollution dynamics of this region. The current studies were conducted to fill this gap by establishing additional information on heavy metal pollution with the focus on levels of heavy metals in airborne particulate matter as well as roadside soil. Hill towns situated under similar topographical and climatic conditions may avail the information on particulate matter pollution in vicinity of traffic hot spots to plan air quality improvement in their town. Lastly, we hope this study would consist of an analysis of anthropogenic activities (in particular urban transportation emissions) and ecologic pollution, as well as attempts for mitigation to fit in the Mizoram state specific environmental scenario.

The results show that there are several human activities that lead to the accumulation of Cu, Fe, Mn, Ni, Pb, and Zn in roadside areas. Contrary, copper and zinc are derived mainly from brake pad wear and tire abrasion, and lead and nickel from fuel combustion and engine oil leakage. Manganese and iron. can be related to natural and road surface wear, and construction. Even after the introduction of unleaded petrol, remaining Pb emissions remain and will be accompanied by an enhanced release of Ni from lubricants and fuel additives. In Aizawl, the stronger compact localization of the metals nearest to the traffic, may be due to more intense traffic, frequent traffic congestion, absence of proper green buffer respectively. The results highlight the necessity for the more effective intervention through a better traffic management, soil remediation, environmental monitoring in terms of the health and ecological risk caused by traffic-related heavy metals in urban hilly towns.

Study sites

The current study was carried out in the Aizawl District, the capital town of Mizoram, situated in the northeastern part of India, just north of the Tropic of Cancer at an altitude of 974 m above mean sea level. Aizawl, a city of over 400,000 people and a literate population base of 98.5%, is the cultural, administrative and economic centre of the state, which is supported by a range of clear hills, a mild climate, and an annual rainfall ranging from 2500–3000 mm. The region has a monsoon climate characteristic of bi-seasonal rainfall; pre-monsoon (Feb–May), monsoon (June–Sept), and post-monsoon (Oct–Jan), with the highest rainfall recorded in the months of July and August. Sampling of heavy metal contamination was carried out in 24 sites (12 within Aizawl city and 12 from peripheral areas) by collecting roadside soil samples and PM₁₀ air samples from four urban points. Meteorological conditions in 2020–2022 were characterized by temperatures ranging from 11.8°C to 29.6°C and with humidity values between 47.7 and 83 g/m³. Hill features, climate, and urban structure in the study area are distinctive, and it is thus important to evaluate hill town-specific air pollution exposure.

The study was conducted in Aizawl district on 24 roadside soil sampling sites and 4 air quality sampling sites. Soil samples from roadside side were collected from 12 urban locations of Aizawl city such as RS-KK1 (Kulikawn), RS-VK2 (Vaivakawn), RS-SK3 (Sikulpuikawn), RS-BV4 (Bethlehem Vengthlang), RS-BB5 (Bungkawn Bazar), RS-LP6 (Laipuitlang), RS-TS7 (Temple Square), RS-RS8 (Ramhlun South), RS-CK9 (Chanmari), RS-BK10 (Bawngkawn), RS-CO11 (Mineco), RS-KT12 (Khatla). The 12 non-urban roadside soil sites outside the Aizawl city were denoted as RS-CR1 (Chamring), RS-SL2 (Sawlung), RS-KR3 (Kepran), RS-SG4 (Seling), RS-TP5 (Tachhip), RS-HF6 (Hmuifang), RS-ST7 (Sailutar), RS-AB8 (Aibawk), RS-SS9 (Sialsuk), RS-TV10 (Tlungvel), RS-SR11 (Sairang) and RS-MT12 (Muallungthu). For air quality investigation, PM₁₀ samples were collected from 4 prominent urban centres of Aizawl City namely A-LP (Laipuitlang), A-BK (Bawngkawn), A-DP (Dawrpui) and A-KT (Khatla) for air quality monitoring. These localities were located specifically to study the spatial distribution of heavy metals in soil and ambient air throughout the urban-rural continuum of Aizawl district.

