EVALUATION OF HAEMATOLOGICAL AND HAEMORRHEOLOGICAL CHANGES IN STREET CLEANERS IN BENIN CITY

BY:

OMORODION, OSAKHONMEN TRIUMPHANT
BMS2001196

DEPARTMENT OF MEDICAL LABORATORY SCIENCE,
SCHOOL OF BASIC MEDICAL SCIENCE,
COLLEGE OF MEDICINE,
UNIVERSITY OF BENIN.
BENIN CITY.

SEPTEMBER, 2025

EVALUATION OF HAEMATOLOGICAL AND HAEMORRHEOLOGICAL CHANGES IN STREET CLEANERS IN BENIN CITY

BY:

OMORODION, OSAKHONMEN TRIUMPHANT
BMS2001196

A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF MEDICAL LABORATORY SCIENCE, SCHOOL OF BASIC MEDICAL SCIENCES, UNIVERSITY OF BENIN, BENIN CITY, EDO STATE IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE AWARD OF BACHELOR OF MEDICAL LABORATORY SCIENCE DEGREE (BMLS) IN MEDICAL LABORATORY SCIENCE.

SEPTEMBER, 2025.

CERTIFICATION

This is to certify that this project is an authentic work carried out OMORODION OSAKHONMEN TRIUMPHANT with matriculation number BMS2001196 under the supervision of DR. (MRS) J. C. OTIKOR in partial fulfillment of the requirement for the award of Bachelor's in Medical Laboratory Science Degree (BMLS) of the Department of Medical Laboratory Science, School of Basic Medical Science, University of Benin, Ugbowo, Benin City, Edo state.

_____ _____

DR. (MRS) J. C. OTIKOR **DATE**

Supervisor

_____ _____

DR. (MRS) Z. OMORUYI **DATE**

Head of Department

_____ _____

EXTERNAL EXAMINER **DATE**

DEDICATION

I dedicate this project to God almighty for making this project work a huge success.

ACKNOWLEDGEMENTS

I express my deepest gratitude to Almighty God for granting me the wisdom, strength, and grace to complete this work.

I sincerely appreciate my supervisor, Dr. (Mrs.) J. C. Otikor, for her patience, expert guidance, and invaluable support throughout this project.

I extend my special thanks to the Head of Department, Medical Laboratory Science, Dr. Mrs. Z. Omoruyi, whose invaluable support contributed significantly to the success of this study.

I am also profoundly thankful to my mother, Mrs. Mary Omorodion, my siblings, and my aunt and uncle, Mr. and Mrs. Iyamu, for their unwavering support, guidance, and encouragement.

Additionally, I thank my friends and well-wishers for their support and motivation.

May God bless and keep you all.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Occupational exposure to environmental pollutants poses significant health risks, particularly for street cleaners who are routinely exposed to dust, vehicle emissions, and other contaminants. This aim of this study was to evaluate the haematological and haemorrheological changes among street cleaners in selected environs of Benin City, Edo State, Nigeria. A total of 100 participants, comprising 50 street cleaners and 50 age- and gender-matched controls, were recruited using a simple random sampling technique. Sociodemographic and occupational data were obtained via structured questionnaires. Venous blood samples were collected under aseptic conditions for analysis of complete blood count, erythrocyte sedimentation rate (ESR), and plasma fibrinogen concentration using automation, Westergren method and Clauss method respectively. Results indicated that street cleaners in Benin City were slightly older (35.84 ± 8.09 years) than controls (33.84 ± 4.21 years), with a predominance of males in both groups (88.0% vs. 80.0%). Most street cleaners had 1–5 years of work experience and worked 4–8 hours per day, 3–5 days per week. Use of personal protective equipment (PPE) varied, with only 36.0% always using PPE, although all participants had access to water and soap for hand hygiene. Haematological analysis revealed significantly higher WBC counts in street cleaners (5.25 ± 0.18 $\times 10^3/\mu L$) compared to control (4.37 ± 0.19 $\times 10^3/\mu L$) ($p<0.05$). Red blood cell (RBC) counts were significantly lower in street cleaners (3.92 ± 0.07 $\times 10^{12}/L$) relative to controls (5.26 ± 0.08 $\times 10^{12}/L$, $p < 0.001$). Haemoglobin (HGB) levels were also reduced in street cleaners (11.45 ± 0.17 g/dL) than control (13.80 ± 0.26 g/dL) ($p < 0.001$). Red cell indices, including MCV, MCH, MCHC, and RDW, were significantly higher in street cleaners, whereas platelet counts and mean platelet volume (MPV) were lower. ESR levels were significantly higher among street cleaners (17.92 ± 1.50 mm/hr) compared to controls (5.78 ± 0.51 mm/hr) ($p < 0.001$), and fibrinogen concentrations were also elevated in street cleaners (460.68 ± 14.88 mg/dL) relative to controls (286.88 ± 6.83 mg/dL) ($p < 0.001$). Correlation analysis showed that fibrinogen and ESR had strong negative correlation with RBC, HGB, and HCT ($p<0.05$). However, ESR and fibrinogen were strongly positively correlated with each other. In conclusion, street cleaning in Benin City is associated with significant hematological and haemorrheological alterations in street cleaners likely driven by chronic exposure to environmental pollutants, systemic inflammation, and oxidative stress.

Keywords: Street cleaners, Haematology, Haemorheology, Erythrocyte sedimentation rate, fibrinogen, Benin City, occupational exposure

CHAPTER ONE

INTRODUCTION

1.1. Background of Study

Solid waste management includes the collection, transport, deposition, treatment and recycling of waste produced by individual households, public institutions and workplaces (Vam Kampen *et al*., 2020). Street cleaning is an integral part of the solid waste management system and an important duty to ensure a clean environment. Specific challenges significantly differ around the world. The increasing population, especially in Africa, Asia and South America, has resulted in severe pressure on urban land, urban utilities and services. In those areas, a major goal is the prevention of transmission of infectious diseases, and this is why street sweepers play an important role in maintaining health in the communities (Wahab and Ogunlola, 2014). For waste collectors and compost workers, the activities and their influence on occupational health have been described in some European studies (Walser *et al*., 2015). Waste collectors usually pick up waste from its point of production, empty refuse containers onto trucks, and deliver the waste to disposal and processing facilities (Velasco *et al*., 2015). Benin City, the largest urban center in Edo State, in southern Nigeria houses much of the challenges of waste disposal issue and indiscriminate dumping, thus far, described. Many of its suburbs (i.e., including residential areas and public places) are littered with domestic and sewage waste, garbage, and chemical waste (Ezeudu and Ezeudu, 2019). Industrial operation is characterized by the generation of large volume of waste in the form of solid, liquid and gas. As a result, the Edo State Waste Management Board (EWMB), established by the local authorities, put in place a monitoring program to regulate environmental quality and implement steps towards a waste-free society. Despite its efforts, Benin City still falls short of achieving Board benchmark levels and ongoing waste management practices are needed. Street cleaners play a major role in cleaning the environment (Adekola *et al*., 2021)

Less is known about the hazards and health effects of street cleaning, and there are no general regulations in this field. Like waste and compost workers, street cleaners are physically stressed and exposed to bioaerosols, which can cause musculoskeletal and respiratory symptoms. When cleaning public facilities or emptying garbage cans, they may suffer from cut injuries, skin irritations and infections. Because they mostly work outdoors, they are exposed to cold, wind or heat (Hoffmeyer *et al*., 2014). Environmental/traffic pollution (dust, particulate matter, ozone, carbon monoxide, nitrogen oxides) and natural UV exposure have to be taken into account as well. In most countries, regardless of whether these are developing, emerging or industrialized countries, street cleaning is predominantly done by hand sweeping by an individual worker or a group. Sweeping can be done with push brooms, as is often the case in developing countries, or mechanically, e.g., by using leaf blowers. However, street cleaners also work with sweepers, machines and mowers or gritting vehicles. In general, activities of street cleaners and the associated health hazards seem to be very complex. According to a study by Johncy *et al*. (2014), street sweeping is one of the most popular occupations of less privileged people in India. Also in a Nigerian study, about 30% of street sweepers never had any formal education (Wahab and Ogunlola, 2014). Most of the street cleaners have little knowledge on occupational health hazards and safety, e.g., regarding the transmission of infections (Munubi and EHS, 2017). While developed countries take measures to prevent occupational health hazards, this is not the case in developing countries (Johncy *et al*., 2014). In Nigeria, street sweepers often use only short-handled brooms and take no precautionary measures, such as wearing face masks or sprinkling water on the street before sweeping, to minimize dust exposure (Wahab and Ogunlola, 2014).

Haematology is a branch of medical science concerned with the study of the blood, its cellular components, and the blood-forming organs. It focuses on analyzing the quantity and structural characteristics (morphology) of the different blood cells, which include red blood

cells (also known as erythrocytes), white blood cells (leucocytes), and platelets (thrombocytes). Haematological investigations are necessary for identifying a wide range of disorders, including infections, anaemia, blood cancers, and clotting abnormalities. They also serve to evaluate the extent of physiological or pathological damage to the blood system (Togun *et al*., 2007). They are reliable indicators of an individual's overall health and physiological status. These parameters provide valuable information into the functioning of the circulatory and immune systems, and are often reflective of the body's response to internal or external stressors (Etim *et al*. (2014). Furthermore, haematological parameters are closely associated with the blood and the organs responsible for its formation, such as the bone marrow and lymphatic system (Bamishaiye *et al*., 2009). Individuals such as street cleaners, who are regularly exposed to environmental contaminants, may experience changes in their blood profile. These changes, detectable through haematological analysis, can provide early warning signs of infection, toxicity, or systemic stress resulting from their occupational environment (Van Kampen *et al*., 2020).

Haemorrheology is the study of how blood flows through the vessels, focusing on the physical and mechanical properties of blood and its components, especially red blood cells and plasma (Alexy *et al*., 2022). Two key haemorrheological parameters are fibrinogen and erythrocyte sedimentation rate (ESR) (Alexy *et al*., 2022). Fibrinogen is a plasma protein that plays an important role in blood clotting and significantly affects blood viscosity. High levels of fibrinogen are often linked to inflammation and an increased risk of cardiovascular disease (Kattula *et al*., 2017). ESR measures how quickly red blood cells settle at the bottom of a test tube in one hour, serving as a general marker of inflammation in the body (Kulkarni and Deep, 2020). For street cleaners, who are regularly exposed to dust, pollutants, and harmful environmental agents, these parameters can be particularly relevant. Prolonged exposure to such conditions can trigger inflammatory responses in the body, which may be reflected in

elevated fibrinogen levels and ESR. Regular monitoring of these indicators in street cleaners can help assess their health status and identify any early signs of inflammation or other health risks (Van Kampen *et al*., 2020).

In Benin City, Edo State, street cleaners often work long hours under challenging conditions, with limited access to personal protective equipment (PPE) or health monitoring services (Edo State Waste Management Board, 2022). Given their constant exposure to various environmental pollutants, it is imperative to investigate the potential impact on their haematological and haemorheological profiles. Such an investigation can provide crucial insights into the health risks faced by this vulnerable occupational group and inform public health interventions.

To ensure the ethical conduct of this study, approval will be obtained from the Ethics Committee of the Ministry of Health, Benin City, Edo State. All participants will be fully informed about the study's objectives, procedures, potential risks, and benefits, and written informed consent will be obtained prior to participation. Participation will be entirely voluntary, with the option to withdraw at any time, and strict confidentiality will be maintained throughout the study. Data collection will involve administering structured questionnaires to gather socio-demographic information, occupational history, and lifestyle factors. Blood samples will be collected under sterile conditions using EDTA anticoagulant tubes for haematological analysis and plain tubes for fibrinogen estimation. Haematological parameters will be measured using an automated haematology analyzer, while haemorheological parameters such as erythrocyte sedimentation rate and fibrinogen concentration will be assessed using standardized laboratory methods. All collected data will be securely stored and managed using unique identification codes to ensure privacy. Statistical analysis will be performed using SPSS software, with descriptive statistics

summarizing the data and inferential tests applied to examine associations between occupational exposure and haematological or haemorheological changes.

1.2. Statement of Problem

Despite the essential role street cleaners play in urban settings, there is a significant gap in the literature regarding their health and well-being, specifically concerning haematological changes. Studies have primarily focused on musculoskeletal injuries and other occupational hazards, largely neglecting potential alterations in blood parameters as a result of prolonged exposure to environmental toxins and physical stressors. For instance, research shows that similar occupational roles are at risk of developing respiratory and cardiovascular complications due to exposure to particulate matter and toxic pollutants, but comprehensive studies focusing on haematological implications among street cleaners remain sparse (Jørgensen *et al*., 2011; Yunoos and Dankoly, 2021).

The prolonged exposure to a mixture of pollutants, including heavy metals, particulate matter, and chemical fumes, can potentially induce oxidative stress, inflammation, and direct toxicity to blood cells and plasma components (Popescu *et al*., 201; Kassenga *et al*., 2018). These insidious changes may not manifest as immediate clinical symptoms but can contribute to chronic health problems, including anaemia, immune dysregulation, or increased cardiovascular risk over time. Without specific data on the haematological and haemorheological status of street cleaners in Benin City, it is challenging to assess the full extent of their occupational health burden and develop targeted preventive measures.

To ensure ethical compliance, approval for this study will be obtained from the Ethics Committee of the Ministry of Health, Benin City, Edo State. Participants will receive clear information about the study's purpose, procedures, potential risks, and benefits, and written informed consent will be obtained. Participation will be voluntary, with the option to withdraw at any time, and confidentiality will be strictly maintained. Data will be collected

using structured questionnaires capturing socio-demographic characteristics, occupational history, and lifestyle factors. Blood samples will be collected under sterile conditions for haematological and haemorheological analyses, including full blood count, erythrocyte sedimentation rate, and fibrinogen concentration, using standardized laboratory methods. All data will be securely stored with unique identification codes to protect participant privacy. Statistical analysis will be conducted using SPSS software, employing descriptive statistics and inferential tests to explore associations between occupational exposure and haematological or haemorheological changes.

To ensure the ethical conduct of this study, approval will be obtained from the Ethics Committee of the Ministry of Health, Benin City, Edo State. All participants will be fully informed about the study's objectives, procedures, potential risks, and benefits, and written informed consent will be obtained prior to participation. Participation will be entirely voluntary, with the option to withdraw at any time, and strict confidentiality will be maintained throughout the study. Data collection will involve administering structured questionnaires to gather socio-demographic information, occupational history, and lifestyle factors. Blood samples will be collected under sterile conditions using EDTA anticoagulant tubes for haematological analysis and plain tubes for fibrinogen estimation. Haematological parameters will be measured using an automated haematology analyzer, while haemorheological parameters such as erythrocyte sedimentation rate and fibrinogen concentration will be assessed using standardized laboratory methods. All collected data will be securely stored and managed using unique identification codes to ensure privacy. Statistical analysis will be performed using SPSS software, with descriptive statistics summarizing the data and inferential tests applied to examine associations between occupational exposure and haematological or haemorheological changes.

1.3. Justification of Study

Street cleaners in Benin City are routinely exposed to various environmental hazards such as dust, vehicle emissions, biological waste, and toxic substances, all of which pose significant health risks. Despite their critical role in maintaining public hygiene, the occupational health of street cleaners is often neglected. Continuous exposure to pollutants and pathogens can negatively affect their blood system, leading to potential haematological and haemorrheological alterations. Evaluating these parameters among street cleaners is essential to identify any subclinical health effects caused by their occupational exposure. This study will provide evidence-based data on the health status of street cleaners and help inform targeted interventions, routine medical surveillance, and policy recommendations aimed at protecting the health of this vulnerable population.

1.4. Aim of Study

The aim of this study is to evaluate the hematological and haemorrheological changes in street cleaners in Benin city.

1.5. Specific Objectives

1. To assess selected the haematological parameters of street cleaners in Benin City.
2. To determine the value of selected haemorheological parameters in street cleaners in Benin City.
3. To compare the value of selected haematological and haemorheological parameters of street cleaners with those of a control group.
4. To explore the correlation between haematological and haemorheological changes among street cleaners.

1.6. Research Questions

1. Are the haematological parameters of street cleaners different from the unexposed control group?

2. Are the haemorrheological parameters of street cleaners different from the unexposed control group?
3. Is there a correlation between haematological and haemorheological changes among street cleaners?

1.7. Research Hypothesis

1.7.1. Null Hypothesis (H_0)

There is no significant difference in haematological and haemorrheological parameters between street cleaners and the control group in Benin City.

1.7.2. Alternate Hypothesis (H_A)

There is a significant difference in haematological and haemorrheological parameters between street cleaners and the control group in Benin City.

CHAPTER TWO

LITERATURE REVIEW

2.1. Street Cleaners

Street cleaners, often referred to as sanitation workers, municipal sweepers, or environmental health workers, are essential members of any urban workforce (Alie *et al*., 2023). They are responsible for maintaining cleanliness in public spaces by removing litter, sweeping roads and sidewalks, clearing gutters and drains, and ensuring that waste is properly collected and disposed of (Van Kampen, 2020). Though their work is frequently overlooked, it plays a central role in sustaining the health, safety, and functionality of cities. These workers are typically employed by municipal authorities or contracted waste management companies, and their duties can range from manual street sweeping and waste collection to operating street cleaning machines and responding to environmental emergencies like blocked storm drains or illegal waste dumping (Nyanza *et al*., 2024). The importance of street cleaners extends far beyond simply keeping areas visually tidy. Their daily efforts directly impact urban sanitation and public health by helping to reduce the accumulation of waste that can attract pests and promote the spread of disease (Kabir *et al*., 2015). In densely populated areas, especially, uncollected garbage and clogged drains can lead to major public health hazards such as cholera, typhoid, malaria, and other vector-borne diseases (Tolera *et al*., 2023). By ensuring streets and public areas remain free of refuse and debris, street cleaners help create healthier living environments for all urban residents, especially those in overcrowded or underserved communities where formal waste systems may be lacking or inconsistent (Kabir *et al*., 2015).

Figure 2.1. Street Cleaners (Kabir *et al*., 2015).

2.1.1. Roles and Responsibilities of Street Cleaners

Street cleaners are essential to the smooth functioning of urban life, and their roles go far beyond simply sweeping streets. On a daily basis, they are responsible for cleaning roads, pavements, public markets, and communal spaces, ensuring these areas remain free from litter, dust, and organic waste that can cause unpleasant odors or attract pests (Benito *et al*., 2021). This routine cleaning helps maintain a clean and visually appealing environment, but it also plays a crucial role in preventing the spread of disease and reducing environmental pollution (Van Kampen *et al*., 2020). Street cleaners also take on the task of waste collection and segregation, often handling waste directly by collecting it in carts or bins and ensuring that recyclables are properly separated from non-recyclables (Hughes *et al*., 2017). This contributes significantly to local recycling efforts and efficient waste management systems. Beyond these daily tasks, they are called upon during special occasions and emergencies (Slutskaya *et al*., 2016). For example, during festive periods or public events, when large crowds generate unusually high amounts of waste, street cleaners often work extended hours to keep areas clean and safe. Similarly, after heavy rainfall, windstorms, or other environmental events, they clear fallen leaves, branches, or debris to ensure that roads and drains remain unobstructed (Mitchell *et al*., 2019).

2.1.2. Occupational Challenges of Street Cleaning

- **Exposure to Dust, Waste, Infectious Materials:** Street cleaners are constantly exposed to various health hazards as part of their daily work. They handle unsegregated waste, which may include sharp objects, rotting food, animal droppings, medical refuse, and other potentially infectious materials (Van Kampen *et al*., 2020). Prolonged exposure to dust and pollutants in high-traffic areas can also lead to respiratory issues such as chronic bronchitis, asthma, and other lung conditions (Park *et al*., 2020). Since many works without proper protective equipment like gloves,

masks, or boots, they are at increased risk of contracting skin infections, gastrointestinal diseases, and vector-borne illnesses. The lack of routine health check-ups or vaccinations further increases their vulnerability, making this a serious but often overlooked public health concern (Van Kampen *et al*., 2020).

- **Physical Strain and Fatigue:** Street cleaning is physically demanding and involves long hours of bending, lifting, walking, and pushing heavy carts or bins, often under harsh weather conditions. Workers may have to start early in the morning or work late at night to avoid obstructing traffic and to cover more ground (Lessa *et al*., 2022). The repetitive nature of these tasks puts immense strain on their muscles and joints, especially the back, knees, and shoulders (Wahab and Ogunmola, 2014). Over time, many street cleaners suffer from chronic pain, fatigue, or musculoskeletal injuries without receiving adequate medical support or rest periods, affecting their overall well-being and productivity (Lessa *et al*., 2022).
- **Social Stigma and Low Public Recognition:** Despite their essential contribution to urban cleanliness and public health, street cleaners are often undervalued and socially marginalized. Many people view the profession as "dirty" or low-status, leading to discrimination or condescending attitudes. This social stigma can cause emotional distress and a lack of self-worth among workers (Hughes *et al*., 2017). They rarely receive appreciation or acknowledgement from the public or government authorities for their efforts, especially during high-risk situations like post-disaster clean-ups or health emergencies. The lack of social dignity not only affects their morale but also discourages younger people from considering this important work (Van Kampen *et al*., 2020).
- **Inadequate Pay and Limited Access to Welfare Programs:** Many street cleaners earn low wages that do not match the intensity or risk level of their jobs. A large

number are hired on a contract or casual basis, which means they lack job security, pensions, health insurance, or paid leave (Park *et al*., 2020). Even in cases where welfare schemes exist, bureaucratic hurdles or corruption often prevent workers from accessing them (Ng *et al*., 2018). The absence of adequate financial compensation and social protection leaves many street cleaners vulnerable to poverty, debt, and poor living conditions. Their families are also affected, with limited access to education, healthcare, or upward mobility (Deery *et al*., 2019).

2.2. Haemorheology

Hemorheology is the scientific study of the flow behavior and physical properties of blood and its cellular elements as they move through the circulatory system. It explores key parameters such as blood viscosity, red blood cell (RBC) deformability, RBC aggregation, and platelet function, all of which are essential for maintaining adequate tissue perfusion and oxygen delivery (Baskurt and Meiselman, 2003). A primary concept in hemorheology is blood viscosity, which refers to the thickness of blood and its resistance to flow. When blood viscosity increases beyond normal levels, it impedes flow through the microvasculature and reduces oxygen delivery to tissues (Javadi and Jamali, 2021). Equally important is RBC deformability. Under physiological conditions, RBCs are highly flexible, allowing them to traverse narrow capillaries. A reduction in deformability leads to impaired microcirculation and diminished tissue oxygenation (Baskurt, 2007).

RBC aggregation, particularly under low shear stress, can increase flow resistance and contribute to sluggish circulation. This aggregation may exacerbate vascular complications in inflammatory and metabolic diseases (Trejo *et al*., 2022). Platelets also influence blood flow by their aggregation and activation. While necessary for haemostasis, excessive platelet activity may promote thrombosis and impair perfusion. Several physiological and pathological factors affect hemorheological properties (Wang and Zennadi, 2020). These

include haematocrit levels, plasma protein composition, temperature, pH, and the presence of systemic inflammation. Hemorheological abnormalities are frequently observed in conditions such as diabetes mellitus, hypertension, and atherosclerosis, and they contribute significantly to cardiovascular morbidity and mortality (Lo Presti *et al*., 2014).

2.2.1. Haemorrheological Response

Haemorrheological response refers to the changes in the flow properties of blood in response to various physiological or pathological conditions. These responses can occur due to alterations in blood viscosity, flow resistance, or other factors that influence blood flow (Nadar *et al*., 2019).

1. Inflammatory conditions are known to cause alterations in haemorrheological properties. This is due to the action of inflammatory mediators and the clumping of red blood cells, which increase blood viscosity. Thus, blood flow may be hindered, potentially worsening the course of inflammatory disorders (Wright and Frier, 2008).
2. Hemodilution: Hemodilution involves a reduction in blood viscosity resulting from either an expansion in plasma volume or a decrease in red blood cell concentration. This effect is commonly seen during medical treatments like fluid replacement or transfusions. The purpose is to enhance circulation by lowering blood viscosity and reducing resistance to flow (Crystal *et al*., 2014).
3. Exercise: Engaging in physical activity triggers haemorrheological changes to support the heightened demand for oxygen and nutrients. This includes increased blood circulation and dilation of blood vessels within the working muscles. Such adaptations promote effective oxygen transport and waste removal. Moreover, exercise can cause a temporary drop in blood viscosity, which further supports efficient circulation and cardiovascular performance (Ivanov, 2022).

4. Hyper viscosity syndrome: Medical disorders like polycythemia and multiple myeloma can result in a condition known as hyper viscosity syndrome, where blood becomes abnormally thick due to elevated red blood cell levels or the presence of atypical plasma proteins. This condition disrupts normal blood flow and may manifest with symptoms such as dizziness and fatigue (Caimi and Carlisi, 2023).
5. Ischemia and reperfusion injury: Ischemia occurs when a tissue or organ receives insufficient blood supply, often leading to tissue injury. Once circulation is restored haemorrheological disturbances can arise. These include alterations in blood flow characteristics, an increase in viscosity, and the generation of reactive oxygen species, all of which may contribute to additional cellular damage (Kalogeris *et al*., 2016).

2.2.2. Factors Affecting Blood Viscosity

2.2.2.1. Shear Rate

Shear rate, defined as the rate at which adjacent layers of fluid move with respect to each other, is one of the most significant determinants of blood viscosity. Blood is a non-Newtonian fluid, meaning its viscosity is not constant and varies with shear rate (Schmid, 2019). At low shear rates, such as during diastole or in venous circulation, red blood cells (RBCs) tend to aggregate, forming rouleaux structures that increase resistance to flow and raise blood viscosity. Conversely, at high shear rates, such as during systole or in arterioles and capillaries, these aggregates are disrupted, and red blood cells deform and align with the direction of flow, leading to a marked reduction in viscosity (Beris *et al*., 2021). This shear-thinning property of blood is crucial for maintaining optimal tissue perfusion and preventing vascular complications. Abnormalities in shear-dependent viscosity may contribute to the pathogenesis of various circulatory disorders (Gogia and Neelamegham, 2015).

2.2.2.2. Temperature

Temperature has a direct inverse relationship with blood viscosity. As temperature increases, the viscosity of blood decreases due to reduced intermolecular forces and increased kinetic energy of plasma and cellular elements, which enhances fluidity (Alexy *et al*., 2022). This is why hypothermic conditions, such as during cold exposure or cardiac surgery with induced hypothermia, can lead to a significant rise in blood viscosity, posing risks for microvascular perfusion and clot formation (Elogail and Mekheimer, 2020). In contrast, fever or localized inflammation may slightly lower blood viscosity, although the presence of inflammatory proteins may counteract this effect (Alexy *et al*., 2022). Temperature-induced changes in blood viscosity can impact oxygen delivery and capillary perfusion, making temperature control a vital aspect of clinical care, especially in surgical settings (Koriko *et al*., 2024).

2.2.2.3. pH and Ionic Strength

Blood viscosity is also influenced by the pH and ionic strength of the plasma, which affect the charge and interactions of plasma proteins and blood cells. Under physiological conditions, red blood cells carry a net negative charge (zeta potential) that promotes electrostatic repulsion and reduces aggregation (Rodrigues *et al*., 2022). A drop in pH (acidosis) or alteration in ionic strength can reduce the zeta potential, promoting cell aggregation and increasing viscosity. Furthermore, changes in ionic strength, such as variations in sodium, calcium, or chloride concentrations, can influence plasma protein conformation and fibrinogen levels, enhancing red cell aggregation and plasma viscosity (Ho *et al*., 2018). These changes are particularly relevant in pathological states like metabolic acidosis, dehydration, or electrolyte imbalance, where increased blood viscosity can contribute to impaired tissue perfusion and organ dysfunction (Bychkova *et al*., 2022).

2.3. Erythrocyte Sedimentation Rate (ESR)

The Erythrocyte Sedimentation Rate (ESR) is a simple, inexpensive, and widely used haematological test that provides insight into the presence and intensity of inflammation in

the body. It measures the distance in millimeters that red blood cells (erythrocytes) fall or settle in a vertical tube of anticoagulated blood over the course of one hour (Simeon *et al*., 2024). Though it does not diagnose a specific disease, it serves as an indirect measure of the acute-phase response and is particularly helpful in monitoring the progression or resolution of inflammatory conditions (Lapic *et al*., 2020). The test is most valuable when used alongside other clinical and laboratory findings, as it reflects general inflammation rather than pinpointing a precise pathological process (Diamanti *et al*., 2025).

2.3.1. Principle and Mechanism of ESR

The ESR test operates on the principle of sedimentation, where red blood cells settle under the influence of gravity when suspended in plasma. In healthy individuals, red blood cells maintain a negative surface charge (zeta potential) which causes them to repel each other and remain suspended in plasma (Kahar, 2022). However, in the presence of acute-phase reactants, most notably fibrinogen and various immunoglobulins the zeta potential is reduced, allowing red blood cells to stick together in stacks known as "rouleaux formations (Grover *et al*., 2016)." These rouleaux are denser and sediment faster, resulting in a higher ESR reading. Therefore, the test indirectly measures the level of inflammation by observing how rapidly erythrocytes settle in a given period (Vassillieva *et al*., 2022).

2.3.2. Methodology and Procedure

The ESR is typically measured using one of two standard methods: the Westergren method or the Wintrobe method (Hashemi *et al*., 2015). The Westergren method is considered the gold standard due to its higher sensitivity. In this method, blood is mixed with an anticoagulant (usually sodium citrate) and placed in a calibrated Westergren tube, which is allowed to stand vertically undisturbed for 60 minutes. The distance that the red blood cells fall from the plasma surface is then measured in millimeters (Schapkaitz *et al*., 2019). The Wintrobe method, on the other hand, uses a shorter tube and undiluted blood, but is less sensitive and

thus less commonly used in clinical practice today. Proper technique, room temperature, and vertical positioning of the tube are crucial for accurate results (Quinn *et al*., 2016).

2.3.3. Factors Affecting ESR

Physiological and pathological factors can influence the ESR value. Physiologically, ESR increases with age and is generally higher in females compared to males, especially during menstruation and pregnancy due to elevated plasma proteins (Siemons *et al*., 2014). Anaemia by lowers the viscosity of blood, thus accelerating sedimentation and increasing ESR. However, conditions like polycythaemia vera, which involve an increased red blood cell mass, slow down sedimentation and lower ESR (Nersesjan *et al*., 2020). Technical factors, such as temperature, tube angle, and timing errors, can also alter ESR readings. It's essential that all procedural steps be standardized to ensure valid results (Brun *et al*., 2018).

2.3.4. Clinical Significance of ESR

Although ESR is a non-specific test, it has significant clinical utility in the detection and monitoring of inflammatory, infectious, and neoplastic conditions. For example, a markedly elevated ESR is often observed in conditions such as temporal arteritis, polymyalgia rheumatica, tuberculosis, rheumatoid arthritis, and systemic lupus erythematosus (Alharthi *et al*., 2024). It is also used to monitor the activity of chronic diseases (rising levels may indicate flare-ups, while declining levels may suggest a positive response to treatment). In cancer patients, a persistently high ESR may suggest disease progression or metastasis (Ebner *et al*., 2025). It is important to note that a normal ESR does not rule out serious pathology, and an elevated ESR should always be interpreted in the clinical context (Kahar, 2022).

2.3.5. Limitations of ESR

Despite its usefulness, the ESR test has several limitations. Its major drawback is lack of specificity as many unrelated conditions can cause elevated results, including infections, autoimmune diseases, malignancies, and even physiological states like pregnancy (Orr *et al*.,

2018). It is also a slow-reacting test; ESR may remain elevated for days or weeks even after an inflammatory stimulus has resolved, reducing its utility in monitoring acute changes. Moreover, the test can be falsely low in certain conditions such as extreme Leukocytosis or sickle cell anaemia, where the shape of the red blood cells hinders rouleaux formation (Kratz *et al*., 2017). Therefore, ESR should never be used as a standalone diagnostic tool but rather with history, physical examination, and laboratory findings (Militello *et al*., 2020).

2.4. Fibrinogen

Fibrinogen is a vital blood plasma protein synthesized by the liver, playing a central role in the body's ability to form clots and control bleeding (Litinov *et al*., 2020). As a key participant in the coagulation cascade, fibrinogen helps halt blood loss and initiates tissue repair. When injury occurs to a blood vessel, it activates a chain of biochemical events that ultimately transform fibrinogen into fibrin (Kohler *et al*., 2015). This transformation is driven by the enzyme thrombin, which cleaves fibrinogen molecules to release fibrinopeptides. This cleavage exposes binding sites that enable the formation of insoluble fibrin strands, which interlace to form the structural meshwork of a blood clot (Vilar *et al*., 2020). These fibrin threads trap platelets and blood cells, creating a firm and stable clot essential for sealing wounds (Medved and Weisel, 2022). Fibrinogen concentrations in the bloodstream can shift depending on physiological or pathological conditions. Elevated levels are often associated with an increased likelihood of thrombosis, while reduced levels are seen in cases of liver dysfunction, major haemorrhage, or inherited deficiencies (Moerloose *et al*., 2010). Fibrinogen is routinely assessed in clinical practice to evaluate bleeding or clotting tendencies. This is typically done using tests like the fibrinogen activity assay or antigen measurement to determine both quantity and functional capacity (Mackie *et al*., 2024).

2.4.1. Structure of Fibrinogen

Fibrinogen is a structurally intricate protein composed of six polypeptide chains arranged in three distinct pairs: Aα, Bβ, and γ chains. Each chain plays a specific role in the clotting process and contributes to the overall architecture of the fibrinogen molecule. The Aα chain, the longest of the three, contains about 610 amino acids and is subdivided into multiple regions, including an N-terminal segment, a coiled-coil region, a central portion, and a C-terminal end. This chain is especially important in the formation and stabilization of fibrin clots (Soria *et al*., 2019). The Bβ chain, made up of around 461 amino acids, also contains several domains similar to those of the Aα chain and is essential for the proper assembly and structure of the fibrin network (Wolberg, 2023; Nencini *et al*., 2024). The γ chain, the shortest at approximately 411 amino acids, is less structurally complex but plays a pivotal role in linking fibrin strands side-by-side during clot maturation (Sovová *et al*., 2020). These three pairs of chains are joined through disulphide bonds, forming a symmetrical, rod-shaped molecule (Soria *et al*., 2019). The Aα and Bβ chains are joined at their C-terminal ends to form dimeric units, and these units are further connected via disulphide bridges in the central region of the molecule, completing the dimeric structure (Mosesson, 2005). During blood clotting, thrombin enzymatically cleaves specific sites on the Aα and Bβ chains, releasing fibrinopeptides and converting fibrinogen into fibrin monomers. These monomers then self-assemble into a three-dimensional fibrin matrix, with the γ chains facilitating the side-to-side linkage of fibrin strands. This cross-linking process results in the formation of a strong, stable fibrin network that underpins the integrity of a mature blood clot (Mosesson, 2005).

2.4.2. Fibrinogen and Haemorheology

Fibrinogen, a soluble protein present in blood plasma, can function as a valuable hemorheological biomarker under certain conditions. Beyond its well-known role in the coagulation cascade as the precursor to fibrin, which forms the backbone of blood clots,

fibrinogen also influences the physical properties of blood before clotting even occurs (Singh *et al*., 2025). In its soluble state, fibrinogen can increase blood viscosity, which refers to the thickness or resistance of blood to flow (Kell *et al*., 2022). When fibrinogen levels are elevated, the resulting rise in viscosity may hinder circulation and elevate the risk of thrombotic events (Zuliani and Midwood, 2015). Fibrinogen also serves as a linking agent that encourages red blood cells (RBCs) to clump together. This aggregation alters the fluid dynamics of blood, increasing viscosity and potentially disrupting microvascular flow (Weisel, 2005). Furthermore, elevated fibrinogen levels have been connected to endothelial dysfunction, which is an impairment in the function of the vascular lining. This dysfunction contributes to abnormal blood flow regulation and favours conditions that promote clot formation, thereby affecting hemorheological balance (Ellins *et al*., 2017). Tracking fibrinogen concentrations in the bloodstream can yield important insights into an individual's hemorheological profile. High fibrinogen levels have been linked to various cardiovascular and inflammatory disorders such as hypertension, systemic inflammation, and atherosclerosis. Therefore, measuring fibrinogen may help in evaluating thrombotic risk, anticipating cardiovascular events, and monitoring disease development or treatment effectiveness (Kressel *et al*., 2009).

2.4.3. Fibrinogen and Inflammation

A growing body of scientific evidence emphasizes the important role that fibrinogen and its degradation products play in regulating inflammation in various tissues (Adams *et al*., 2007). Increased levels of fibrinogen in the bloodstream, even before it moves out of the vessels into surrounding tissues, are recognized as indicators of a proinflammatory condition. These elevated levels are also considered early warning signs for the development of vascular inflammatory diseases such as hypertension and atherosclerosis (Makris *et al*., 2018). Similarly, high concentrations of fibrin breakdown products, such as D-dimer, are widely

used in clinical settings as markers of inflammation. They are also indicators of increased clotting activity and help in predicting the likelihood of thrombotic complications (Greaves and Pula, 2025). Furthermore, peptides that are released during fibrin formation, including fibrinopeptide B, which is cleaved from fibrinogen by thrombin, can act as chemical signals that attract immune cells like leukocytes. These peptides can directly influence inflammatory responses (Hasselbalch *et al*., 2023). In many cases, the inflammatory actions of fibrinogen and its fragments are linked to their ability to interact with and activate various immune cells through specific receptor-ligand interactions (Zapata *et al*., 2022). Importantly, these inflammatory processes occur through molecular binding sites that are different from those used in the blood clotting pathway (Hasselbalch *et al*., 2023).