Sample preparation

The monthly samples were classified according to three seasonal phases: Pre-Monsoon (February–May), Monsoon (June–September) and Post-Monsoon (October–January). Samples were taken in the soil by means of a collection plate and recorded in hermetically sealed plastic bags. Three samples from each site were mixed and utilized as the composite sample. The samples from the composites were homogenized and split in half. One sub-sample was employed for direct determination of soil pH and soil water content. The other half was air-dried to a constant weight, ground to fine powder and screened through a 2 mm sieve. Such treated samples were kept in polythene bags for analysis. The sieved soil samples were then analyzed for organic carbon (C), total nitrogen (N), available phosphorus (P), and available potassium (K). Further, the same samples were utilized for the determination of heavy metal levels such as copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn).

Methods of Analysis

Seasonal soil samples (Pre-monsoon, Monsoon and Post-monsoon) were collected from twenty-four roadside sites – 12 urban and 12 non-urban with 3 replicates at each site. Soil pH (1:2 soil-water suspension), moisture content (oven-drying at 105°C), soil organic carbon (Walkley and Black, 1934), total nitrogen (Kjeldahl method), available phosphorus (method by Bray and Kurtz No. 1, 1945), and available potassium (Flame Photometry with 1N NH₄OAc extract) of the soil were determined. For determination of heavy metals (Cu, Fe, Mn, Ni, Pb, Zn), 1 g of soil that was previously sieved (through 0.15 mm screen) was digested with concentrated HNO₃, H₂O₂, and HCl according to a modified USEPA method and analyzed by AAS. Urban samples were collected at four sampling locations (coded PM-A1 to PM-A4) on a monthly basis for PM₁₀ by high-volume air samplers; filter papers were digested in 3% HNO₃ and 8% HCl and extracted and reported for Cu, Pb, Ni, and Zn using AAS as per the guidelines laid down by CPCB (2013). To determine the magnitude of pollution and existing ecological risk, contamination indices including EF, Igeo, CF, and PLI were calculated. Statistical analysis like one-way, two-way

ANOVA, correlation analysis, standard deviation and standard error was performed using MS Excel to establish the significance of results.

Physicochemical Properties of Roadside Soil

The pH of roadside soils of both urban and rural areas of Aizawl was alkaline, varying from 7.34 ± 1.13 at RS-MT5 during winter to 11.40 ± 0.67 at RS-KT12 in monsoon. High pH in monsoon is due to leaching and dilution of acidic constituents by rainfall. Maximum with $60.62 \pm 0.94\%$ SMC at RS-MT5 and minimum value with SMC $16.59 \pm 1.10\%$ at RS-KT12 recorded in monsoon and winter, respectively. The highest SOC value ($3.88 \pm 0.37\%$) was recorded at RS-MT5 during monsoon and the lowest ($1.12 \pm 0.41\%$) at RS-KT12 during winter indicating clear urban-rural contrast. Among the nutrients, TN was the most variable (0.05 ± 0.02 to $0.19 \pm 0.01\%$) concentration was recorded in the RSSR11 (monsoon) and in the RSCO11 (winter), respectively. The highest value for Available Phosphorus (AP) was recorded for RS-SR11 (rural) (0.88 ± 0.01 kg/ha) in monsoon and the least at RS-KT12 (urban) (0.13 ± 0.02 kg/ha) in winter. The mean AK reached a maximum of 1.82 ± 0.12 kg/ha in RS-CK9 in the rainfall season and decreased to 0.51 ± 0.04 kg/ha in RS-KT12 in the winter. These indices show obvious seasonal and urban-rural distributions.