2.4.4. Fibrinogen as an Acute Phase Protein

Fibrinogen is classified as an acute-phase protein and plays a significant role in the body's defense mechanisms during inflammation and tissue damage (Obeagu *et al*., 2022). Acute-phase proteins are a group of plasma proteins whose concentrations fluctuate in response to systemic disturbances such as infection, trauma, or inflammation. These proteins are primarily produced in the liver and form a part of the innate immune system's early response to harm (Hayakawa, 2017). When the body encounters infection or injury, it initiates a rapid and coordinated defense known as the acute-phase response. During this process, inflammatory mediators such as cytokines are released in response to harmful stimuli. Among these cytokines, interleukin-6 (IL-6) plays a central role in triggering the production of acute-phase proteins (Obeagu *et al*., 2022). IL-6 stimulates liver cells, known as hepatocytes, to increase the synthesis and release of fibrinogen into the bloodstream. This rise in fibrinogen levels contributes to several protective functions during periods of inflammation and tissue repair (Zhuo *et al*., 2016). A major role of fibrinogen in this response is its involvement in blood clot formation. As a precursor to fibrin, fibrinogen is transformed into

an insoluble protein by the enzyme thrombin when injury occurs (Smith *et al*., 2015). The resulting fibrin threads form a web-like structure that stops bleeding and supports tissue healing (Hulshof *et al*., 2021). Beyond its role in coagulation, fibrinogen also contributes to immune activity during inflammation. It provides a structural platform that assists immune cells in reaching the site of infection or injury. By interacting with various immune components, fibrinogen influences immune cell behavior and enhances the inflammatory response (Smith *et al*., 2015). Clinically, measuring fibrinogen levels can offer useful information about inflammatory activity in the body. When combined with other markers such as C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR), elevated fibrinogen levels can help detect inflammation and assess its severity. Tracking changes in fibrinogen concentration over time is also helpful in evaluating the progression of inflammatory conditions or monitoring the effectiveness of treatment (Kattula *et al*., 2017).

2.4.5. Fibrinogen to Platelet Ratio

The fibrinogen-to-platelet ratio (FPR) has emerged as a possible hemorheological indicator in certain clinical contexts. This ratio combines the levels of fibrinogen and platelet count to reflect the interaction between clotting activity and platelet function, both of which impact blood flow properties (Lin *et al*., 2021). The concept behind using FPR as a biomarker is based on the critical relationship between fibrinogen and platelets in maintaining haemostasis and regulating circulation. An elevated FPR has been linked to a higher risk of cardiovascular complications, including heart attacks and strokes, and may indicate underlying inflammation and a greater likelihood of thrombosis in such conditions (Zhuo *et al*., 2016). Additionally, FPR has been studied in the context of inflammatory diseases like rheumatoid arthritis and systemic lupus erythematosus, where both fibrinogen levels and platelet activity tend to be increased. In these cases, the FPR may offer insight into disease severity and the potential for vascular problems (Hulshof *et al*., 2021).

2.5. Haemorrheological Alterations in Disease States

2.5.1. Cardiovascular Diseases

In cardiovascular diseases such as hypertension and atherosclerosis, haemorrheological properties of blood are often significantly altered. Increased blood viscosity can result from elevated haematocrit levels, reduced red blood cell deformability, and increased plasma fibrinogen. These changes increase resistance to blood flow, contributing to higher vascular pressure and potentially impairing tissue perfusion (Valeanu *et al*., 2020). In atherosclerosis, the thickened arterial walls and narrowed vessels further exacerbate these issues, making blood flow more turbulent and inefficient. This adds strain to the heart and can accelerate the progression of vascular damage (Roy and Chakraborty, 2024).

2.5.2. Diabetes mellitus

Diabetes mellitus is associated with multiple haemorrheological abnormalities, including increased blood and plasma viscosity, elevated levels of fibrinogen, and impaired red blood cell deformability. Hyperglycaemia can lead to glycation of plasma proteins and membrane structures, reducing the flexibility of red blood cells and promoting aggregation. These changes hinder microcirculatory flow and oxygen delivery to tissues, which contributes to diabetic complications such as retinopathy, nephropathy, and peripheral vascular disease. Insulin resistance and chronic inflammation also play a role in these haemorrheological disturbances (Obeagu, 2024).

2.5.3. Sickle Cell Disease

Sickle cell disease is a classic example of a condition where blood rheology is severely compromised. The abnormal haemoglobin in sickle cells causes red blood cells to become rigid and crescent-shaped under deoxygenated conditions. These misshapen cells are less deformable, more adhesive, and prone to forming aggregates that obstruct capillaries (Nader *et al*., 2019). As a result, blood viscosity can be unpredictably elevated during crises, leading

to ischemia, pain episodes, and organ damage. Chronic haemolysis and inflammation further disrupt the rheological balance, creating a vicious cycle of vascular injury (Lu *et al*., 2020).

2.5.4. Inflammatory and Infectious Conditions

In various inflammatory and infectious diseases, changes in blood rheology are commonly observed. During inflammation, the release of cytokines increases the concentration of acute-phase reactants such as fibrinogen and C-reactive protein. These proteins elevate plasma viscosity and promote red blood cell aggregation (Grover *et al*., 2016). Infections may also stimulate white blood cell proliferation and alter red blood cell morphology, further affecting flow characteristics. These changes can impair microvascular perfusion and exacerbate tissue hypoxia, which complicates recovery and increases the risk of organ dysfunction (Grover *et al*., 2016).

2.5.5. Cancer

Cancer can induce profound haemorrheological changes due to both the disease itself and the effects of treatments such as chemotherapy. Tumors often secrete pro-inflammatory cytokines and clotting factors, which elevate plasma viscosity and fibrinogen levels (Kaur *et al*., 2022). Cancer cells may also disrupt the normal balance of blood components by invading bone marrow or stimulating the production of abnormal cells. Increased blood viscosity and coagulability raise the risk of thromboembolic events, which are common complications in many types of malignancy (Ositadinma *et al*., 2015).

2.5.6. Stroke and cerebrovascular disorders

In stroke and related cerebrovascular disorders, blood rheology plays a key role in determining the extent of damage and recovery potential. Increased blood viscosity, especially when combined with reduced red blood cell deformability, can compromise cerebral perfusion. This is particularly critical in ischemic stroke, where adequate oxygen delivery is already impaired. Elevated fibrinogen levels and platelet aggregation may promote

clot formation, while sluggish microcirculatory flow can prolong ischemic injury (Song *et al*., 2017).

2.6. Haematological Parameters

Blood is a crucial circulatory tissue consisting of cells suspended in plasma, and it plays a fundamental role in maintaining the body's internal stability (Isaac *et al*., 2013). Haematological parameters, which include red blood cells and their indices, white blood cells, and platelets, are measurable elements that originate from haematopoietic stem cells. At birth, the bone marrow is highly active in producing these blood cells. However, as a person grows older, the marrow gradually transforms into fatty tissue, which can influence blood cell production and related parameters. Monitoring these haematological values is essential because they provide important information about the immune system. They also assist in making informed treatment decisions and in tracking both disease progression and response to therapy, which contributes to effective patient management (Azuonwu *et al*., 2017).

2.6.1 Red blood cells

Erythrocytes, or red blood cells, are the primary cellular component of blood and are noted for their flexible, biconcave shape (Fischbach, 2003). This unique shape increases their surface area, allowing for effective oxygen delivery to various tissues and organs throughout the body. The average human body contains around 5 liters of blood, with red blood cells making up about 2 liters of this volume (Fischbach, 2003). Each litre of blood typically contains approximately 5 trillion red blood cells, although this number can vary based on factors such as health status, age, and sex. These cells are produced in the bone marrow and usually remain in circulation for about 120 days before being removed and replaced by newly formed erythrocytes (Cheesbrough, 2006).

Figure 2.2. Red Blood Cell Structure (Isaac *et al*., 2013).

2.6.2 Packed cell volume (PCV)

Packed cell volume, also referred to as haematocrit (HCT) or erythrocyte volume fraction (EVF), represents the proportion of red blood cells in the blood expressed as a percentage. PCV plays an essential role in the transport of oxygen and nutrients absorbed by the body. The normal PCV range is 40 to 52 percent for males and 36 to 48 percent for females (Hoffbrand *et al*., 2016).

2.6.3 Haemoglobin

Haemoglobin is an iron-containing metalloprotein present in red blood cells responsible for carrying oxygen. It imparts the red color to the cells (Fischbach, 2003) and primarily functions to deliver oxygen to body tissues while transporting carbon dioxide back from the tissues to the lungs (Hoffbrand *et al*., 2016). Normal range of Haemoglobin in males is 135-175g/L and females 115-155g/L (Hoffbrand *et al*., 2016).

2.6.4 Platelets

Platelets, also known as thrombocytes, are the smallest blood cells. They lack a nucleus and have a circular, flattened disk-like shape. Platelets are vital for blood clotting, preserving the integrity of blood vessels, and aiding in vasoconstriction. Their average lifespan is about 7.5 days. Platelet count is an important component of the coagulation profile (Fischbach, 2003).

Normal platelets count in adult is 140-400 × 10^9 10^9/L

Children: 150-450 × 10^9 10^9/L (Fischbach, 2003).

2.6.4.1. Mean Platelet Volume (MPV)

Mean platelet volume (MPV) is a key haematological measurement that reflects the average size and size variation within a population of platelets in the blood. It provides insight into the uniformity or diversity of platelet sizes, which can be an important indicator of platelet production and activity (Fischbach, 2003). MPV is particularly useful in the clinical setting for helping to differentiate among various causes of thrombocytopenia, a condition

characterized by a low platelet count. Changes in MPV can suggest whether thrombocytopenia results from decreased platelet production in the bone marrow, increased destruction or consumption of platelets, or other underlying disorders (Hoffbrand *et al*., 2016). Mean platelet volume: Adults: 7.4- 10.4fL, Children: 7.4-10.4fL (Fischbach, 2003).

2.6.5. Red Cell Indices

2.6.5.1. Mean Cell Haemoglobin Concentration (MCHC)

The mean cell haemoglobin concentration gives the concentration of Haemoglobin in g/l of packed red cells. It is calculated from the haemoglobin (Hb) and PCV as follows:

$$\text{MCHC (g/l)} = \frac{(Haemoglobin\ in\ g/100m\ by\ l\ of\ blood)\ x100\ g/d}{Volume\ of\ packed\ cells/100ml\ of\ blood.}$$

Normal range for MCHC is between 315-360g/l (Cheesbrough, 2006).

Low MCHC values are associated with iron deficiency anaemia, thalassemia trait, while increase MCHC is associated marked spherocytosis which is rare (Cheesbrough, 2006).

2.6.5.2. Mean Cell Volume (MCV)

The mean red cell volume (MCV) provides information on red cell size. It is measured in femtolitres (fl) and is determined from PCV and obtained RBC count. It can be calculated as

$$\text{MCV} = \frac{(Volume\ of\ packed\ cells/100\ ml\ of\ blood)\ fl}{Red\ blood\ cell\ count\ in\ millions/ml}\ \text{(fl)}$$

Normal range is between 80-98fl low MCV values is found in microcytic anaemias such as iron deficiency anaemia, anaemia of chronic disease and thalassaemia while increased MCV value is found in macrocytic anaemia, marked reticulocytosis, and chronic alcoholism (Cheesbrough, 2006).

2.6.5.3. Mean Cell Haemoglobin (MCH)

The MCH gives the amount of haemoglobin in pictograms (pg) in an average red cell. It is calculated from the obtained haemoglobin and RBC count.

Normal range is 27-34 pg (Hoffbrand *et al*., 2016).

$$\text{MCH} = \frac{(Haemoglobin\ in\ g/100ml\ of\ blood\ )pg/cell}{Red\ blood\ cell\ counts\ in\ millions/ml.}$$

2.6.5.4. Red Cell Distribution Width (RDW)

The red cell distribution width is used to assess the degree of anisocytosis (abnormal fluctuation in size of red blood cells). The measurement can be utilised in the evaluation of various haematological illnesses and in monitoring response to treatment. Normal range is between 11.5-14.5 coefficients of variation (CV) of red cell size (Fischbach, 2003).

2.6.6. White Blood Cells (WBCs) Count

White blood cells, also called leukocytes, play a crucial role in the immune system by supporting both innate and adaptive immunity (Iwasaki and Medzhitov, 2015). The total white blood cell (WBC) count measures the number of different types of leukocytes in one milliliter of blood, including neutrophils, lymphocytes, monocytes, eosinophils, basophils, as well as immature or abnormal cells (Hoffbrand *et al*., 2016). An increased WBC count, referred to as leucocytosis, can result from a variety of benign or serious conditions. In cases of elevated WBC levels, further investigations such as detailed differential counts, examination of blood smears, and consideration of clinical information are essential to determine the underlying cause (Chabot-Richards and George, 2014). On the other hand, a reduced WBC count, known as leukopenia, can occur in multiple diseases and requires careful differential and morphological evaluation to identify which specific cell types are affected and to detect any abnormal cells (Fischbach, 2003). Normal WBC levels range from 4,500 to 11,000 cells per microliter (4.5 to 11.0 × 10^9/L) (Chabot-Richards and George, 2015). The differential count assesses the proportion of each type of white blood cell (Chesbrough, 2006).

2.3.6.1. Lymphocytes

Lymphocytes are a category of white blood cells that play a crucial role in the body's specific immune defense against infections and foreign substances (Hoffbrand *et al*., 2016). In adults, they represent roughly 20 to 40 percent of the total white blood cell population. These cells circulate in the bloodstream and are densely located in lymphoid tissues like the spleen, tonsils, and lymph nodes, which serve as primary sites for immune activation. Acting as immune-competent cells, lymphocytes work together with phagocytes to defend the body against infectious agents and harmful substances. The immune functions of lymphocytes mainly involve two primary types: B cells and T cells. B cells mature within the bone marrow and travel through the blood, while T cells originate from precursor cells that migrate to the thymus, where they mature (Hoffbrand *et al*., 2016). Another important group of lymphocytes is the natural killer (NK) cells. These cells are larger, contain cytoplasmic granules, and typically display surface markers such as CD16, CD56, and CD57. NK cells specialize in identifying and eliminating cells with decreased expression of HLA class molecules, including those infected by viruses or undergoing malignant transformation (Hoffbrand *et al*., 2006). Reference range; Adults and Children: 20% to 40% of total white blood cells (Ficshbach, 2003).

2.3.6.2. Monocytes

Monocytes are the largest cells found in the bloodstream, with a diameter of approximately 15 to 18 micrometers, and they constitute about 7 percent of the total white blood cell count. Their nuclei are relatively large and usually exhibit an indented or folded shape rather than being multilobed. These cells are highly mobile and have the ability to engulf particles through phagocytosis. The cytoplasm of monocytes contains numerous small vacuoles, giving it a characteristic ground-glass texture (Fischbach, 2003). Although monocytes can ingest pathogens and large debris, they do not replace neutrophils in the primary role of

bacterial destruction. Instead, monocytes typically move into inflamed tissues following granulocytes and are commonly present in areas of chronic infection (Thiele *et al*., 2001). Reference range; Adults and Children: 2% to 8% of total white blood cells (Ficshbach, 2003).

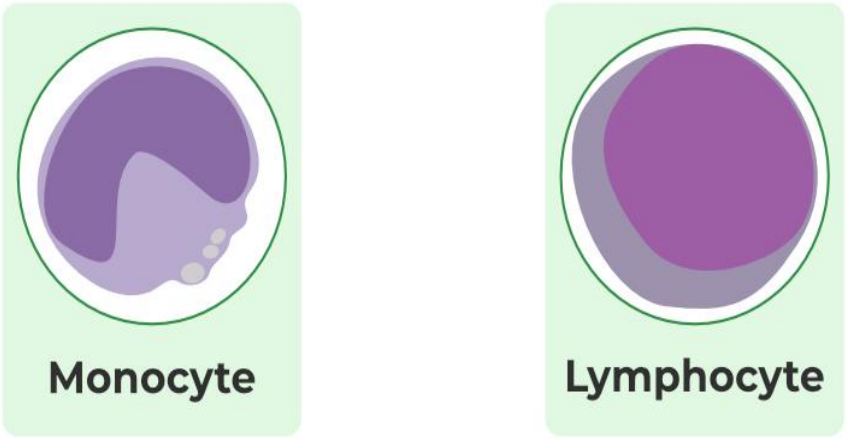


Figure 2.3. Structure of Lymphocyte and Monocyte (Sun *et al*., 2021).

2.6.6.3. Neutrophils

Neutrophils are a type of white blood cell that can be identified microscopically due to their staining affinity for neutral dyes. They are essential in the body's immune defense by targeting and destroying harmful microorganisms. Neutrophils constitute between 50 and 80 percent of the total white blood cell count and usually measure between 9 and 15 micrometers in diameter. These cells rapidly migrate to sites where infection or tissue injury has occurred. An elevated neutrophil count is referred to as neutrophilia, while a reduced count is known as neutropenia (Hoffbrand *et al*., 2016). Reference range; Adults: 40% to 60% of total white blood cells, Children: 25% to 40% of total white blood cells (Ficshbach, 2003).

2.3.6.4. Eosinophils

Eosinophils are white blood cells classified as granulocytes, involved in protecting the body against infections, allergic reactions, and inflammatory processes. They contain large, uniformly sized cytoplasmic granules that stain bright red with eosin dye (Hoffbrand *et al*., 2016). Produced in the bone marrow, eosinophils enter the bloodstream before migrating into various tissues, especially those associated with the respiratory system, gastrointestinal tract, and skin. These cells carry approximately one-third of the body's total histamine and play a significant role in allergic responses and defense against parasitic infections (Fischbach, 2003). Normal range of eosinophils is 0-0.7 x 10^9/L.

2.3.6.5. Basophils

Basophils are another type of white blood cell and granulocyte that participate in immune responses to allergens and parasitic infections (Yamanishi *et al*., 2017). They are notable for their numerous dark cytoplasmic granules, which often conceal the nucleus. These granules contain substances such as heparin and histamine, which are important in allergic and inflammatory reactions. Basophils show strong binding to basic dyes during histological

staining and play a crucial role in hypersensitivity reactions. They are the rarest granulocytes, comprising less than one percent of the total white blood cell population (Hoffbrand *et al*., 2016). Normal range for basophils is 0.02-0.05 x 10^9/L (Fischbach, 2003).

Differential: 0%-1.0% of total white blood cell count (Fischbach, 2003).