Heavy Metal Contamination of Roadside Soil – within Aizawl city

In the Aizawl city the concentration of heavy metals were quite higher, related with heavy vehicular traffic and urban activities. Copper (Cu) concentration was maximum 1.78 ± 0.31 ppm at RS-CK9 during pre-monsoon and minimum 0.46 ± 0.12 ppm at RS-KT12 during lockdown/winter. Fe was maximum at RS-CK9 (1134.09 ± 25.87 ppm) and minimum at RS-KT12 (537.63 ± 29.47 ppm) during post-monsoon and monsoon, respectively. 13.57 ± 1.02 ppm for Mn was noticed in RS-CO11 during pre-monsoon and reduced up to 2.82 ± 0.34 ppm in RS-KT12 during lockdown/winter. Among the heavy metals nitrosopahur [3], nickel (Ni) concentration was highest in the ambient environment of RS-CO11 (2.03 ± 0.51 ppm) during pre-monsoon and lowest in RS-KT12 (0.32 ± 0.03 ppm) during lockdown. The highest value (7.33 ± 0.71 ppm) of Pb shown by RS-KT12 during monsoon and the lowest of (1.11 ± 0.21 ppm) at RS-CO11 during lockdown. Zinc (Zn) The

concentration was observed maximum of 2.27 ± 0.08 ppm in RS-CK9 during pre-monsoon and minimum of 0.56 ± 0.07 ppm whereas at RS-KT12 during lockdown. Seasonal trends exhibit peak high levels during pre-monsoon and the lowest during monsoon or lockdown.

Heavy Metal Contamination of Roadside Soil – outside Aizawl City

Heavy metal concentrations were relatively lower as compared to that of urban sites in rural locations about Aizawl city, however still influenced by highway traffic and seasonal characters. Cu exhibited the maximum of 1.16 ± 0.03 ppm on RS-SR11 during post-monsoon, and the minimum of 0.39 ± 0.09 ppm on RS-SL2 during monsoon. Fe was maximum at 1021.36 ± 19.03 ppm at RS-SR11 in monsoon and minimum at 403.12 ± 34.65 ppm at RS-MT5 during lockdown. Mn was the highest at 8.57 ± 0.52 ppm at RS-SR11 at post-monsoon, and the lowest at 3.46 ± 0.15 ppm at RS-SL2 in monsoon. Ni level was maximum (1.68 ± 0.08 ppm) at RS-SR11 during pre-monsoon while the minimum (0.28 ± 0.03 ppm) at RS-MT5 during lockdown. Pb was highest 8.14 ± 0.37 ppm at RS-SR1 during monsoon, the maximum among all rural and urban sites and lowest 1.04 ± 0.06 ppm at RS-MT5 in lockdown. Zn was maximum at 2.21 ± 0.18 ppm in RS-SR11 during pre-monsoon and minimum at 0.71 ± 0.11 ppm in RS-MT5 in monsoon. RS-SR11 always presented the highest rural metal concentrations, reflecting its proximity to heavy traffic.

Metal Contents in Air Samples

The airborne metals were highest concentration in urban sites, showing pre-monsoon peaks linked with dust and traffic emissions. In site A-DP, the concentration peaks for Cu, Fe, Mn, Ni, Pb, and Zn were found to be 666.5 ng/m^3 , 2396.13 ng/m^3 , 411.88 ng/m^3 , 0.18 ng/m^3 , 215.12 ng/m^3 , and 376.25 ng/m^3 respectively in pre-monsoon. Higher while lower values were found at the least trafficked residential side (site A-LP): Cu: 112.2 ng/m^3 , Fe: 602.45 ng/m^3 , Mn: 98.16 ng/m^3 , Ni: 0.03 ng/m^3 , Pb: 64.17 ng/m^3 , Zn: 105.87 ng/m^3 Hg: $0.01\text{--}0.2 \text{ ng/m}^3$ mainly in monsoon. Pb had a unique monsoon-specific elevation in some sites, perhaps as a result of resuspension from painted surfaces and construction materials. Highest concentrations were highly associated with traffic volume and season in markets and commercial zones.