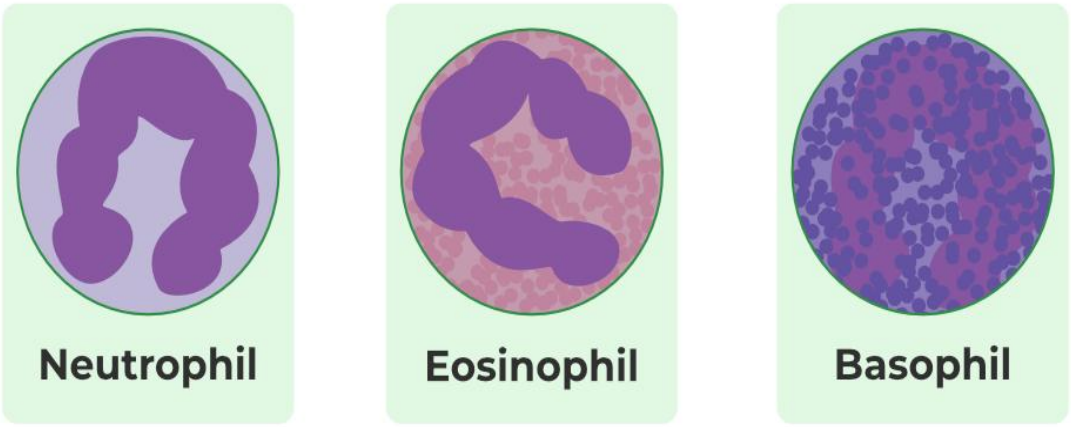


Figure 2.4. Structure of Neutrophil, Eosinophil and Basophils (Siemińska *et al*., 2021).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Area

The study was conducted in Benin City, Edo State, Nigeria, focusing on street cleaners operating in selected environs, including Uselu, Ugbowo, Oluku, Ekenwan, and their surrounding areas. Benin City comprises three Local Government Areas; Egor, Oredo and Ikpoba-Okha Local Government Areas respectively, with a population of 1,086,882 people. Benin City is bounded to the west by Ovia North East Local Government Area and the North-East by Uhunmwuode Local Government Area and South by Ethiope-West Local Government Area of Delta State. Benin City is known for its dense urban population engaged in various economic activities, including waste management and maintaining a serine environs.

3.2. Study Population

The study population comprised of street cleaners working in the selected environs of Benin City and the surrounding areas with the responsibility of maintaining clean streets, roads and environment in general. A control group matched for age and gender but without occupational exposure to street cleaning was recruited for comparative analysis.

3.3. Study Subjects

For the purpose of this study, a total of one hundred (100) adult street cleaners working in Uselu, Ugbowo, Oluku, Ekenwan, and the surrounding environs of Benin City were recruited. Only individuals who had been actively engaged in street cleaning for at least six months and who voluntarily consented to participate were included in the study. Both male and female street cleaners aged 18 years and above were considered eligible.

3.4. Selection Criteria

3.4.1. Inclusion Criteria

1. Street cleaners aged 18 years and above working in Uselu, Ugbowo, Oluku, Ekenwan, and the surrounding environs of Benin City.
2. Individuals who have been actively engaged in street cleaning for at least six months.
3. Street cleaners who voluntarily provide informed consent to participate in the study.
4. Workers who are apparently healthy and without a history of chronic hematological or cardiovascular disorders.

3.4.2. Exclusion Criteria

1. Individuals below 18 years of age.
2. Street cleaners who have been employed for less than six months.
3. Workers with known chronic illnesses such as anemia, hypertension, diabetes, or bleeding disorders that may affect hematological or haemorheological parameters.
4. Those who decline to provide consent or are unwilling to participate.
5. Individuals currently on medications that could influence blood parameters, such as anticoagulants or hematopoietic drugs.
6. Pregnant or lactating women.

3.5. Sample Size Determination

Sample size was determined using single population proportion estimate considering the level of significances at 5% and the prevalence of occupational hazard from street cleaning from a previous study conducted which was 94% (Johnson and John, 2020).

The sample size for this study was obtained using Formula as described by (Daniel, 1999).

$$Sample\ size = \frac{Z^2\ P\ (1 - P)}{d^2}$$

N = required sample size

Z = confidence level at 95% (standard value of 1.96)

P = Prevalence of occupational hazard from street cleaning (94% = 0.940)

D = margin of error at 5% (standard value = 0.05)

$$N = \frac{1.96^2 \times 0.940\ (1 - 0.940)}{0.05^2} \qquad = 87.$$

Minimum sample size calculated is 87. In order to account for non-response, 10% of the sample size (i.e., 8.7) was added to the calculated sample size; this gave a sample size of 95.7, which was approximated to 96 study subjects.

A total of 100 street cleaners were recruited for this study with 50 participants as study control.

NOTE: Due to non-compliance from the street cleaners and time factor for this research, the sample size was reduced to 50 for the street cleaners and 50 for the study control.

3.6. Ethical Approval

Ethical approval was sought and obtained from the Research and Ethics Committee of the Ministry of health, Edo state. All necessary permissions were secured from relevant local government authorities and waste management agencies prior to commencement of the study. Informed consent was obtained from all study participants after a clear explanation of the study objectives, procedures, and potential risks.

3.7. Method of Data collection

A well-structured questionnaire was used to collect sociodemographic information. Additional information on occupational exposure was also obtained from the street cleaners. Only participants who provided informed consent were included in the study.

3.8. Sampling Technique

Simple random sampling technique was used in selecting street cleaners randomly, in which everyone who falls under this category would participate in this study.

3.9. Sample Collection

Under aseptic conditions, approximately 7 milliliters of venous blood were collected from the antecubital vein of each study participant using a sterile needle and syringe. Four milliliters (4 ml) of the blood were dispensed into an ethylene diamine tetra-acetic acid (EDTA) container for full blood count (FBC) and erythrocyte sedimentation rate (ESR) analysis. The remaining 3 ml was dispensed into sodium citrate container and then centrifuged at 4000 rpm for 5 minutes to separate the plasma. The plasma obtained was used for fibrinogen determination. All samples were handled carefully to maintain integrity and prevent hemolysis prior to laboratory analysis.

3.10. Laboratory Analysis

3.10.1. Full Blood Count

The Complete blood parameters were analysed immediately after sample collection using the automated three parts ERMA Haematology Auto analyser PCE-210N (Diamond Diagnostic; Holliston, USA). Calibration and standardization of the equipment, processing and analysis of the samples were done strictly according to the manufacturer's instructions.

3.10.1.1. Detection Principle of Autoanalyzer

The instrument counts and sizes the cells. It detects and measures changes in electrical resistance when a particle (such as a cell) passes through a gem aperture sensor.

Sample was diluted in a conductive liquid. Each time a blood cell will pass through the aperture a resistant signal will be generated because blood cells are bad conductors. When cell goes through the aperture, the resistance increases with increase in cell volume. According to the Ohm formulary: U=RI (U =Voltage I =Current R =Resistance). If I is invariable, U is increased as cell volume increases. Treat by magnifying circuit, the voltage

signal is amplified; background noise is removed, and receives the signal to analysis. WBC and RBC/PLT are analysed by two different circuits. The MPU analyses and calculates the cells, then gives the histograms. The count of PLT adopts an advanced liquid, electron and soft system, which can settle the repetitive count of the cells. If RBC enters the analysis area, they will have similar pulses with PLT.

3.10.1.2. Procedure

The whole blood was properly mixed and inserted into the probe. Then 20 μL of the blood was aspirated into the instrument. The analysis was immediately done and the results displayed on the screen after about 1-2 minutes, which was printed by the printer.

3.10.2. Erythrocyte Sedimentation Rate (ESR)

3.10.2.1. Principle

The erythrocyte sedimentation rate (ESR) measures the rate at which red blood cells settle at the bottom of a vertical tube over a specified period, usually one hour. This process occurs due to the aggregation of red blood cells in the presence of plasma proteins, particularly fibrinogen and immunoglobulins. An increased ESR indicates the presence of inflammation, infection, or other conditions affecting plasma composition and red blood cell properties.

3.10.2.2. Materials Used in Performing ESR

1. EDTA-anticoagulated blood sample
2. Westergren tubes
3. Sodium citrate solution
4. Rack for vertical placement of tubes
5. Pipette and tips
6. Timer or stopwatch

3.10.2.3. Reagents Used

Sodium citrate solution was used as an anticoagulant to prevent clotting during the test. All reagents were prepared according to standard laboratory protocols and stored under recommended conditions to maintain effectiveness.

3.10.2.4. Procedure

1. The EDTA-anticoagulated blood sample was mixed gently to ensure homogeneity.
2. For ESR measurement using the Westergren method, 4 parts of blood were mixed with 1 part of 3.8% sodium citrate solution (4:1 ratio) to prevent clotting.
3. The mixture was drawn into a Westergren tube up to the 200 mm mark and placed vertically in a stand at room temperature without disturbance.
4. After one hour, the distance in millimeters that the red blood cells had fallen from the top of the plasma column was measured.
5. The ESR value was recorded for each participant.

3.10.4. Fibrinogen Concentration – Clauss Method

3.10.4.1. Principle

The Clauss method measures plasma fibrinogen concentration based on the time it takes for a clot to form when a high concentration of thrombin is added to diluted plasma. The clotting time is inversely proportional to the fibrinogen concentration: shorter clotting times indicate higher fibrinogen levels, while longer times indicate lower levels.

3.10.4.2. Materials Used

1. Citrated blood sample
2. Centrifuge
3. Pipettes and tips
4. Test tubes
5. Water bath or automated coagulometer (if available)

6. Timer or stopwatch
7. Reagent: Thrombin solution

3.10.4.3. Reagents Used

The following reagents were used for the determination of plasma fibrinogen using the Clauss method:

- **Fibrinogen Reagent:** Bovine thrombin, approximately 100 NIH U/mL, prepared in a buffer containing stabilizers and preservatives.
- **Imidazole Buffer:** Imidazole buffer solution with stabilizers and preservatives, used to dilute plasma samples to the required concentration.

3.10.4.5. Procedure

1. A sufficient volume of the thrombin reagent was brought to room temperature.
2. A 1:10 dilution of the plasma was prepared with imidazole buffer (25 µL plasma + 225 µL buffer).
3. 100 µL of the diluted plasma was added into a test tube.
4. The test tube was incubated at 37ºC for 2 minutes.
5. 50 µL of the thrombin reagent was added, and the timer was immediately started.
6. The clotting time was recorded.
7. Fibrinogen concentrations were reported in mg/dL and calculated from a calibration curve using the master curve provided in the kit.

3.11. Statistical Analysis

Data obtained from this research was presented and analyzed using statistical package for social sciences (SPSS) version 21.0 (IBM Inc. USA). Analysis of variance (ANOVA) was used to compare means and results was expressed in means ± SEM. Differences was considered to be statistically significant when the p value obtained is ≤ 0.05.

CHAPTER FOUR

RESULTS

The mean age of the control group was 33.84 ± 4.21 years, while street cleaners were slightly older with a mean age of 35.84 ± 8.09 years. In terms of age distribution, almost half of the controls (48.0%) were between 21–30 years, whereas the largest proportion of street cleaners (36.0%) were in the 31–40 years group. Males predominated in both groups, representing 80.0% of controls and 88.0% of street cleaners, with females accounting for 20.0% and 12.0%, respectively. Regarding marital status, half of the controls were single (50.0%) compared to 30.0% of street cleaners, while marriage was more common among street cleaners (66.0%) than controls (44.0%); small proportions in both groups were divorced, and only the control group recorded widows (2.0%). Educational attainment varied across groups, with more controls (56.0%) attaining tertiary education compared to street cleaners (26.0%), while secondary education was most common among street cleaners (58.0%) and controls (36.0%). Religion was dominated by Christianity in both groups, accounting for 80.0% of controls and 92.0% of street cleaners; Islam was reported by 14.0% of controls and 8.0% of street cleaners, while traditional religion was observed only among controls (6.0%) (Table 4.1).

Table 4.1. Sociodemographic Parameters of Control Participants and Street Cleaners

Parameters	Control (%) (n=50)	Street Cleaners (%) (n=50)
Mean Age	Mean age= 33.84 ± 4.21	Mean age= 35.84 ± 8.09
Age (Years)		
21-30	24 (48.0)	16 (32.0)
31-40	15 (30.0)	18 (36.0)
41-50	7 (14.0)	14 (28.0)
51-60	4 (8.0)	2 (4.0)
Gender		
Male	40 (80.0)	44 (88.0)
Female	10 (20.0)	6 (12.0)
Marital Status		
Single	25 (50.0)	15 (30.0)
Married	22 (44.0)	33 (66.0)
Divorced	2 (4.0)	2 (4.0)
Widowed	1 (2.0)	0 (0)
Education		
None	0 (0)	0 (0)
Primary	4 (8.0)	8 (16.0)
Secondary	18 (36.0)	29 (58.0)
Tertiary	28 (56.0)	13 (26.0)
Religion		
Christianity	40 (80.0)	46 (92.0)
Islam	7 (14.0)	4 (8.0)
Traditional	3 (6.0)	0 (0)

Among the street cleaners, 20.0% had worked for less than 1 year, 40.0% for 1–5 years, 28.0% for 6–10 years, and 12.0% for more than 10 years, indicating that the majority had between 1 and 5 years of work experience. In terms of daily working hours, most respondents (68.0%) reported working 4–8 hours per day, while 24.0% worked less than 4 hours, and only 8.0% worked more than 8 hours daily. With respect to the number of working days per week, 60.0% of the street cleaners worked 3–5 days, 36.0% worked 6–7 days, and only 4.0% worked fewer than 3 days. The use of personal protective equipment (PPE) varied, with 36.0% reporting that they always used PPE, 24.0% using it most times, 20.0% sometimes, and smaller proportions using it rarely (10.0%) or never (10.0%). Notably, all respondents (100.0%) reported having access to water and soap for handwashing (Table 4.2).

Table 4.2. Occupational Information of Street Cleaners (n=50)

Questions	Number	Percentage
How long on the job?		
<1 year	10	20.0
1–5 years	20	40.0
6–10 years	14	28.0
>10 years	6	12.0
How many hours per day?		
<4 hours	12	24.0
4-8 hours	34	68.0
>8 hours	4	8.0
How many days per week?		
<3 days	2	4.0
3-5 days	30	60.0
6-7 days	18	36.0
How often PPE used?		
Always	18	36.0
Most times	12	24.0
Sometimes	10	20.0
Rarely	5	10.0
Never	5	10.0
Access to water/soap for handwashing?		
Yes	50	100.0
No	0	0

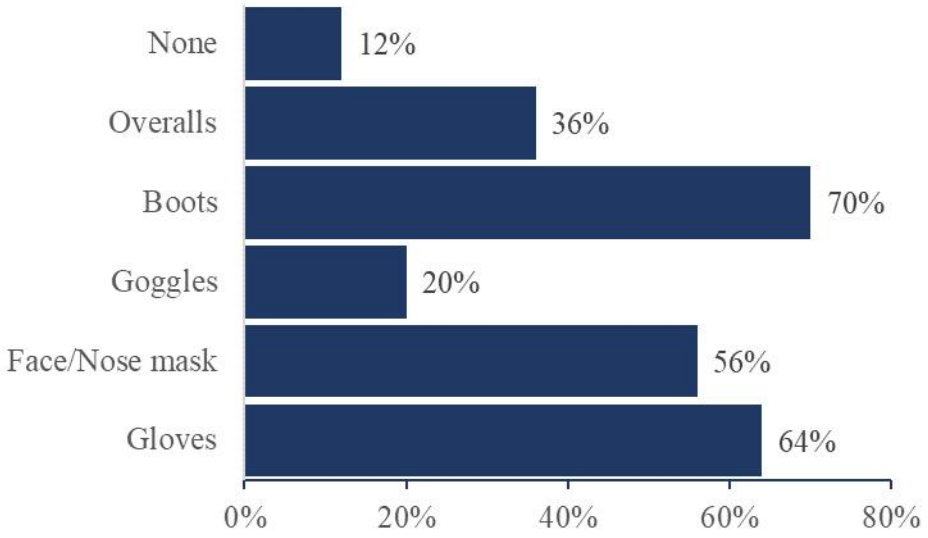


Figure 4.1. Use or personal protective equipment by street cleaners.

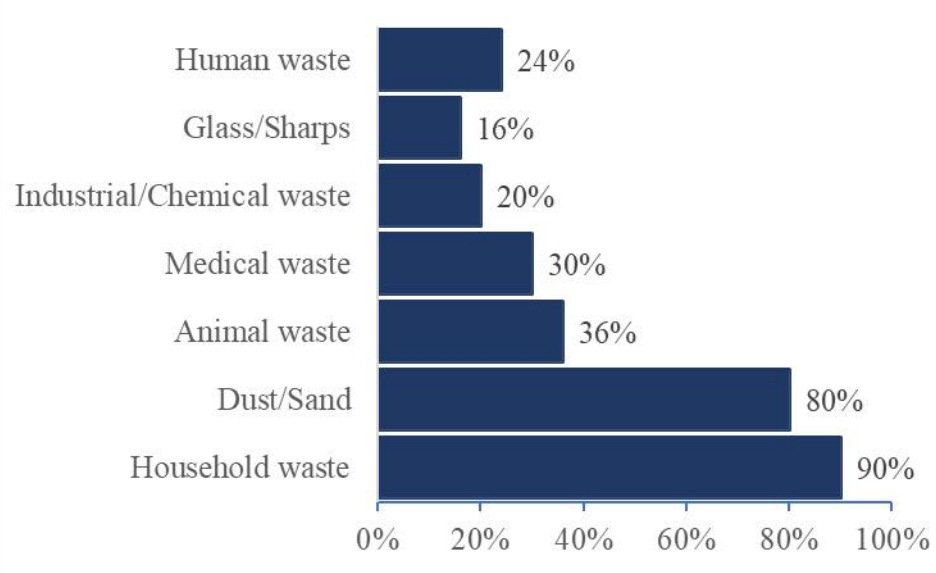


Figure 4.2. Type of wastes handled by street cleaners.