Indices of pollution – PLI, Igeo, EF, CF

Index of Pollution indicated a moderate to high contamination along urban and rural stations. Contamination Factor (CF) of Pb were the highest as 6.69 in RS-SR11 and Cu 5.19 in RS-CK9, respectively, which indicated that the pollution was serious. The Pollution Load Index (PLI) exceeded the acceptable limits (>1.0) at several sites, ranging from a maximum of 4.64 for Cu in RS-CK9 to 6.60 for Pb in RS-SR11. The Enrichment Factor (EF) exhibited maximum enrichment of Pb (2.54) in RS-KT12, and that of Ni (2.67) in RS-SR11. Values of Geo-accumulation Index (Igeo) indicated moderate pollution and Zn Igeo content was highest in RS-KT12 (1.68) and Pb Igeo content was highest in RS-SR11 (1.76). Here, these indices illustrate that both high traffic-urban and some rural high way-adjacent sites emerged as monitors with high contamination influx.

Impact of COVID-19 Lockdown on Heavy Metal Level

Heavy metal concentrations declined significantly for all the sites during the COVID-19 lockdown period. In urban soils, Cu concentration decreased to 0.46–0.92 ppm, and the post-lockdown values increased to 1.16–1.78 ppm. Mn decreased to 2.82–3.96 ppm during lockdown and increased rapidly to 8.57 ppm in RS-SR11 after lockdown was lifted. Similar patterns were observed for Zn and Fe, Zn decreased to 0.56 ppm and increased to 2.27 ppm post-lockdown. Airborne Pb also significantly decreased after lockdown. These variations pointed out anthropic origin-traffic and human activities- as the main responsible of heavy metals pollution in soil and air. Lockdown provided a baseline of pollution levels caused by daily urban activity.

Since Aizawl is a hilly terrain with a lack of resources, and facing new challenges due to new environmental issues, a multi-dimensional low-cost approach is the necessity of the hour for ameliorating soil and air pollution by heavy metals. Top-line measures include increasing public awareness through local-language ad campaigns and radio, setting up community action via neighbourhood programs like “Soil Health Saturdays,” and bringing eco-education to schools. With respect to pollution control policy, priority should be given to low-emission zones, regular checking of

vehicles, and stricter rules about dumping and dust. Greening the city with the help of hyperaccumulators for screen walls and phytoremediation along with developing rooftop gardens and rainwater harvesting will help in reducing the contamination and erosion. Community-based air and soil quality monitoring, with basic testing kits and mobile sharing of data, should guide adaptive strategies. Practical collaboration with local institutions and the training of municipal staff and community representatives are also required for implementation. Waste management interventions such as segregation and composting must be given topmost priority especially in hotspot areas. Ethically community-engaged, inclusive designs through agroforestry, soil conversation, and adaptive agriculture will ensure sustainability. Ongoing assessment and feedback with visual tools, locally-attended metrics, and inclusive decision-making platforms such as MCDA should further enable the piecing together and restructuring of solutions that best resonate with Aizawl's particular socio-natural environment.

Conclusion

The present study facilitate to understand the spatial and seasonal variations on the physicochemical characteristics and heavy metal content of road side soil and air of the Aizawl city and its surrounding areas. High concentrations of Pb, Zn and Ni were observed inside the city during dry season, reflecting the effects of emissions from automotive sources, construction and urban activities, while peripheral rural areas presented lower values. The PLI, Igeo and CF values also revealed moderate to high pollution degrees at some hotspots. The air samples also showed a disturbing increase in particulate-bound heavy metals, which have direct links to human health. Comparisons after COVID indicate a small and transient reduction in pollution as a result of reduced anthropogenic activities. With Aizawl's delicate hill ecosystem and resource constraints, the focus must be on low cost, community-based methods that are sensitive to local circumstances. These need to include environmental education, green infrastructure, and indigenous phytoremediation, policy adherence, and participatory monitoring. Reliable application of such measures will not only reduce heavy metal pollution but also contribute to the long-term ecological resilience and

public awareness, for a healthier urban environment for both current and future generations.