The mean white blood cell (WBC) count was not significantly different street cleaners (5.25 ± 0.18 $\times 10^3/\mu L$) compared to controls (5.37 ± 0.19 $\times 10^3/\mu L$, $p = 0.110$). Lymphocyte (LYM) percentages were slightly lower in street cleaners (45.10 ± 1.01%) than in controls (47.11 ± 1.09%), but this difference was not statistically significant ($p = 0.180$). MID (%) and granulocyte (GRAN) percentages showed no significant differences between the two groups ($p = 0.186$ and $p = 0.358$, respectively). Red blood cell (RBC) counts were significantly reduced in street cleaners (3.92 ± 0.07 $\times 10^{12}/L$) compared with controls (5.26 ± 0.08 $\times 10^{12}/L$, $p < 0.001$). Haemoglobin (HGB) levels were significantly lower in street cleaners (11.45 ± 0.17 g/dL) than in controls (13.80 ± 0.26 g/dL, $p < 0.001$). Haematocrit (HCT) did not differ significantly between groups ($p = 0.462$). Red cell indices showed marked differences. Street cleaners had significantly higher mean corpuscular volume (MCV) (92.38 ± 0.91 fL vs. 69.89 ± 0.67 fL, $p < 0.001$), mean corpuscular haemoglobin (MCH) (35.23 ± 0.36 pg vs. 21.75 ± 0.21 pg, $p < 0.001$), and mean corpuscular haemoglobin concentration (MCHC) (38.14 ± 0.17 g/dL vs. 31.21 ± 0.14 g/dL, $p < 0.001$). Red cell distribution width (RDW) was also significantly elevated among street cleaners for both RDW-SD (52.91 ± 0.63 fL vs. 38.09 ± 0.36 fL, $p < 0.001$) and RDW-CV (17.71 ± 0.10% vs. 14.35 ± 0.12%, $p < 0.001$). Platelet counts were markedly lower in street cleaners (151.64 ± 8.25 $\times 10^3/\mu L$) compared with controls (328.58 ± 17.47 $\times 10^3/\mu L$, $p < 0.001$). Finally, mean platelet volume (MPV) was significantly reduced in street cleaners (10.07 ± 0.11 fL) relative to controls (10.76 ± 0.15 fL, $p < 0.001$) (Table 4.3).

Table 4.3. Haematological Parameters of Control and Street Cleaners

Parameters	Control (n=50)	Street Cleaners (n=50)	t	p value
WBC ($\times 10^3/\mu L$)	5.37±0.19	5.25±0.18	-3.346	0.110
LYM (%)	47.11±1.09	45.10±1.01	1.351	0.180
MID (%)	8.90±0.32	9.45±0.26	1.332	0.186
GRAN (%)	43.98±1.18	45.44±1.06	0.923	0.358
RBC ($10^{12}/L$)	5.26±0.08	3.92±0.07	13.082	<0.001
HGB (g/dL)	13.80±0.26	11.45±0.17	-8.119	<0.001
HCT (%)	36.60±0.48	36.05±0.57	0.738	0.462
MCV (fL)	69.89±0.67	92.38±0.91	-19.902	<0.001
MCH (pg)	21.75±0.21	35.23±0.36	-32.293	<0.001
MCHC (g/dL)	31.21±0.14	38.14±0.17	30.739	<0.001
RDW-SD (fL)	38.09±0.36	52.91±0.63	20.527	<0.001
RDW-CV (%)	14.35±0.12	17.71±0.10	-21.608	<0.001
PLT ($\times 10^3/\mu L$)	328.58±17.47	151.64±8.25	9.157	<0.001
MPV (fL)	10.76±0.15	10.07±0.11	3.690	<0.001

Values shown are Mean ± SEM, P<0.05 was considered statistically significant.

Table 4.4. Effect Sizes of Differences in Haematological Parameters

Parameters	Cohen's d (Effect Size)	95% Confidence Interval
RBC (10^{12}/L)	2.62	2.076, 3.149
HGB (g/dL)	1.62	2.074, 1.168
MCV (fL)	-3.98	-4.657, -3.296
MCH (pg)	-6.46	-7.440, -5.471
MCHC (g/dL)	-6.15	-7.089, -5.200
RDW-SD (fL)	-4.11	-4.797, -3.407
RDW-CV (%)	-4.32	-5.038, -3598
PLT ($\times 10^3$/μL)	1.83	1.360, 2.296
MPV (fL)	0.74	0.331, 1.142

Note. Cohen's *d* values are interpreted as follows: 0.20–0.49 = small effect, 0.50–0.79 = moderate effect, and ≥0.80 = large effect. Negative values indicate lower mean values in control compared to street cleaners, while positive values indicate higher mean values.

The erythrocyte sedimentation rate (ESR) was significantly higher among street cleaners (17.92 ± 1.50 mm/hr) compared with controls (5.78 ± 0.51 mm/hr, $p < 0.001$). Similarly, fibrinogen concentration was markedly elevated in street cleaners (460.68 ± 14.88 mg/dL) relative to controls (286.88 ± 6.83 mg/dL, $p < 0.001$) (Table 4.5).

Table 4.5. Fibrinogen Concentration and Erythrocyte Sedimentation Rate of Control and Street Cleaners

Parameters	Control (n=50)	Street Cleaners (n=50)	t	p value
ESR (mm/hr)	5.78±0.51	17.92±1.50	-7.645	<0.001
Fibrinogen (mg/dL)	286.88±6.83	460.68±14.88	-10.619	<0.001

Values shown are Mean ± SEM, P<0.05 was considered statistically significant.

Table 4.6. Effect Sizes of Differences in Fibrinogen Concentration and ESR

Parameters	Cohen's d (Effect Size)	95% Confidence Interval
ESR (mm/hr)	-1.53	-1.972, -1.079
Fibrinogen (mg/dL)	-2.12	-2.612, -1.629

Note. Cohen's *d* values are interpreted as follows: 0.20–0.49 = small effect, 0.50–0.79 = moderate effect, and ≥0.80 = large effect. Negative values indicate lower mean values in control compared to street cleaners, while positive values indicate higher mean values.

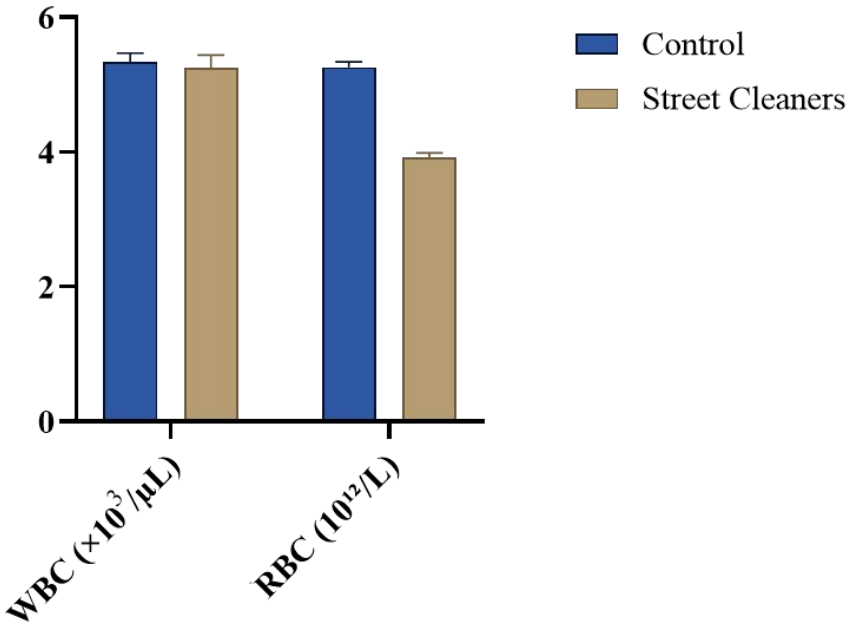


Figure 4.3. Chart showing White blood cell and red blood cell counts of control and street cleaners.

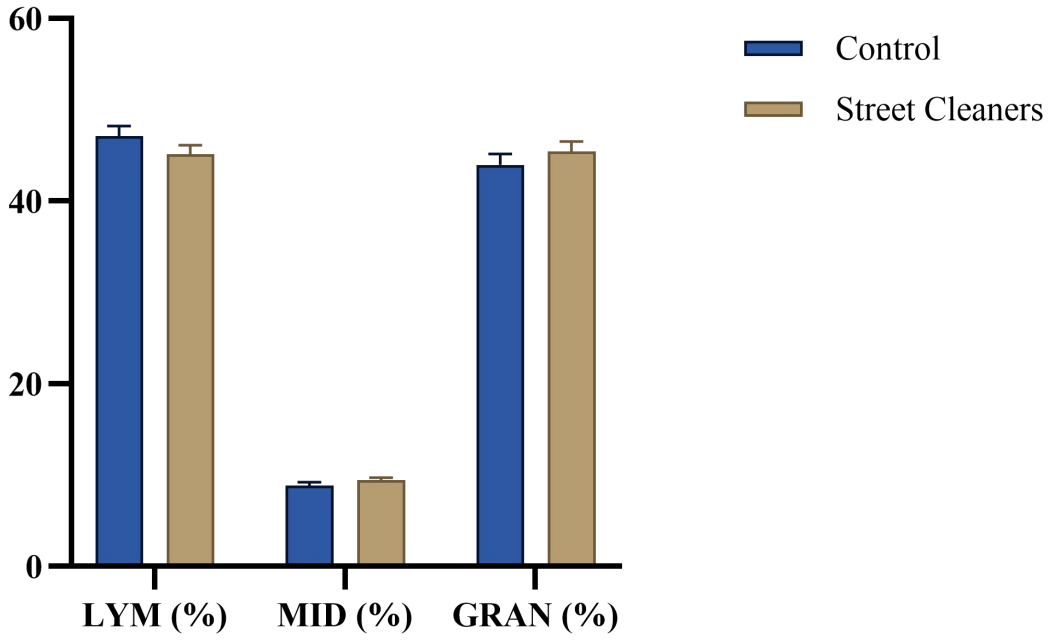


Figure 4.4. Chart showing differential counts of white blood cell of control and street cleaners.

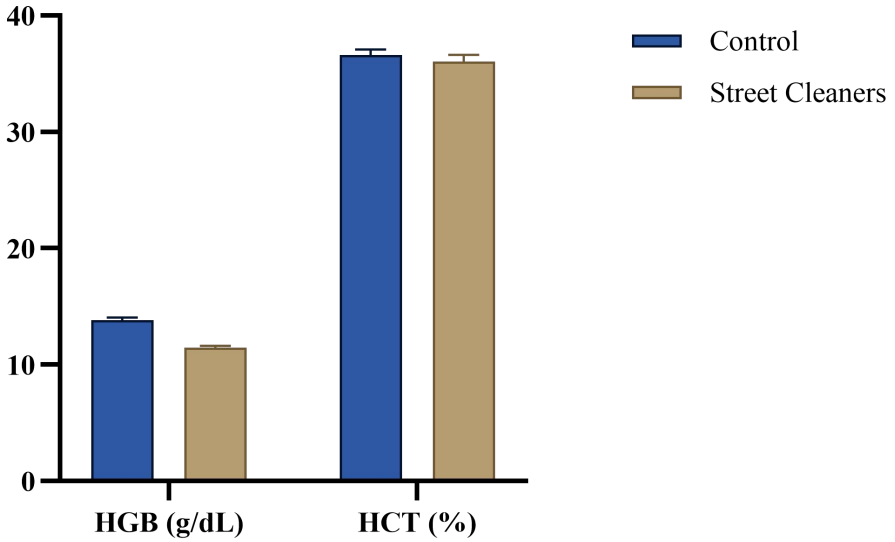


Figure 4.5. Chart showing haematocrit and haemoglobin concentration of control and street cleaners.

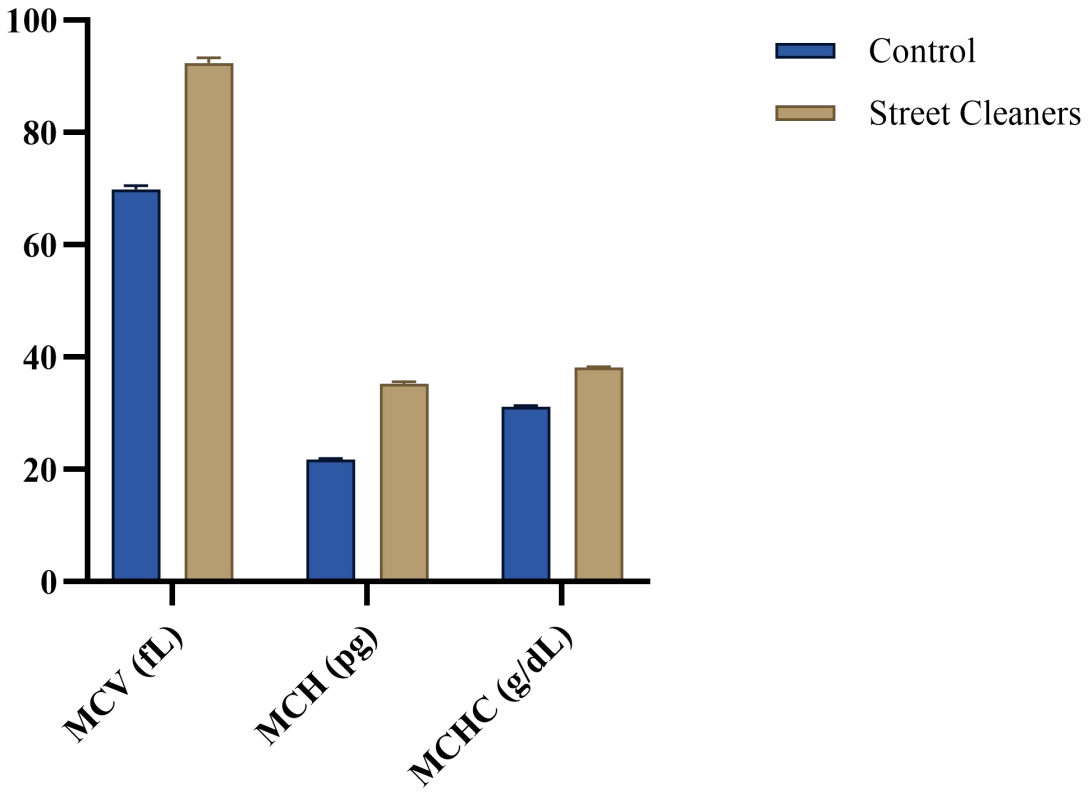


Figure 4.6. Chart showing MCV, MCH and MCHC of control and street cleaners.

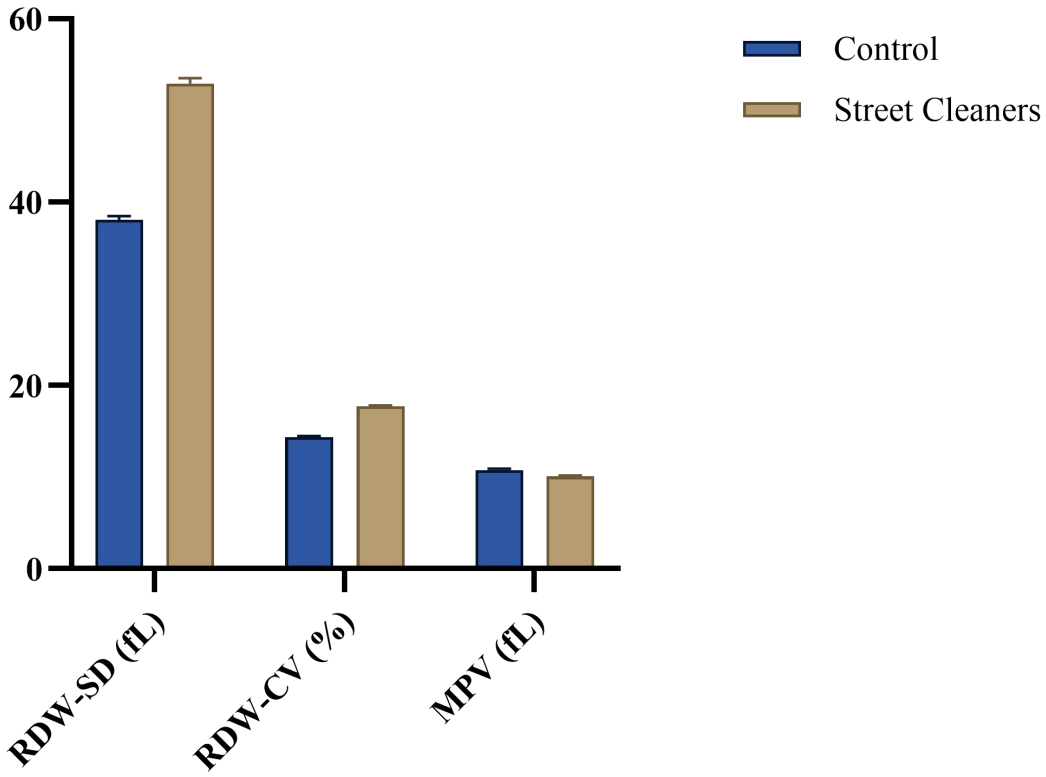


Figure 4.7. Chart showing RDW-SD, RDW-CV and MPV of control and street cleaners.

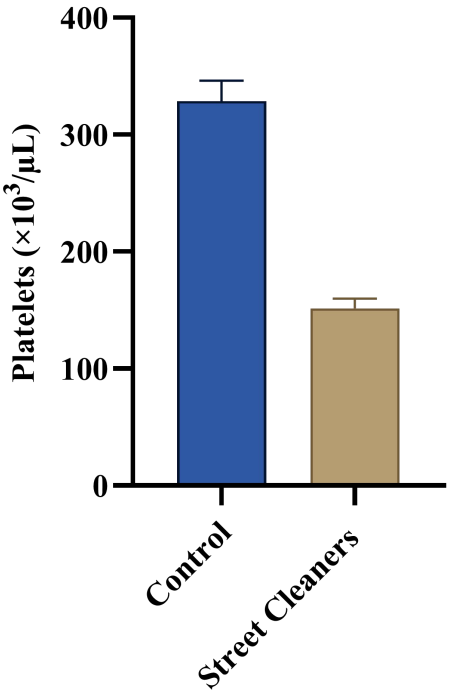


Figure 4.8. Chart showing platelet count of control and street cleaners.

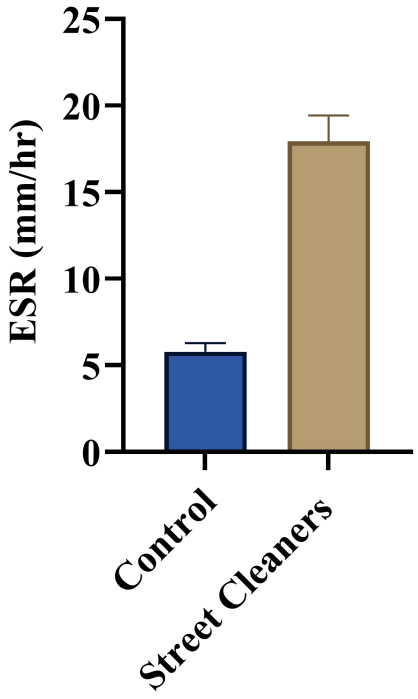


Figure 4.9. Chart showing erythrocyte sedimentation rate of control and street cleaners.

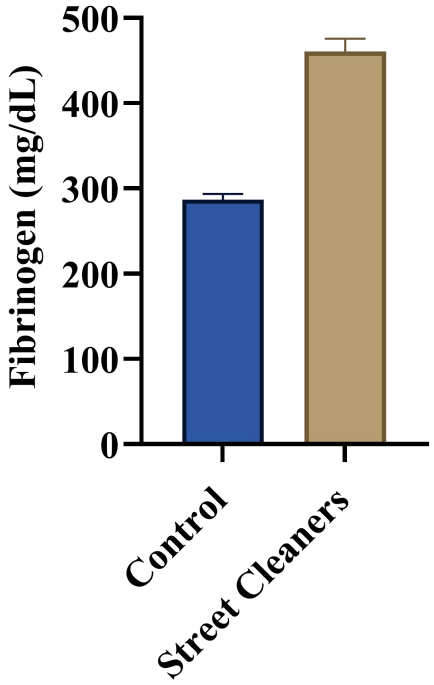


Figure 4.10. Chart showing fibrinogen concentration of control and street cleaners.

RBC showed strong positive correlations with HGB (r = 0.79) and HCT (r = 0.77). HGB was also strongly and positively correlated with HCT (r = 0.97). ESR had strong negative correlations with RBC (r = –0.74), HGB (r = –0.83), and HCT (r = –0.83), while fibrinogen was also negatively correlated with these same red cell parameters: RBC (r = –0.54), HGB (r = –0.72), and HCT (r = –0.69). ESR and fibrinogen, however, were strongly and positively correlated with each other (r = 0.91). Platelet count showed weak correlations with most parameters. WBC did not show notable correlations with other parameters (Figure 4.11). The p values of the correlation are shown in table 4.7.

Table 4.7. Correlations of some Haematological Parameters, Erythrocyte

Sedimentation Rate and Fibrinogen Concentration

Parameters	WBC	RBC	HGB	HCT	PLT	ESR	Fibrinogen
WBC	–	0.574	0.934	0.816	0.041	0.427	0.054
RBC	0.574	–	<0.001	<0.001	0.105	<0.001	<0.001
HGB	0.934	<0.001	–	<0.001	0.126	<0.001	<0.001
HCT	0.816	<0.001	<0.001	–	0.236	<0.001	<0.001
PLT	0.041	0.105	0.126	0.236	–	0.668	0.869
ESR	0.427	<0.001	<0.001	<0.001	0.668	–	<0.001
Fibrinogen	0.054	<0.001	<0.001	<0.001	0.869	<0.001	–

Note. Two-tailed significance (*p*) values from Pearson's correlations are reported.

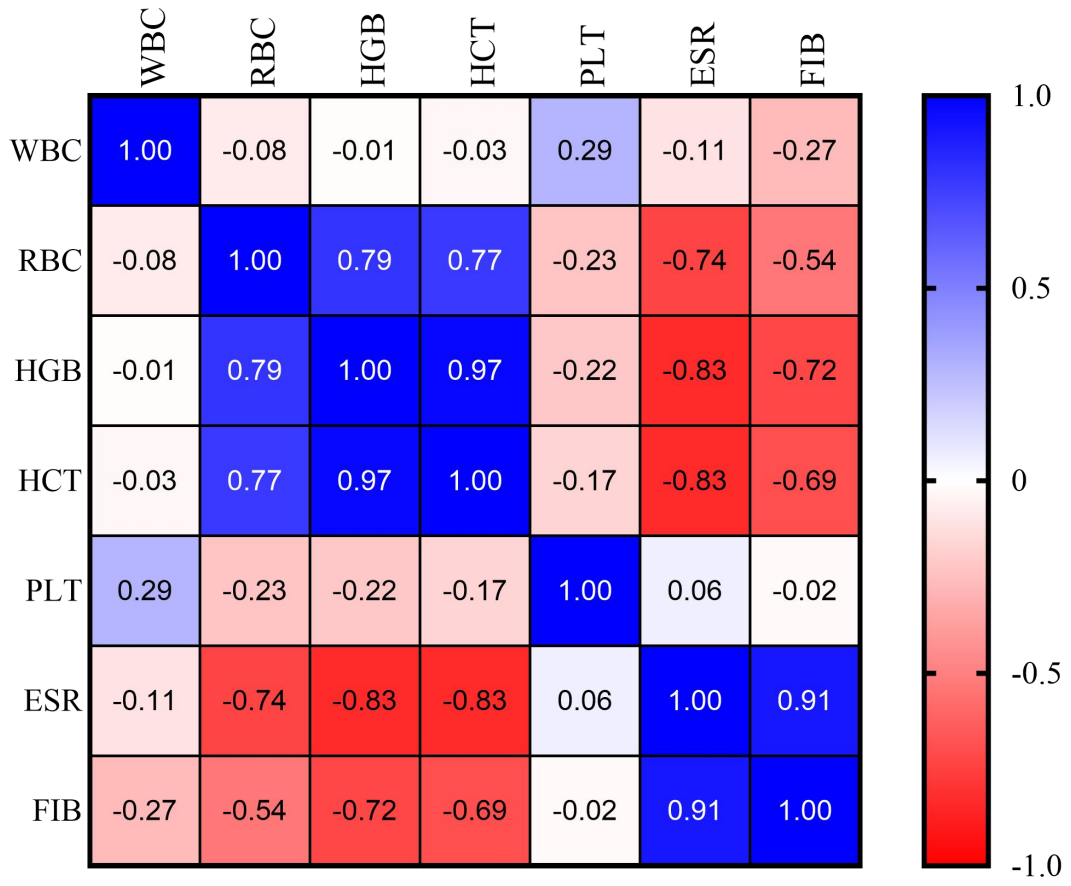


Figure 4.11. Correlation heatmap of some haematological parameters, erythrocyte sedimentation rate and fibrinogen concentration. **Note.** Values shown are Pearson's correlation coefficients (*r*). Correlation coefficients (r) range from –1 to +1, where values closer to +1 indicate a stronger positive relationship, values closer to –1 indicate a stronger negative relationship, and values near 0 indicate little or no linear relationship.

Key: WBC=White Blood Cells, RBC=Red Blood Cells, HGB=Hemoglobin, HCT=Hematocrit, PLT=Platelets, ESR=Erythrocyte Sedimentation Rate, FIB=Fibrinogen.

FINDINGS

The findings from the study were as follows:

1. The mean white blood cell (WBC) count was not different among street cleaners compared to controls.
2. The lymphocyte (LYM) percentages were slightly lower in street cleaners than in controls but this difference was not statistically significant.
3. The MID (%) and granulocyte (GRAN) percentages showed no significant differences between the two groups.
4. The red blood cell (RBC) counts were significantly reduced in street cleaners compared with controls.
5. The haemoglobin (HGB) levels were significantly higher in control than in street cleaners.
6. The haematocrit (HCT) did not differ significantly between the two groups.
7. The red cell indices showed marked differences, with street cleaners having significantly higher mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) compared with controls.
8. The red cell distribution width (RDW) was significantly elevated among street cleaners for both RDW-SD and RDW-CV.
9. The platelet counts were lower in street cleaners compared with controls.
10. The mean platelet volume (MPV) was significantly reduced in street cleaners relative to controls.
11. The erythrocyte sedimentation rate (ESR) was significantly higher among street cleaners compared with controls.

12. The fibrinogen concentration was markedly elevated in street cleaners compared with controls.
13. The RBC showed strong positive correlations with HGB and HCT.
14. The HGB was also strongly and positively correlated with HCT.
15. The ESR had strong negative correlations with RBC, HGB, and HCT.
16. The fibrinogen was negatively correlated with RBC, HGB, and HCT.
17. The ESR and fibrinogen were strongly and positively correlated with each other.
18. The platelet count showed weak correlations with most parameters.
19. The WBC did not show notable correlations with other parameters.

CHAPTER FIVE

5.1. Discussion

This study evaluated haematological and haemorheological changes among street cleaners in Benin City, with the aim of identifying potential occupational health risks associated with exposure to environmental pollutants, physical exertion, and work-related stress. Street cleaning is a physically demanding occupation that often involves exposure to dust, vehicular emissions, biological wastes, and extreme weather conditions which are factors that have been documented to have side effect in the body (Van Kampen *et al*., 2020).

In this study, the mean age of street cleaners (35.84 ± 8.09 years) shows that this occupation is mainly taken up by individuals in their productive years, with most workers between 31–50 years. Similar studies have also reported that middle-aged adults dominate sanitation jobs due to limited alternative employment opportunities in Nigeria (Aladejebi *et al*., 2025). Males were more represented than females, reflecting the physically demanding nature of the job. This agrees with findings from other studies on waste handlers and street sweepers (Yunoos and Dankoly, 2021). Most street cleaners were married, suggesting family responsibilities as a driving factor for taking up the work, similar to previous reports (Park *et al*., 2020). Educationally, a majority had only secondary education, consistent with studies showing that low educational attainment often leads to engagement in informal, high-risk occupations (Solberg *et al*., 2021).

The occupational profile of street cleaners indicates substantial exposure to multiple health risks. Prolonged years on the job and long daily working hours increase cumulative exposure to dust, fumes, and hazardous wastes, which have been associated with respiratory problems and infections in previous studies (Poole and Basu, 2017). Although access to water and soap was universal, irregular use of PPE suggests gaps in occupational health compliance, likely due to discomfort, inadequate supply, or lack of enforcement. Similar studies among

sanitation workers in Nigeria and other developing countries have consistently reported poor PPE adherence despite high exposure risks (Al-Bayati *et al*., 2023). The limited use of essential gear such as goggles and overalls also increase vulnerability to injuries, chemical irritants, and infections (Buhler *et al*., 2025).

In this study, white blood cell counts were not different in street cleaners compared to controls. However, in comparison to other studies, elevations in WBC have been reported among sanitation and waste handlers in both Nigeria and other countries (Tehrani *et al*., 2024; Dauda *et al*., 2018), with authors attributing such increases to persistent antigenic stimulation and chronic inflammation. Street cleaners had significantly lower RBC counts, yet their haemoglobin concentrations were higher than those of the control group. This can be explained by the observed changes in red cell indices. The significantly elevated MCV, MCH, and MCHC indicate that the surviving erythrocytes are larger and contain more haemoglobin per cell, consistent with macrocytosis and hyperchromia (Adewoyin *et al*., 2019). This suggests that, in response to environmental stressors such as exhaust fumes and chemical pollutants, the bone marrow may produce fewer but haemoglobin-rich red cells as a compensatory mechanism to preserve oxygen transport (Scharf *et al*., 2020). Inhalation of carbon monoxide from moving cars, in particular, leads to the formation of carboxyhaemoglobin, which reduces oxygen delivery to tissues and stimulates erythropoietin release, thereby enhancing haemoglobin synthesis (Piantadosi, 2019). At the same time, oxidative stress and toxic exposures may accelerate red cell destruction or impair normal erythropoiesis, contributing to the overall reduction in RBC numbers (Orrico *et al*., 2023). The higher MCV, MCH, and MCHC values in street cleaners, coupled with the elevated RDW can be explained by oxidative damage to red cell membranes, micronutrient deficiencies such as folate or vitamin B12 deficiency, or impaired bone marrow function (Tijjani *et al*., 2024) which are all conditions that are more common in low-income

populations who often undertake street cleaning (Rakanita *et al*., 2020). Increased RDW has been linked not only to anaemia but also to systemic inflammation and even higher cardiovascular risk (Fava *et al*., 2019). Platelet parameters also showed significant alterations, with street cleaners exhibiting both reduced platelet counts and reduced mean platelet volume (MPV). This shows impaired platelet production, as smaller platelet size reflects reduced bone marrow activity or toxic suppression of megakaryopoiesis. Chronic exposure to environmental pollutants such as hydrocarbons and other toxicants may directly inhibit platelet formation or damage progenitor cells in the bone marrow, leading to a simultaneous decline in platelet number and size (Scharf *et al*., 2020).

Street cleaners demonstrated markedly elevated ESR and fibrinogen levels compared to controls, both of which were statistically significant. Elevated ESR is a nonspecific marker of inflammation and reflects the tendency of red blood cells to aggregate in the presence of increased plasma proteins such as fibrinogen and globulins (Simeon *et al*., 2024). The significantly higher fibrinogen concentration observed among street cleaners provides a direct explanation for the rise in ESR, since fibrinogen promotes rouleaux formation and accelerates erythrocyte sedimentation (Vijayaraghavan *et al*, 2022). Similar findings have been reported in occupational groups with high exposure to dust and exhaust fumes, where persistent environmental stressors triggered systemic inflammation and elevated acute-phase reactants (Laleman *et al*., 2018; Rohleder, 2019). Chronic exposure to pollutants in the street cleaning environment is therefore likely to induce a persistent low-grade inflammatory state, stimulating hepatic synthesis of fibrinogen and other acute-phase proteins (Menzel *et al*., 2021). Elevated fibrinogen not only drives higher ESR but also contributes to increased blood viscosity and hypercoagulability (Nunns *et al*., 2017). These findings are consistent with earlier reports linking stress to elevated fibrinogen and increased cardiovascular risk (Ellins *et al*., 2017; Dabass *et al*., 2016). The strong positive correlations between RBC, HGB, and

HCT reflect their close physiological relationship in determining oxygen-carrying capacity (Chang *et al*., 2025). The negative correlations of ESR and fibrinogen with these red cell parameters suggest that systemic inflammation and increased plasma protein levels may suppress erythropoiesis or promote red cell destruction (Zivot *et al*., 2018). The strong positive correlation between ESR and fibrinogen confirms fibrinogen's role as a major driver of red cell aggregation and sedimentation during inflammation (Saldanha and Silva-Herdade, 2018).

5.2. Conclusion

This study indicates that street cleaners in Benin City experience some changes in their blood parameters compared to controls. Although white blood cell counts showed no major differences, street cleaners had lower red blood cell and platelet counts. Their red cell indices, erythrocyte sedimentation rate, and fibrinogen levels were higher, suggesting changes in red blood cells and increased inflammation. Overall, the results suggest that street cleaning may affect blood health, highlighting the importance of regular health checks for street cleaners.

5.3. Recommendations

1. Medical laboratory scientists should strengthen research on haematological and inflammatory alterations observed among street cleaners, providing scientific evidence that informs occupational health policies and interventions.
2. Routine laboratory-based medical check-ups, including haematological profiling and biomarker monitoring, should be coordinated by medical laboratory scientists to enable early detection and management of occupational health effects.
3. Medical laboratory scientists should collaborate with nutritionists to provide data-driven nutritional support programs and health education, using laboratory findings to address deficiencies and mitigate oxidative stress.
4. Provide street cleaners with adequate personal protective equipment (PPE), including gloves, masks, boots, and overalls, and ensure consistent and correct use.
5. Reduce exposure to dust, fumes, and chemical pollutants through improved waste management strategies and safer, well-structured work schedules.
6. Promote awareness of occupational risks and conduct training on safe handling of hazardous materials and hygienic practices.

5.4. Contribution to Knowledge

1. This study has been able to show significant alteration in both hematological and haemorrheological parameters via RBC, platelet indices, and elevated inflammatory markers.
2. The research establishes a clear link between chronic environmental exposures and systemic inflammation, as reflected by elevated ESR and fibrinogen levels in street cleaners.
3. Findings show the need to consider occupational exposure as a determinant of blood health and potential cardiovascular risk in low-income urban workers.
4. The study contributes baseline data for future occupational health interventions, policies, and longitudinal studies targeting sanitation workers in Nigeria and similar settings.

5.5. Limitations of Study

1. The study was cross-sectional, which limits the ability to establish causal relationships between occupational exposures and haematological changes.
2. The sample size was relatively small (n=50 per group), which may affect the generalizability of the findings to all street cleaners in Benin City or other regions.
3. The study relied on a single time-point measurement for haematological and haemorrheological parameters, which may not reflect long-term or seasonal variations.

REFERENCES

Adams, R. A., Schachtrup, C., Davalos, D., Tsigelny, I. and Akassoglou, K. (2007). Fibrinogen signal transduction as a mediator and therapeutic target in inflammation: lessons from multiple sclerosis. *Current Medicinal Chemistry*. 14(27): 2925-2936.

Adewoyin, A. S., Adeymi, O., Davies, N. O. and Ogbenna, A. A. (2019). Erythrocyte Morphology and Its. *Erythrocyte*. 7(1): 1-5.

Aladejebi, O., Bamkole, P., Bukola, A. T. and Kayode, A. (2025). Slum Entrepreneurship: A Panacea for Solving Nigeria's Socio-Economic Hardship in Lagos State, Nigeria. *The Journal of Accounting and Management*. 15(2): 230-253.

Al-Bayati, A. J., Rener, A. T., Listello, M. P. and Mohamed, M. (2023). PPE non-compliance among construction workers: An assessment of contributing factors utilizing fuzzy theory. *Journal of Safety Research*. 85: 242-253.

Alexy, T., Detterich, J., Connes, P., Toth, K., Nader, E., Kenyeres, P. and Simmonds, M. J. (2022). Physical properties of blood and their relationship to clinical conditions. *Frontiers in Physiology*. 13: 906768.

Alharthi, A. H., Al-Shehri, S. H. A., Albarqi, M. A. A., Alshehri, M. S., Alshehri, A. M., Amer, A. M. and Alassiry, A. M. A. (2024). Laboratory markers of inflammation: CRP and ESR in clinical practice. *Journal of International Crisis and Risk Communication Research*. 7(S8): 2376.

Alie, M., Abich, Y., Demissie, S. F., Weldetsadik, F. K., Kassa, T., Shiferaw, K. B. and Assefa, Y. A. (2023). Magnitude and possible risk factors of musculoskeletal disorders among street cleaners and solid waste workers: a cross-sectional study. *BMC Musculoskeletal Disorders*. 24(1): 493.

Azuonwu, O., Nnenna, I. and Uwuma, O. E. (2017). Evaluation of haematological profile of geriatric subjects in port Harcourt metropolis of Niger Delta of Nigeria. *Journal of Clinical Laboratory Medicine*. 2(1): 3-7.

Baskurt, O. K. (2007). Mechanisms of blood rheology alterations. *Biomedical and Health Research-Commission of the European Communities then IOS Press*. 69(1): 170.

Baskurt, O. K. and Meiselman, H. J. (2003). Blood rheology and hemodynamics. *Seminars in Thrombosis and Haemostasis*. 29(5): 435-450.

Benito, B., Guillamón, M. D., Martínez-Córdoba, P. J., and Ríos, A. M. (2021). Influence of selected aspects of local governance on the efficiency of waste collection and street cleaning services. *Waste Management*. 126: 800-809.

Beris, A. N., Horner, J. S., Jariwala, S., Armstrong, M. J., and Wagner, N. J. (2021). Recent advances in blood rheology: a review. *Soft Matter*. 17(47): 10591-10613.

Brun, J. F., Varlet-Marie, E., Richou, M., Mercier, J. and Raynaud de Mauverger, E. (2018). Blood rheology as a mirror of endocrine and metabolic homeostasis in health and disease. *Clinical Hemorheology and Microcirculation*. 69(1–2): 239–265.

Buhler, W., Dittman, B. and Langley, R. L. (2025). Personal Protective Equipment. In *Farm Toxicology: A Primer for Rural Healthcare Practitioners*. Cham: Springer Nature Switzerland. pp. 23-50.

Bychkova, A. V., Lopukhova, M. V., Wasserman, L. A., Degtyarev, Y. N., Kovarski, A. L., Chakraborti, S., and Mitkevich, V. A. (2022). The influence of pH and ionic strength on the interactions between human serum albumin and magnetic iron oxide nanoparticles. *International Journal of Biological Macromolecules*. 194: 654-665.

Caimi, G. and Carlisi, M. (2023). The unpredictable erythrocyte deformability alteration in some hematological disorders: How the classification of primary hyper viscosity syndromes could change. *Clinical Hemorheology and Microcirculation*. 2(1): 1-9.

Chabot-Richards, D. S. and George, T. I. (2014). Leukocytosis. *International Journal of Laboratory Haematology*. 36(3): 279-288.

Chang, L., Li, D., Zhu, K., Liu, M. and Duan, J. (2025). Correlation Between Retinal Vascular Oxygen Saturation, Red Blood Cell Parameters and Hemorheology Parameters in Healthy Adults. *Clinical Optometry*. 2(1): 231-240.

Cheesbrough, M. (2006). Investigation of bleeding disorders. District Laboratory Practice in Tropical Countries. Part 2. Cambridge University Press Publication. Pp. 340-347.

Crystal, G. J., Czinn, E. A., and Salem, M. R. (2014). The mechanism of increased blood flow in the brain and spinal cord during haemodilution. *Anaesthesia and Analgesia*. 118(3): 637-643.

Dabass, A., Talbott, E. O., Venkat, A., Rager, J., Marsh, G. M., Sharma, R. K. and Holguin, F. (2016). Association of exposure to particulate matter (PM2.5) air pollution and biomarkers of cardiovascular disease risk in adult NHANES participants (2001–2008). *International Journal of Hygiene and Environmental Health*. 219(3): 301-310.

Dauda, Y., Sandabe, U. K., Sani, S., Aka, L. O. and Ikaimase, V. C. (2016). Effects of dust particles on body weight and some haematological parameters in rats in Maiduguri metropolis, Nigeria. *Comparative Clinical Pathology*. 25(5): 925-932.

Deery, S., Kolar, D., and Walsh, J. (2019). Can dirty work be satisfying? A mixed method study of workers doing dirty jobs. *Work, Employment and Society*. 33(4): 631-647.

Diamanti, D., Pieroni, C., Pennisi, M. G., Marchetti, V., Gori, E., Paltrinieri, S., and Lubas, G. (2025). The erythrocyte sedimentation rate (ESR) in veterinary medicine: a focused review in dogs and cats. *Animals*. 15(2): 246.

Ebner, R., Sheikh, G. T., Brendel, M., Ricke, J. and Cyran, C. C. (2025). ESR essentials: staging and restaging with FDG-PET/CT in oncology—practice recommendations by the European Society for Hybrid, Molecular and Translational Imaging. *European Radiology*. 35(4): 1894–1902.

Ellins, E. A., Rees, D. A., Deanfield, J. E., Steptoe, A. and Halcox, J. P. (2017). Increased fibrinogen responses to psychophysiological stress predict future endothelial dysfunction implications for cardiovascular disease? *Brain, Behavior, and Immunity*. 60(1): 233-239.

Elogail, M. A., and Mekheimer, K. S. (2020). Modulated viscosity-dependent parameters for MHD blood flow in microvessels containing oxytactic microorganisms and nanoparticles. *Symmetry*. 12(12): 2114.

Etim, N. N., Williams, M. E., Akpabio, U. and Offiong, E. E. (2014). Haematological parameters and factors affecting their values. *Agricultural Science*. 2(1): 37-47.

Ezeudu, O. B. and Ezeudu, T. S. (2019). Implementation of circular economy principles in industrial solid waste management: Case studies from a developing economy (Nigeria). *Recycling*. 4(4): 42.

Fava, C., Cattazzo, F., Hu, Z. D., Lippi, G. and Montagnana, M. (2019). The role of red blood cell distribution width (RDW) in cardiovascular risk assessment: useful or hype? *Annals of Translational Medicine*. 7(20): 581.

Fischbach, F. (2003). A Manual of Laboratory and Diagnostic Tests.7th Edition. Lippincott Williams and Wilkins Publishers. Chicago. Pp.1-422.

Gogia, S., and Neelamegham, S. (2015). Role of fluid shear stress in regulating VWF structure, function and related blood disorders. *Biorheology*. 52(5-6): 319-335.

Greaves, J. and Pula, G. (2025). Hyperactivity and Pro-inflammatory Functions of Platelets in Diabetes. *Frontiers in Bioscience-Landmark*. 30(1): 26190.

Grover, H. S., Saini, R., Bhardwaj, P. and Bhardwaj, A. (2016). Acute-phase reactants. *Journal of Oral Research and Review*. 8(1): 32–35.

Hashemi, R., Majidi, A., Motamed, H., Amini, A., Najari, F. and Tabatabaey, A. (2015). Erythrocyte sedimentation rate measurement using as a rapid alternative to the Westergren method. *Emergency*. 3(2): 50.

Hasselbalch, H. C., Junker, P., Skov, V., Kjær, L., Knudsen, T. A., Larsen, M. K. and Willumsen, N. (2023). Revisiting circulating extracellular matrix fragments as disease markers in myelofibrosis and related neoplasms. *Cancers*. 15(17): 4323.

Hayakawa, M. (2017). Dynamics of fibrinogen in acute phases of trauma. *Journal of Intensive Care*. 5(1): 3.

Ho, Y. T., Azman, N. A., Loh, F. W. Y., Ong, G. K. T., Engudar, G., Kriz, S. A., and Kah, J. C. Y. (2018). Protein corona formed from different blood plasma proteins affects the colloidal stability of nanoparticles differently. *Bioconjugate Chemistry*. 29(11): 3923-3934.

Hoffbrand, A.V., Moss, P. A. H. and Petit, J. E. (2016). Haematological changes in systemic diseases. *Essential Haematology*, 7th Edition. Blackwell publishing, Oxford. Pp.1-150.

Hoffmeyer, F., van Kampen, V., Taeger, D., Deckert, A., Rosenkranz, N., KaBen, M., Schantora, A. L., Bruning, T., Raulf, M. and Bunger, J. (2014). Prevalence of and relationship between rhinoconjunctivitis and lower airway diseases in compost workers with current or former exposure to organic dust. *Annals of Agricultural and Environmental Medicine*. 21(4).

Hughes, J., Simpson, R., Slutskaya, N., Simpson, A., and Hughes, K. (2017). Beyond the symbolic: A relational approach to dirty work through a study of refuse collectors and street cleaners. *Work, Employment and Society*. 31(1): 106-122.

Hulshof, A. M., Hemker, H. C., Spronk, H. M., Henskens, Y. M. and Ten Cate, H. (2021). Thrombin–fibrin(ogen) interactions, host defense and risk of thrombosis. *International Journal of Molecular Sciences*. 22(5): 2590.

Isaac, L. J., Abah, G., Akpan, B. and Ekaette, I. U. (2013, September). Haematological properties of different breeds and sexes of rabbits. In *Proceedings of the 18th Annual Conference of Animal Science Association of Nigeria*. Pp. 24-27.

Ivanov, I. (2022). Hemorheological alterations and physical activity. *Applied Sciences*. 12(20): 10374.

Iwasaki, A. and Medzhitov, R. (2015). Control of adaptive immunity by the innate immune system. *Nature Immunology*. 16(4): 343-353.

Javadi, E., and Jamali, S. (2021). Hemorheology: the critical role of flow type in blood viscosity measurements. *Soft Matter*. 17(37): 8446-8458.

Johncy, S. S., Dhanyakumar, G. and Samuel, T. V. (2014). Chronic exposure to dust and lung function impairment: a study on female sweepers in India. *National Journal of Physiology, Pharmacy and Pharmacology*. 4(1): 15.

Johnson, O. E. and John, U. A. (2020). Occupational hazards and health problems among street sweepers in Uyo, Nigeria. *Ibom Medical Journal*. 13(2): 90-100.

Jørgensen, M., Rasmussen, C., Carneiro, I., Flyvholm, M., Olesen, K., Ekner, D. and Holtermann, A. (2011). Health disparities between immigrant and Danish cleaners. *International Archives of Occupational and Environmental Health*. 84(6): 665-674.

Kabir, A., Farhana, N., Akter, F., Jesmin, S., and Ali, A. (2015). Sweeping practices, perceptions and knowledge about occupational safety and health hazards of street sweepers in Dhaka city, Bangladesh: a qualitative inquiry. *International Journal of Community Medicine and Public Health*. 2(3): 237-243.

Kahar, M. A. (2022). Erythrocyte sedimentation rate (with its inherent limitations) remains a useful investigation in contemporary clinical practice. *Annals of Pathology and Laboratory Medicine*. 9: R9–R17.

Kalogeris, T., Baines, C. P., Krenz, M. and Korthuis, R. J. (2016). Ischemia/reperfusion. *Comprehensive Physiology*. 7(1): 113.

Kassenga, G. R., Mbuligwe, S. E. and Lyimo, S. C. (2018). Occupational hazards and health problems among municipal solid waste collectors in Dar es Salaam, Tanzania. *Journal of Environmental and Public Health*. 20(1): 1-9.

Kattula, S., Byrnes, J. R. and Wolberg, A. S. (2017). Fibrinogen and fibrin in haemostasis and thrombosis. *Arteriosclerosis, Thrombosis, and Vascular Biology*. 37(3): e13-e21.

Kaur, S., Mayanglambam, P., Bajwan, D. and Thakur, N. (2022). Chemotherapy and its adverse effects-A systematic review. *International Journal of Nursing Education and Research*. 10(4): 399-402.

Kell, D. B., Laubscher, G. J. and Pretorius, E. (2022). A central role for amyloid fibrin microclots in long COVID/PASC: origins and therapeutic implications. *Biochemical Journal*. 479(4): 537-559.

Köhler, S., Schmid, F. and Settanni, G. (2015). The internal dynamics of fibrinogen and its implications for coagulation and adsorption. *PLOS Computational Biology*. 11(9): e1004346.

Koriko, O. K., Adegbie, K. S., Shah, N. A., Animasaun, I. L., and Olotu, M. A. (2024). Numerical solutions of the partial differential equations for investigating the significance of partial slip due to lateral velocity and viscous dissipation: the case of blood-gold Carreau nanofluid and dusty fluid. *Numerical Methods for Partial Differential Equations*. 40(2): e22754.

Kratz, A., Plebani, M., Peng, M., Lee, Y. K., McCafferty, R., Machin, S. J. and International Council for Standardization in Haematology (ICSH). (2017). ICSH recommendations for modified and alternate methods measuring the erythrocyte sedimentation rate. *International Journal of Laboratory Hematology*. 39(5): 448–457.

Kressel, G., Trunz, B., Bub, A., Hülsmann, O., Wolters, M., Lichtinghagen, R. and Hahn, A. (2009). Systemic and vascular markers of inflammation in relation to metabolic syndrome and insulin resistance in adults with elevated atherosclerosis risk. *Atherosclerosis*. 202(1): 263-271.

Kulkarni, M. S. and Deep, G. S. (2020). Detection of arthritis by erythrocyte sedimentation rate (ESR) test—A review. *Research Journal of Pharmacology and Pharmacodynamics*. 12(4): 177-180.

Laleman, W., Claria, J., Van der Merwe, S., Moreau, R. and Trebicka, J. (2018). Systemic inflammation and acute-on-chronic liver failure: too much, not enough. *Canadian Journal of Gastroenterology and Hepatology*. 2018(1): 1027152.

Lapić, I., Padoan, A., Bozzato, D., and Plebani, M. (2020). Erythrocyte sedimentation rate and C-reactive protein in acute inflammation: meta-analysis of diagnostic accuracy studies. *American Journal of Clinical Pathology*. 153(1): 14-29.

Lessa, R. S., and Fernandes, R. D. C. P. (2022). Lower extremity pain, physical and psychological demands in urban cleaning workers: a cross-sectional study. *Revista Brasileira de Saúde Ocupacional*. 47: e2.

Lin, C., Pan, H., Qiao, Y., Huang, P., Su, J. and Liu, J. (2021). Fibrinogen level combined with platelet count for predicting haemorrhagic transformation in acute ischemic stroke patients treated with mechanical thrombectomy. *Frontiers in Neurology*. 12: 716020.

Litvinov, R. I., Pieters, M., de Lange-Loots, Z. and Weisel, J. W. (2020). Fibrinogen and fibrin. *Macromolecular Protein Complexes III: Structure and Function*. 471–501.

Lo Presti, R., Hopps, E., and Caimi, G. (2014). Hemorheological abnormalities in human arterial hypertension. *Korea-Australia Rheology Journal*. 26(2): 199-204.

Lu, M., Rab, M. A., Shevkoplyas, S. S. and Sheehan, V. A. (2020). Blood rheology biomarkers in sickle cell disease. *Experimental Biology and Medicine*. 245(2): 155-165.

Mackie, I., Casini, A., Pieters, M., Pruthi, R., Reilly-Stitt, C. and Suzuki, A. (2024). International council for standardisation in haematology recommendations on fibrinogen assays, thrombin clotting time and related tests in the investigation of bleeding disorders. *International Journal of Laboratory Hematology*. 46(1): 20-32.

Makris, K., Haliassos, A., Chondrogianni, M. and Tsivgoulis, G. (2018). Blood biomarkers in ischemic stroke: potential role and challenges in clinical practice and research. *Critical Reviews in Clinical Laboratory Sciences*. 55(5): 294-328.

Medved, L. and Weisel, J. W. (2022). The story of the fibrin(ogen) αC-domains: evolution of our view on their structure and interactions. *Thrombosis and Haemostasis*. 122(8): 1265–1278.

Menzel, A., Samouda, H., Dohet, F., Loap, S., Ellulu, M. S. and Bohn, T. (2021). Common and novel markers for measuring inflammation and oxidative stress ex vivo in

research and clinical practice—which to use regarding disease outcomes? *Antioxidants*. 10(3): 414.

Militello, C., Pasquini, A., Medina Valentin, A. A., Simčič, P., De Feo, G. and Lubas, G. (2020). The canine erythrocyte sedimentation rate (ESR): evaluation of a point-of-care testing device (MINIPET DIESSE). *Veterinary Medicine International*. 2020(1): 3146845.

Moerloose, P., Boehlen, F. and Neerman-Arbez, M. (2010). Fibrinogen and the risk of thrombosis. *Seminars in Thrombosis and Hemostasis*. 31(1): 7–17.

Mosesson, M. W. (2005). Fibrinogen and fibrin structure and functions. *Journal of Thrombosis and Haemostasis*. 3(8): 1894-1904.

Munubi, A. A. and EHS, B. (2017). Effects of occupational health hazards on street cleaners' health in Eldoret town, Uasin Gishu County, Kenya. *International Journal of Health and Pharmacy Research*. 3(4): 1-0.

Nader, E., Skinner, S., Romana, M., Fort, R., Lemonne, N., Guillot, N. and Connes, P. (2019). Blood rheology: key parameters, impact on blood flow, role in sickle cell disease and effects of exercise. *Frontiers in Physiology*. 10: 1329.

Nencini, F., Bettiol, A., Argento, F. R., Borghi, S., Giurranna, E., Emmi, G. and Becatti, M. (2024). Post-translational modifications of fibrinogen: implications for clotting, fibrin structure and degradation. *Molecular Biomedicine*. 5(1): 45.

Nersesjan, V., Zervides, K. A., Sørensen, A. L., Kjær, L., Skov, V. and Hasselbalch, H. C. (2020). The red blood cell count and the erythrocyte sedimentation rate in the diagnosis of polycythaemia vera. *European Journal of Haematology*. 104(1): 46–54.

Nunns, G. R., Moore, E. E., Chapman, M. P., Moore, H. B., Stettler, G. R., Peltz, E. and Sauaia, A. (2017). The hypercoagulability paradox of chronic kidney disease: The role of fibrinogen. *The American Journal of Surgery*. 214(6): 1215-1222.

Nyanza, E. C., Jackson, S. O., Magoha, L., Chilipweli, P., Joshua, J., and Madullu, M. T. (2024). Perceived occupational health risks, noise and dust exposure levels among street sweepers in Mwanza City in Northern Tanzania. *PLOS Global Public Health*. 4(2): e0002951.

Obeagu, E. I. (2024). Red blood cells as biomarkers and mediators in complications of diabetes mellitus: A review. *Medicine*. 103(8): e37265.

Obeagu, E. I., Muhimbura, E., Kagenderezo, B. P., Nakyeyune, S. and Obeagu, G. U. (2022). An Insight of Interleukin-6 and Fibrinogen: In Regulating the Immune System. *Journal of Biomedical Science*. 11(10): 83.

Orinya, O. F., Elom, S. O., Agbafor, K. N., Akubugwo, E. I., Okoroh, P. N., Ikwuazom, O. O. and Agu, K. A. (2024). Impact of Quarry Dust on Haematological and Hepatic Parameters of Guinea Pigs Exposed to Quarry Dust at Umuoghara and Amoffia NGBO Quarry Sites of Ebonyi State. *Systematic Reviews in Pharmacy*. 15(11): 10-15.

Orr, C. K., Najm, A., Young, F., McGarry, T., Biniecka, M., Fearon, U. and Veale, D. J. (2018). The utility and limitations of CRP, ESR and DAS28-CRP in appraising disease activity in rheumatoid arthritis. *Frontiers in Medicine*. 5: 185.

Orrico, F., Laurance, S., Lopez, A. C., Lefevre, S. D., Thomson, L., Möller, M. N. and Ostuni, M. A. (2023). Oxidative stress in healthy and pathological red blood cells. *Biomolecules*. 13(8): 1262.

Ositadinma, I. M., Ikponmwosa, O. S. and Okechukwu, O. C. (2015). Haemorheology and Red Cell indices in HIV Positive Individuals on Antiretroviral Therapy in Delta State, Nigeria. *International Journal of Current Research and Review*. 7(12): 24.

Park, J., Lee, J. and Lee, M. S. (2020). Occupational health injuries by job characteristics and working environment among street cleaners in South Korea. *International Journal of Environmental Research and Public Health*. 17(7): 2322.

Piantadosi, C. A. (2019). Toxicity of carbon monoxide: hemoglobin vs. histotoxic mechanisms. In *Carbon Monoxide*. CRC Press. Pp. 163-186.

Poole, C. J. M. and Basu, S. (2017). Systematic Review: Occupational illness in the waste and recycling sector. *Occupational Medicine*. 67(8): 626-636.

Popescu, L., Arsene, A. L. and Georgescu, L. C. (2011). Health risks associated with occupational exposure to heavy metals in waste collection workers. *Environmental Research and Development*. 6(1): 163-169.

Quinn, J. G., Tansey, E. A., Johnson, C. D., Roe, S. M. and Montgomery, L. E. A. (2016). Blood: tests used to assess the physiological and immunological properties of blood. *Advances in Physiology Education*. 40(2): 165–175.

Rakanita, Y., Sinuraya, R. K., Suradji, E. W., Suwantika, A. A., Syamsunarno, M. R. A. and Abdulah, R. (2020). The Challenges in Eradication of Iron Deficiency Anemia in Developing Countries. *Systematic Reviews in Pharmacy*. 11(5): 1-5.

Rodrigues, T., Mota, R., Gales, L., and Campo-Deaño, L. (2022). Understanding the complex rheology of human blood plasma. *Journal of Rheology*. 66(4): 761-774.

Rohleder, N. (2019). Stress and inflammation–The need to address the gap in the transition between acute and chronic stress effects. *Psychoneuroendocrinology*. 105(2): 164-171.

Roy, M. and Chakraborty, S. (2024). How does the stiffness of blood vessel walls and deposited plaques impact coronary artery diseases? *Physics of Fluids*. 36(8).

Saldanha, C. and Silva-Herdade, A. S. (2018). Fibrinogen involvement in hemorheology and inflammation. *Advances in Medicine and Biology*. 128: 115-146.

Schapkaitz, E., RabuRabu, S. and Engelbrecht, M. (2019). Differences in erythrocyte sedimentation rates using a modified Westergren method and an alternate method. *Journal of Clinical Laboratory Analysis*. 33(2): e22661.

Scharf, P., Broering, M. F., Oliveira da Rocha, G. H. and Farsky, S. H. P. (2020). Cellular and molecular mechanisms of environmental pollutants on hematopoiesis. *International Journal of Molecular Sciences*. 21(19): 6996.

Schmid-Schönbein, H. (2019). Fluid dynamics and hemorheology in vivo: the interactions of hemodynamic parameters and hemorheological “properties” in determining the flow behaviour of blood in microvascular networks. *Clinical Blood Rheology*. Pp. 129-219.

Seringec, N., Guncu, G., Arihan, O., Avcu, N. and Dikmenoglu, N. (2015). Investigation of hemorheological parameters in periodontal diseases. *Clinical Hemorheology and Microcirculation*. 61(1): 47-58.

Siemińska, I., Poljańska, E. and Baran, J. (2021). Granulocytes and cells of granulocyte origin—the relevant players in colorectal cancer. *International Journal of Molecular Sciences*. 22(7): 3801.

Siemons, L., Ten Klooster, P. M., Vonkeman, H. E., van Riel, P. L., Glas, C. A. and van de Laar, M. A. (2014). How age and sex affect the erythrocyte sedimentation rate and C-reactive protein in early rheumatoid arthritis. *BMC Musculoskeletal Disorders*. 15(1): 368.

Simeon, C. A., Beega, G. F., Abiola, S. A., Wofuru, C. D. and Eze, C. C. (2024). Significance of inflammatory biomarkers in clinical diagnostics: Erythrocyte sedimentation rate versus other inflammatory biomarkers—A review. *International Journal of Science and Research Archive*. 12(1): 1980-1995.

Singh, T., Hasan, M., Gaule, T. G. and Ajjan, R. A. (2025). Exploiting the molecular properties of fibrinogen to control bleeding following vascular injury. *International Journal of Molecular Sciences*. 26(3): 1336.

Slutskaya, N., Simpson, R., Hughes, J., Simpson, A., and Uygur, S. (2016). Masculinity and class in the context of dirty work. *Gender, Work and Organization*. 23(2): 165-182.

Smith, S. A., Travers, R. J. and Morrissey, J. H. (2015). How it all starts: Initiation of the clotting cascade. *Critical Reviews in Biochemistry and Molecular Biology*. 50(4): 326-336.

Song, S. H., Kim, J. H., Lee, J. H., Yun, Y. M., Choi, D. H. and Kim, H. Y. (2017). Elevated blood viscosity is associated with cerebral small vessel disease in patients with acute ischemic stroke. *BMC Neurology*. 17(1): 20.

Soria, J., Mirshahi, S., Mirshahi, S. Q., Varin, R., Pritchard, L. L., Soria, C. and Mirshahi, M. (2019). Fibrinogen αC domain: its importance in physiopathology. *Research and Practice in Thrombosis and Haemostasis*. 3(2): 173-183.

Sovová, Ž., Štikarová, J., Kaufmanová, J., Májek, P., Suttnar, J., Šácha, P. and Dyr, J. E. (2020). Impact of posttranslational modifications on atomistic structure of fibrinogen. *PLoS One*. 15(1): e0227543.

Sun, W., Song, X., Dong, M., Liu, Z., Song, Y., Wang, L. and Song, L. (2021). DNA binding protein CgIkaros-like regulates the proliferation of agranulocytes and granulocytes in oyster (Crassostrea gigas). *Developmental and Comparative Immunology*. 124: 104201.

Tehrani, A. M., Berijani, N., Hajiketabi, S. and Samadi, M. (2024). Tracking bioaerosol exposure among municipal solid waste workers using hematological and inflammatory biomarkers. *Environmental Pollution*. 352(1): 124124.

Tijjani, A. U., Yusuf, A. A. and Kuliya-Gwarzo, A. (2024). Lower Hematocrit is Associated with High Oxidative Stress and Low Antioxidant Status in Men Occupationally Exposed to Petrol. *Nigerian Journal of Basic and Clinical Sciences*. 21(1): 65-72.

Tolera, S. T., Temesgen, S., Mulat Endalew, S., Alamirew, T. S., and Temesgen, L. M. (2023). Global systematic review of occupational health and safety outcomes among sanitation and hygiene workers. *Frontiers in Public Health*. 11: 1304977.

Trejo-Soto, C., Lázaro, G. R., Pagonabarraga, I., and Hernández-Machado, A. (2022). Microfluidics approach to the mechanical properties of red blood cell membrane and their effect on blood rheology. *Membranes*. 12(2): 217.

Valeanu, L., Ginghina, C. and Bubenek-Turconi, S. (2022). Blood rheology alterations in patients with cardiovascular diseases. *Romanian Journal of Anaesthesia and Intensive Care*. 28(2): 41.

Van Kampen, V., Hoffmeyer, F., Seifert, C., Brüning, T. and Bünger, J. (2020). Occupational health hazards of street cleaners–a literature review considering prevention practices at the workplace. *International Journal of Occupational Medicine and Environmental Health*. 33(6): 701-732.

Vasilieva, A. D., Yurina, L. V., Azarova, D. Y., Ivanov, V. S., Strelnikova, P. A., Bugrova, A. E. and Rosenfeld, M. A. (2022). Development of a diagnostic approach based on the detection of post-translation modifications of fibrinogen associated with oxidative stress by the method of high efficiency liquid chromatography. *Russian Journal of Physical Chemistry B*. 16(1): 118–122.

Velasco Garrido, M., Bittner, C., Harth, V. and Preisser, A. M. (2015). Health status and health-related quality of life of municipal waste collection workers–a cross-sectional survey. *Journal of Occupational Medicine and Toxicology*. 10(1): 22.

Vijayaraghavan, M., Chatterjee, S., Sumantran, V. N. and Jayavelu, T. (2022). Revisiting dextran effect on red blood cell to understand the importance of rouleaux distribution and red blood cell-endothelial cell adhesion. *Biomass Conversion and Biorefinery*. 2(1): 1-11.

Vilar, R., Fish, R. J., Casini, A. and Neerman-Arbez, M. (2020). Fibrin(ogen) in human disease: both friend and foe. *Haematologica*. 105(2): 284.

Wahab, B. and Ogunlola, B. (2014). The nature and challenges of street sweeping in Ado-Ekiti. *African Journal for the Psychological Studies of Social Issues*. 17(3): 145-153.

Walser, S. M., Gerstner, D. G., Brenner, B., Bünger, J., Eikmann, T., Janssen, B., Kolb, S., Kolk, A., Nowak, D., Raulf, M. and Sagunski, H. (2015). Evaluation of exposure–response relationships for health effects of microbial bioaerosols–a systematic review. *International Journal of Hygiene and Environmental Health*. 218(7): 577-589.

Wang, Q., and Zennadi, R. (2020). Oxidative stress and thrombosis during aging: the roles of oxidative stress in RBCs in venous thrombosis. *International Journal of Molecular Sciences*. 21(12): 4259.

Weisel, J. W. (2005). Fibrinogen and fibrin. *Advances in Protein Chemistry*. 70(2): 247-299.

Wolberg, A. S. (2023). Fibrinogen and fibrin: synthesis, structure, and function in health and disease. *Journal of Thrombosis and Haemostasis*. 21(11): 3005-3015.

Wright, R. J., and Frier, B. M. (2008). Vascular disease and diabetes: is hypoglycemia an aggravating factor? *Diabetes/Metabolism Research and Reviews*. 24(5): 353-363.

Yamanishi, Y., Miyake, K., Iki, M., Tsutsui, H. and Karasuyama, H. (2017). Recent advances in understanding basophil-mediated Th2 immune responses. *Immunological Reviews*. 278(1): 237-245.

Yunoos, A. and Dankoly, U. (2021). Prevalence of low back pain among street cleaners in Northeastern Nigeria. *Nigerian Journal of Basic and Clinical Sciences*. 18(1): 24-30.

Zapata-Acevedo, J. F., García-Pérez, V., Cabezas-Pérez, R., Losada-Barragán, M., Vargas-Sánchez, K. and González-Reyes, R. E. (2022). Laminin as a biomarker of blood–brain barrier disruption under neuroinflammation: a systematic review. *International Journal of Molecular Sciences*. 23(12): 6788.

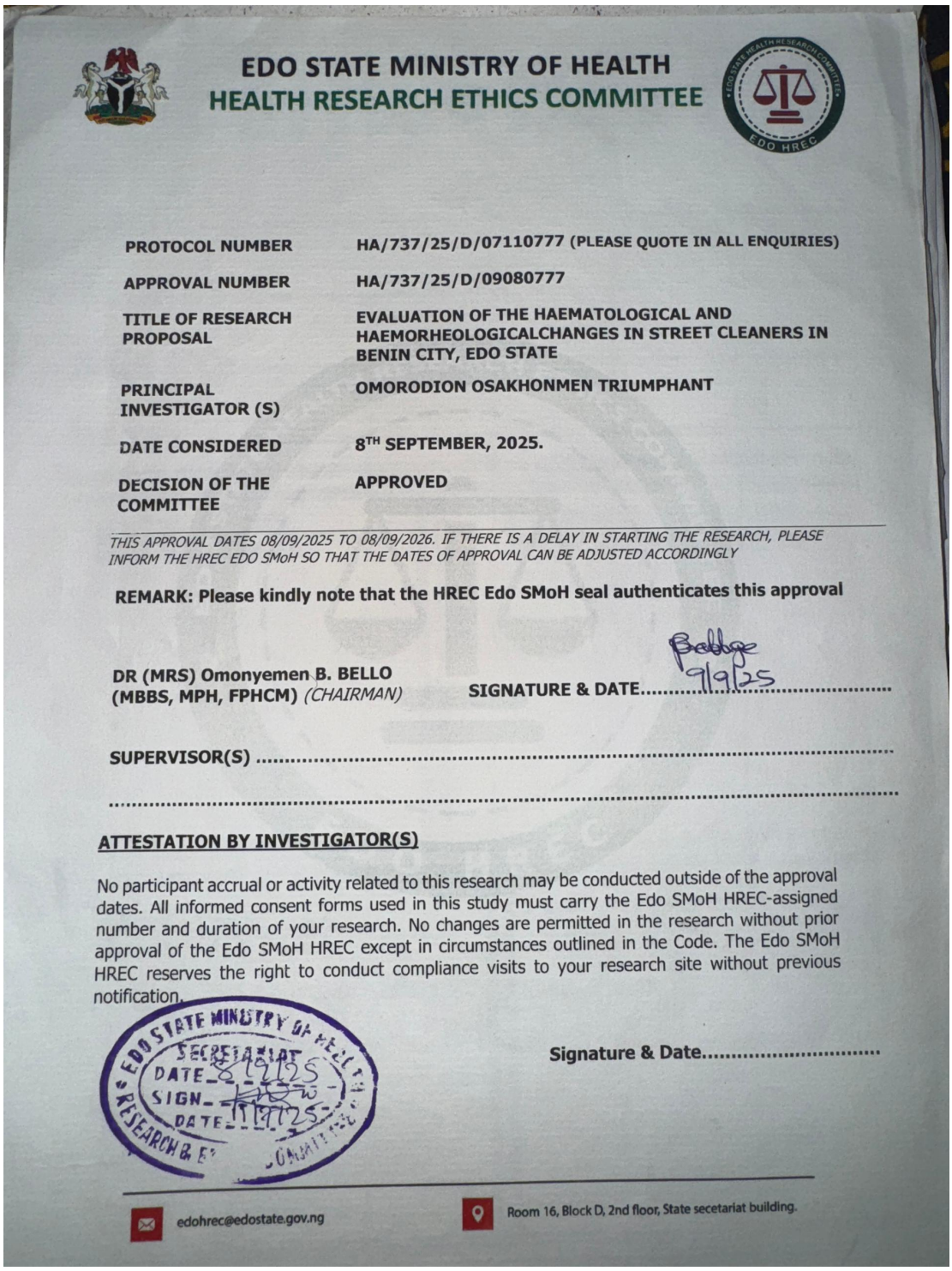
Zhou, Z., Xu, M. J. and Gao, B. (2016). Hepatocytes: a key cell type for innate immunity. *Cellular and Molecular Immunology*. 13(3): 301-315.

Zivot, A., Lipton, J. M., Narla, A. and Blanc, L. (2018). Erythropoiesis: insights into pathophysiology and treatments in 2017. *Molecular Medicine*. 24(1): 11-16.

Zuliani-Alvarez, L. and Midwood, K. S. (2015). Fibrinogen-related proteins in tissue repair: how a unique domain with a common structure controls diverse aspects of wound healing. *Advances in Wound Care*. 4(5): 273-285.

APPENDIX I

ETHICAL APPROVAL



EDO STATE MINISTRY OF HEALTH
HEALTH RESEARCH ETHICS COMMITTEE

PROTOCOL NUMBER	**HA/737/25/D/07110777 (PLEASE QUOTE IN ALL ENQUIRIES)**
APPROVAL NUMBER	**HA/737/25/D/09080777**
TITLE OF RESEARCH PROPOSAL	**EVALUATION OF THE HAEMATOLOGICAL AND HAEMORHEOLOGICALCHANGES IN STREET CLEANERS IN BENIN CITY, EDO STATE**
PRINCIPAL INVESTIGATOR (S)	**OMORODION OSAKHONMEN TRIUMPHANT**
DATE CONSIDERED	**8TH SEPTEMBER, 2025.**
DECISION OF THE COMMITTEE	**APPROVED**

THIS APPROVAL DATES 08/09/2025 TO 08/09/2026. IF THERE IS A DELAY IN STARTING THE RESEARCH, PLEASE INFORM THE HREC EDO SMoH SO THAT THE DATES OF APPROVAL CAN BE ADJUSTED ACCORDINGLY

REMARK: Please kindly note that the HREC Edo SMoH seal authenticates this approval

DR (MRS) Omonyemen B. BELLO
(MBBS, MPH, FPHCM) *(CHAIRMAN)* **SIGNATURE & DATE**..... 9/9/25

SUPERVISOR(S) .....

.....

ATTESTATION BY INVESTIGATOR(S)

No participant accrual or activity related to this research may be conducted outside of the approval dates. All informed consent forms used in this study must carry the Edo SMoH HREC-assigned number and duration of your research. No changes are permitted in the research without prior approval of the Edo SMoH HREC except in circumstances outlined in the Code. The Edo SMoH HREC reserves the right to conduct compliance visits to your research site without previous notification.

EDO STATE MINISTRY OF HEALTH SECRETARIAT DATE 8/9/25 SIGN DATE 11/9/25 RESEARCH & E

Signature & Date.....

edohrec@edostate.gov.ng

Room 16, Block D, 2nd floor, State secetariat building.

APPENDIX II

QUESTIONNAIRE FOR STREET CLEANERS AND CONTROL GROUP IN BENIN CITY

Research Topic: Evaluation of the Haematological and Haemorheological changes in street cleaners in Benin City, Edo state.

SECTION A (SOCIODEMOGRAPHICS)

1. Age (in years): _____
2. Gender: ☐ Male ☐ Female
3. Marital Status: ☐ Single ☐ Married ☐ Divorced/Separated ☐ Widowed
4. Highest Educational Qualification: ☐ No formal education ☐ Primary ☐ Secondary ☐ Tertiary
5. Religion: ☐ Christianity ☐ Islam ☐ Traditional

SECTION B: OCCUPATIONAL INFORMATION (FOR STREET CLEANERS ONLY)

1. If you are in the Control Group, please skip
2. Are you a street cleaner? ☐ Yes ☐ No (If no, end interview)
3. How long on the job? ☐ <1 year ☐ 1–5 years ☐ 6–10 years ☐ >10 years
4. How many hours per day? ☐ <4 hrs ☐ 4–8 hrs ☐ >8 hrs
5. How many days per week? ☐ <3 days ☐ 3–5 days ☐ 6–7 days
6. PPE used? (Tick all that apply) ☐ Gloves ☐ Face/Nose mask ☐ Goggles ☐ Boots ☐ Overalls ☐ None ☐ Other: _____
7. How often PPE used? ☐ Always ☐ Most times ☐ Sometimes ☐ Rarely ☐ Never
8. Types of waste handled? (Tick all that apply) ☐ Household ☐ Dust/Sand ☐ Industrial/Chemical ☐ Medical ☐ Animal ☐ Glass/Sharps ☐ Human waste ☐ Other: _____
9. Access to water/soap for handwashing? ☐ Yes ☐ No ☐ Sometimes

APPENDIX III

INFORMED CONSENT FORM

To the Participant:

I understand that my participation in this study is voluntary and I can withdraw at any time without any penalty. I have read and understood the information provided about this study, including the purpose of collecting blood samples for haematological and haemorheological analysis.

I understand that the blood sample will be collected by a qualified health professional and will be used solely for the purpose of this research. My personal information will be kept confidential and my identity will not be revealed in any reports or publications.

[ ] I have read the above information and agree to provide a blood sample for this study.

[ ] I do not agree to provide a blood sample for this study.

Participant's Signature/Thumbprint: _____

Date: ___/___/___ (DD/MM/YYYY)

Interviewer's Name: _____

Interviewer's Signature: _____

Interviewer's Notes (Optional)

- Any difficulties encountered during the interview:
- Observations about the participant's general health or demeanour:
- Any additional relevant information: