Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: https://atbuscienceforum.com.ng/index.php/jpas

Trend and Pattern of Studies on Corrosion and Corrosion Science: Fundamentals of Corrosion Science and Application of Artificial Intelligence and Machine Learning

Ezekiel Oluwaseun FEHINTOLA

Department of Chemistry, Adeyemi Federal University of Education, Ondo, Nigeria

Abstract

Corrosion is a complex physicochemical process that results in the gradual degradation and loss of functional integrity of metallic materials due to interactions with their surrounding environment. Factors such as electrochemical reactions, aggressive chemical species, moisture, and elevated salt concentrations accelerate material deterioration, often leading to structural failure. Beyond the deterioration of engineering components, corrosion poses significant threats to human safety, environmental sustainability, and economic development. Its impacts are widespread across critical sectors including manufacturing, production, energy, transportation, and civil infrastructure. This study presents a comprehensive review of corrosion science, corrosion monitoring techniques, and emerging artificial intelligence (AI)-driven approaches for corrosion prediction and management. Relevant information was systematically collected, synthesized, and refined from journals, conference proceedings, theses, books, and other credible scientific sources published between 1800 and May 2026, covering a period of 226 years. Literature was obtained from major databases including Web of Science (WoS), Google Scholar, and the Multidisciplinary Digital Publishing Institute (MDPI). Bibliometric analysis revealed that 1,091,722 publications (approximately 4,831 articles annually) focused on corrosion and corrosion science, while 73,202 publications (approximately 324 articles annually) addressed the application of Artificial Intelligence (AI), Artificial Neural Networks (ANN), and Machine Learning (ML) in corrosion-related studies. Publication trends for both categories exhibited exponential growth. The review identified major corrosion forms, including erosion, cavitation, fretting, microbiologically influenced corrosion, atmospheric corrosion, fatigue corrosion, waterline corrosion, selective leaching, dry (chemical) corrosion, wet (electrochemical) corrosion, galvanic corrosion, pitting corrosion, stress-corrosion cracking, and intergranular corrosion. Corrosion monitoring and detection techniques were classified into Visual Inspection, Non-Destructive Testing (NDT), Destructive Testing (DT), and Analytical Techniques. Furthermore, AI-, ANN-, and ML-based models have significantly enhanced the speed, efficiency, and accuracy of corrosion prediction. The study concludes that early corrosion prediction, coupled with effective monitoring and control strategies, can substantially reduce economic losses, while AI-driven approaches offer practical advantages over traditional methods, particularly in inaccessible or hazardous environments.

Keywords

Corrosion Management, Corrosion Risks, Corrosion Monitoring Techniques, Benefits, Selection, Advanced Technologies, Machine Learning, Artificial Intelligence

ISSN 1119-4618 JPAS

Faculty of Science, ATBU Bauchi

Corresponding Author Ezekiel Oluwaseun FEHINTOLA Department of Chemistry, Adeyemi Federal University of Education, Ondo, Nigeria

INTRODUCTION

Corrosion is a main problem in industries and organisations such as oil and gas industries, chemical manufacturing and processing industries, civil and construction engineering, marine and hydraulic engineering, highway and transportation engineering, because corrosion reduces the life span and strength, appearance, and physical features of materials as well as equipment needed for all these industries and engineering processes (Li et al., 2015, Chouhan et al., 2013; Jawad et al., 2026). "Corrosion remains a persistent and costly challenge in infrastructure and manufacturing systems, affecting the longevity, safety, and efficiency of metallic components and structures. Corrosion continues to pose significant challenges across various infrastructures and manufacturing systems, compromising the structural integrity and functionality of metallic and composite materials in essential constructions such as bridges, pipelines, and offshore platforms, and affecting production machinery and assembly lines" (Adeleke and Peter, 2021; Oladosu et al., 2021 a and b, Onukwulu, et al., 2021, Adewoyin et al., 2023). Figure 1 presents the effects of corrosion on an industrial cooling pipeline.

The appearances of corrosion are diverse. The appearance of corrosion is in the form of atmospheric corrosion, uniform corrosion, pitting corrosion, stress corrosion, crevice corrosion, erosion corrosion, selective corrosion, fretting corrosion, intergranular corrosion, cracking or corrosion fatigue, galvanic corrosion, and waterline corrosion. Figure 2 shows a selected form of corrosion available. Each of these forms of corrosion is influenced by a multifaceted interaction of environmental, operational factors, and materials (Liu et al., 2021; Adewoyin et al., 2023). Despite the development, manufacturing, and applications of protective varnishes and corrosion inhibitors, the economic impact and effects of corrosion remain deep. Corrosion generates annual losses valued in the trillions of American dollars (US$) due to equipment replacement and maintenance, machine dysfunction, risk, and safety incidents (Elmas et al., 2023; Adewoyin et al., 2023).

Figure 1: the effects of corrosion on an industrial cooling pipeline

Figure 2a: a selected form of corrosion available

Figure 2b: a selected form of corrosion available

The economic burden of corrosion can be attributed to several factors and assessments across sectors such as oil and gas industries, transportation and highway industries, energy and chemical processing, and construction and civil engineering. These highlighted sectors and many other sectors have witnessed calamitous events emphasizing the cruciality of vigorous and the importance of corrosion science, prevention practices and knowledge (Ogunwole, et al., 2022, Onukwulu, et al., 2022; Okeke, et al., 2022, Adewoyin et al., 2023; Souza et al., 2025 Talbot, and Talbot2018. Tan et al., 2026, Thakur et al.,2026, Ulhaq 2025, Usman et al.,2025 Yang et al., 2026, Yuldashova et al.,2026). Notable catastrophes caused by corrosion are pipeline ruptures, bridge collapses and shutdown of engines due to mechanical faults, which are the highlight of the potential consequences that endanger operational continuity, human risk and safety, as well as ecological integrity (Elmas et al., 2023, Adewoyin et al., 2023). "The weakening of metallic structures due to corrosion can cause structural failures that endanger people's lives. Furthermore, the corrosion of pipelines and equipment can result in spills of hazardous and polluting substances, leading to detrimental ecological and human effects" (Ruiz et al., 2024; Oyetola, 2026, Palit, 2018, Pedeferri et al., 2018, Qamar and Zardari, 2023; Rajendran and Subbian, 2026; Ridwan et al., 2026; Rodrigo et al., 2026 , Ruiz et al., 2024, Ryl, 2020, Saminathan et al., 2024, Sastri,1998, Sheldon2018, Singh et al.,2025a.. and b).

Corrosion monitoring is a management practice of deliberately averting corrosion effects and harm with an effort to safeguard tangible and valuable assets (Guma and Dele, 2025) . The urgency for active knowledge of corrosion, corrosion detection, corrosion science, corrosion monitoring, and corrosion predictive procedures is strong, particularly given that there is a growing regulatory scrutiny of immediate infrastructure integrity and veracity (Ossai, 2019; Adewoyin et al., 2023). Traditional modelling practices for corrosion, corrosion detection, corrosion science, corrosion monitoring, and corrosion prediction are foundational and fundamental, but often fail to capture the complex, dynamic nature of real-world corrosion situations. Many conventional models depend heavily on empirical data resulting from laboratory backgrounds and basic mathematical frameworks, which are inadequate to address the unpredictability in features (temperature, pressure, material properties and relative humidity (Ossai, 2019: Adewoyin et al., 2023). These limitations often result in conventional predictions that do not accurately show or reflect actual corrosion rates, resulting in excessive maintenance interventions and unanticipated or surprising equipment failures (Ossai, 2019). These traditional approaches struggle to establish or provide the tailored or reliable insights required or needed for proactive infrastructure and corrosion management (Adewoyin et al., 2023).

Emerging trends in Artificial Intelligence (AI), Artificial Neural Network (ANN) and Machine Learning (ML) are restructuring the landscape of corrosion, corrosion modelling, and corrosion science by permitting the analysis of large and complex datasets. Machine learning techniques, such as support vector machines, supervised learning, and neural networks, are attractive and instrumental in discovering intricate patterns, trends, and relationships that conventional techniques might miss (Ogu, et al., 2023, Adebisi et al., 2023, Onukwulu, et al., 2023a and b, Adewoyin et al., 2023). These ANN, AI, and ML-enhanced models influence historical data from inspections, through environmental monitoring, and to material characteristics to establish and provide real-time predictive insights on corrosion properties and behaviour (Elmas et al., 2023; Adewoyin et al., 2023). These transitions not only boost the accuracy of corrosion rate forecasts but in-addition facilitate condition-based and situation-based maintenance and support risk-informed decision-making across several industrial and engineering sectors (Lin et al., 2023, Elmas et al., 2023; Adewoyin et al., 2023). Nonetheless, while ANN, AI and ML provide promising improvements, the quality and scope of datasets employed in these models frequently vary significantly. In addition, comprehensive datasets are necessary and needed to effectively train these AI systems. However, numerous and similar existing datasets can be biased or incomplete, thus limiting the generalizability or reliability of the resulting predictive models (Ma et al., 2021; Adewoyin et al., 2023). Future research and studies on AI, ANN and ML must emphasize improving dataset quality and quantity, standardizing data assemblage practices, and professionally integrating machine learning models into real-world monitoring systems and facilities to enhance the prediction capabilities, practical applicability and reliability (Lin et al., 2023). In summary, these inquiries underscore the imperative for continuous study and research, and improve development in the realm of AI-augmented corrosion science and corrosion modelling.

It has been documented that in the last three decades; several studies and research have focused on the national and global economic impact of corrosion. Through different and several approaches, all these studies have determined and evaluated costs equivalent damage caused by corrosion to be between 3.0 and 4.0 % of each nation's gross domestic product (GDP). In Europe (Spain), the cost amounts to over 4.0×10^7 EUR in the year 2022 (Ruiz et al., 2024). These economic losses through the impact of corrosion have a negative influence on the competitiveness of industries and institutions and, consequently, an overall impact on the country's economic development and growth. The overall implementation of effective knowledge on corrosion and corrosion science, corrosion models and scientific management of corrosion could reduce national and global expenditure between 2.5×10^1 and 3.0×10^1 % (Ruiz et al., 2024). In addition, the implications of the impact of corrosion for safety, risk and on the environment are more significant (Okeke, et al., 2022, Olisakwe et al., 2022, Lin et al., 2023, Ruiz et al., 2024, Adewoyin et al., 2023). With the knowledge of corrosion, corrosion science, scientific management of corrosion and improved development in the realm of AI-augmented corrosion science and corrosion modelling, these negative impacts of corrosion on national and global expenditure can be reduced. The objectives of this review are to provide data and information on the trend and pattern of studies on corrosion and corrosion science through the fundamentals of corrosion science and the application of artificial intelligence and machine learning, with the key aim of enhancing the efficacy of corrosion management strategies and fostering greater resilience in critical infrastructure.

MATERIALS AND METHODS

The main tool utilised for identifying relevant literature for this review was general academic search engines, aggregators and discipline-specific and regional repositories such as Web of Science, Public Library of Science (PLOS), E-Theses Online Service (ETHOS), Royal Society of Chemistry, Google Scholar or CORE were used to identify and establish relevant papers. Citation managers such as Mendeley, Zotero, and EndNote were used to store, tag, and annotate the articles downloaded. Articles between 1800 and May 2026 of the keywords were sorted by publication year, relevance, subject area, or keyword to avoid information overload. The keywords such as corrosion, corrosion science, machine learning, artificial intelligence, deep learning, corrosion in material science, simulation of corrosion, atmospheric corrosion, pitting corrosion and metallic materials, alloys, carbon steel, reinforced concrete, different models using artificial neural network (ANN), random forest (RF), support vector machine (SVM) and optimization were used individually and in combination. In the research, peer-reviewed articles written and published in English were downloaded, considered, and evaluated. Review papers, conference and workshop abstracts, and studies not directly related to the keywords were excluded. The data and obtained information were analysed using Microsoft Excel.

RESEARCH FINDINGS

The results of the research findings are presented and discussed as follows:

- **Definitions of Corrosion**

Corrosion has been defined as "The steady either deterioration or degradation of a metal or metallic material due to either chemical or electrochemical reaction within the surrounding environment of the metal.". Another simple definition says that "Corrosion is the destructive attack of a metal by its environment.". Corrosion is a natural process that causes the gradual destruction or deterioration of metals and other materials due to either chemical or electrochemical reactions with their environment. Corrosion is the process by which metallic material either degrades or loses its initial quality due to several factors, such as chemical reactions in the environment and high concentrations of salts, leading to efficient failure of the component ((Harsimran et al., 2021; Ibrahimi et al., 2021; Rajendran and Subbian, 2025). Corrosion frequently occurs when metals or metallic substances are exposed to moisture, air, acids, high concentrations of salts, high concentrations of dissolved solids in water or air, or other corrosive substances (Odeyemi and Alaba, 2025; Adewoyin et al., 2023, Jumbo-Egwurugwu et al., 2026). Corrosion is referred to as either a natural process or a process in which solid substances, specifically metallic substances or metals, undergo modification in physical or chemical properties through chemical reactions with oxygen (as either oxidation or reduction, redox). "Corrosion refers to a process wherein a solid substance, specifically a metal, undergoes alteration through a chemical reaction with oxygen. It entails the gradual deterioration of the material, characterized by its consumption or erosion over time. In a broader sense, corrosion can be understood as the general tendency of materials to seek a state of greater stability or lower internal energy" (Fehintola, 2021; Abdulmutaali et al., 2025; Adebisi et al., 2023a. Adebisi et al.,2023b, Adebisi et al., 2023c, Adebisi et al., 2021 , Adeleke and Peter, 2021, Adewoyin et al., 2023, Aljibori et al., 2023a, Aljibori et al., 2023b, ASTM, 2002, Chen et al., 2025., Chouhan et al., 2013, Coelho et al., 2022, Elmas et al., 2023, Fehintola 2021, Guma and Dele, 2025, Guo and Rong, 2026, Hamid and Gomaa, 2025, Harsimran et al., 2021).

"Corrosion is a natural process that converts a refined metal to a more chemically stable form, such as its oxides, hydroxides, or sulphides. It is the gradual destruction of materials (usually metals) by chemical and/or electrochemical reactions within their environment. The term corrosion can be defined as the interaction (electrochemical reaction) of a metal with the surrounding environment, causing a slow, steady and irreversible deterioration in the metal, in both physical and chemical properties " (Sastri, 1998, Fehintola, 2021), Corrosion is the product of the destruction of a metal as a result of an electrochemical reaction between the metal or alloy and its surrounding environment. (Jones,1996, Fehintola, 2021). American Society for Testing and Materials (ASTM International, 2002) defined corrosion as the deterioration of different types of materials, usually metals as a result of chemical or electrochemical reaction between the metal and the environment, producing material and weakening of its properties. Corrosion is an industrially and economically challenging environmental material degradation process that has a profound influence on human lives, with an overwhelming annual global cost of about 2.5 trillion dollars (Ruiz et al., 2024;

Ibrahimi et al., 2021, Imran et al., 2023, Jawad et al., 2026, Jones 1996, Jumbo-Egwurugwu et al., 2026, Khalaf et al., 2024, Khalilov et al., 2026; Kucharlapati et al., 2025, Kurtz et al., 2023, Li et al., 2015 Lin et al., .2023, Lin et al., 2023, Liu et al., 2021; Ma et al., 2021, Mubeen et al.,2026, Nrior et al., 2026.Odeyemi and Alaba2025. Ogu et al.,2023 , Ogunwole et al., 2022 , Okeke et al.,2022 , Okeke et al., 2022 , Okeke et al., .(2023d, Okeke et al., 2023c , Okeke et al., 2023b).

ISO (International Organization for Standardization, 2015) defined corrosion as the interaction between a metal and its environment, physico-chemically, that results in the variation in the properties of the metal and which may eventually lead to changes in the functions of the metal and the environment. Sheldon (2018) and Fehintola (2021) define corrosion as the product of the destruction of the electrochemical interaction between a metal or its alloys and its environment. "Corrosion is the weakening or destruction of metals and alloys in the presence of an environment by chemical or electrochemical means. In simple terminology, corrosion processes involve a reaction of metals with environmental species". Corrosion of metals is defined as the spontaneous destruction of metals chemically, electrochemically, or biochemically as a result of their interactions with the environment. Therefore, corrosion can be referred to as the opposite of the extraction of metals from ores. It is also known as the Destructive Oxidation Reaction of Metals by the environmental oxidizing agents. Rusting is the commonest form of corrosion. All metals, including the noble metals such as platinum, gold, silver and others. will undergo corrosion inasmuch as these metals are exposed to a powerful oxidizing agent that results in the formation of oxides, hydroxides and sometimes carbonates, sulphides, and even nitrides (Fehintola, 2021). "Corrosion of metals entails the gradual deterioration of the material, characterized by its consumption or erosion over time. In a broader sense, corrosion can be understood as the general tendency of materials to seek a state of greater stability or lower internal energy" (Fehintola, 2021).

- **Effects of Corrosion on the Materials**

The major impacts of corrosion on the materials can be summarised as weakening of metal structures, reduction of efficiency, performance and life of equipment, contamination of products, demand for high maintenance and replacement costs, and decreased both environmental and occupational safety, increased occupational hazards and environmental damage through air and water pollutions

- **Types of Corrosion**

Corrosion is the gradual deterioration of metals or alloys due to chemical or electrochemical reactions with their environment. The causes of corrosion can be summarised as metals tend to return to their natural state (ores) by reacting with substances in their environment and common corrosive environments: moisture, oxygen, acids, salts, and pollutants. Corrosion occurs in different forms depending on the environment, metal, and conditions of exposure. Types of corrosion can be expressed as follows (Figure 2; Ibrahimi et al., 2021, Imran et al., 2023, Jawad et al., 2026, Jones 1996, Jumbo-Egwurugwu et al., 2026, Khalaf et al., 2024, Khalilov et al., 2026; Kucharlapati et al., 2025, Kurtz et al., 2023, Li et al., 2015 Lin et al., .2023, Lin et al., 2023, Liu et al., 2021; Ma et al., 2021, Mubeen et al.,2026, Nrior et al., 2026.Odeyemi and Alaba2025. Ogu et al.,2023 , Ogunwole et al., 2022 , Okeke et al.,2022 , Okeke et al., 2022 , Okeke et al., .(2023d, Okeke et al., 2023c , Okeke et al., 2023b):

a) **Dry (Chemical) Corrosion: (**Direct reaction with gases at high temperatures). Dry corrosion, known as chemical corrosion, is the deterioration of a metal caused by a direct chemical reaction between the metal and specific dry gases in the absence of an aqueous (water-based) electrolyte. Dry corrosion usually occurs at high temperatures when metals are exposed to gases such as oxygen, sulphur dioxide, chlorine, hydrogen sulphide, or other reactive gases. The main mechanisms of dry Corrosion are as follows:

- The metal surface comes into contact with a dry corrosive gas.
- A chemical reaction occurs between the metal and the gas.
- A layer of corrosion product (oxide, sulphide, chloride) forms on the metal surface.
- The corrosion layer may either:
  i. Protect the metal by preventing further attack, or
  ii. Crack or flake off, exposing fresh metal and allowing continued corrosion.

The common types of dry Corrosion are as follows:

- Oxidation Corrosion (Occurs when metals react with oxygen at elevated temperatures.
- Sulphidation Corrosion (Occurs due to reaction with sulphur-containing gases).
- Halogen Corrosion (Occurs when metals react with chlorine, fluorine, or other halogens) and
- Liquid-Metal Corrosion (Occurs when a metal is attacked by a molten metal).

b) **Wet (Electrochemical) Corrosion**: (occurs in the presence of an electrolyte or moisture).

Wet corrosion is a type of corrosion that occurs when a metal is exposed to a liquid environment, usually containing water (like moisture, rain, or an electrolyte solution). It involves electrochemical reactions on the metal surface. In wet corrosion, tiny anodic and cathodic regions form on the metal, at the anode, metal atoms lose electrons (oxidation) and go into solution as ions, and at the cathode, a reduction reaction occurs (often involving oxygen or hydrogen ions). The presence of water or an electrolyte allows ions to move, completing the corrosion process. This process is also known as electrochemical corrosion. An example of wet corrosion is the rusting of iron in the presence of water and oxygen, which is a common case of wet corrosion.

c) **Galvanic Corrosion**: (occurs when two dissimilar metals are in electrical contact in an electrolyte. An example is the corrosion of steel bolts in contact with copper). Galvanic corrosion is a form of electrochemical corrosion that occurs when two dissimilar metals with similar charges or valencies are electrically connected in the presence of an electrolyte (such as water, seawater, or moist soil). In this situation, the more active (less noble) metal becomes the anode and corrodes, the more noble metal becomes the cathode and is protected, and the electrolyte allows the flow of ions, completing the corrosion circuit. The main mechanisms of galvanic corrosion are that two different metals are in electrical contact, an electrolyte is present, a potential difference develops between the metals, electrons flow from the anodic metal to the cathodic metal and the anodic metal loses metal ions and corrodes. An example of galvanic corrosion is when steel is connected to copper in seawater; the steel acts as the anode and corrodes, and copper acts as the cathode and remains protected. The key factors that affect galvanic corrosion are as follows:

- Difference in electrode potentials between the metals.
- Conductivity of the electrolyte.
- Ratio of cathode area to anode area.
- Temperature and environmental conditions.
- Distance between the metals

Types of Galvanic Corrosion

Galvanic corrosion is commonly classified according to the way the galvanic cell is formed as follows:

- **Dissimilar Metal Galvanic Corrosion:** Occurs when two different metals or alloys are in electrical contact in an electrolyte and the less noble metal acts as the anode and corrodes. An example of Galvanic corrosion is steel connected to copper in seawater.
- **Concentration Cell Corrosion**: Occurs when different areas of the same metal are exposed to different concentrations of oxygen, ions, or electrolytes. The area of the metal with lower concentration becomes anodic and corrodes. An example of this is a metal surfaces partly covered by deposits.
- **Differential Aeration Corrosion**: A specific type of concentration cell corrosion caused by differences in oxygen concentration. Areas of the metal with less oxygen become anodic and corrode. An example of this type of corrosion is corrosion under water droplets or beneath gaskets.
- **Active–Passive Cell Corrosion**: Occurs when one part of a metal is in the active state while another part remains passive. The active region of the metal becomes the anode and corrodes rapidly. This type of corrosion is common in stainless steels when the passive film is damaged locally.

d) **Pitting Corrosion**: Localized attack forming small pits or holes. Localized attack that causes small holes or pits in the metal surface. Pitting corrosion is a highly localized form of corrosion that causes the formation of small holes, pits, or cavities on the surface of a metal. Pitting corrosion is one of the most dangerous forms of corrosion because it can cause failure with very little overall material loss. The key characteristics of Pitting corrosion are that the corrosion occurs at specific points on a metal surface, pitting corrosion produces deep pits while most of the surface remains unaffected, pitting corrosion is difficult to detect because the pits may be small and hidden and pitting corrosion can lead to sudden equipment failure. The main mechanism of pitting corrosion are that the protective oxide film on the metal surface is damaged or breaks down, a small anodic area forms at the damaged spot of the metal, the surrounding surface of the metal acts as the cathode, the metal dissolution occurs at the anodic site, creating a pit and the pit grows deeper as corrosion continues. The causes of Pitting corrosion are as follows:

- Presence of chloride ions (seawater).
- Stagnant solutions.
- Surface defects or scratches.
- Deposits and contaminants on the metal surface.
- Breakdown of passive films on metals such as stainless steel.

Examples of Pitting corrosion are pitting of stainless steel in seawater, aluminum corrosion in chloride-containing environments and corrosion of storage tanks and pipelines.

Effects of Pitting corrosion: The major effects of Pitting corrosion are **that Pitting corrosion r**educed mechanical strength, produces leakage in pipes and tanks, produces premature equipment failure, and increases maintenance and repair costs

Types of Pitting Corrosion: Pitting corrosion can be classified based on the mechanism that initiates the pit as follows:

- **Stable Pitting:** In Pitting corrosion, once initiated, the pit continues to grow on its own, and the environment inside the pit becomes increasingly aggressive, accelerating corrosion. Pitting corrosion is the most dangerous type because it can lead to perforation and failure.
- **Metastable Pitting:** These are small pits that form but stop growing after a short period. The metal's protective film reforms (re-passivates) and is often considered the early stage of pitting corrosion.
- **Chloride-Induced Pitting**: Pitting corrosion caused by the presence of chloride ions (Cl^-), such as those found in seawater and salt solutions. Pitting corrosion is common in stainless steels, aluminum alloys, and other passive metals. This corrosion is one of the most frequently encountered forms of pitting.
- **Deposit-Induced Pitting**: This corrosion occurs beneath deposits of dirt, scale, corrosion products, or biological growth. The deposit creates localized differences in oxygen concentration, promoting pit formation.
- **Crevice-Associated Pitting**: This is corrosion that initiates within narrow gaps or crevices where stagnant solution exists. It is often found under gaskets, washers, bolts, and lap joints. It is closely related to Crevice Corrosion.

d) **Crevice Corrosion**: Occurs in shielded areas such as gaps or joints. Occurs in tight spaces or crevices where stagnant solutions accumulate.

e) **Uniform Corrosion**: Corrosion that occurs evenly across the entire surface exposed to the environment. An example of uniform corrosion is the rusting of steel in the atmosphere.

f) **Stress corrosion cracking:** This is the corrosion caused due to the presence of stress and a corrosive environment. Corrosion is established by the presence of tensile stress, which is accelerated by mutilation to the surface of the metal. The specific mechanism for this corrosion is not well established or understood, but it is assumed that the corrosion is due to either applied force or internal force (stress), which causes atoms of the material to leave the anodic tips of incipient cracks. Stress corrosion cracking can cause sudden and catastrophic failure of a component, even when the overall corrosion rate is low. The three Conditions Required for Stress corrosion cracking are Susceptible material (certain steels, aluminum alloys, stainless steels), Tensile stress (applied stress or residual stress from welding, machining) and Specific corrosive environment (chlorides, caustic solutions, ammonia). The two Types of Stress corrosion cracking are intergranular Stress corrosion cracking (Cracks propagate along grain boundaries) and transgranular stress corrosion cracking (Cracks pass through the grains of the metal).

g) **Intergranular Corrosion:** Intergranular corrosion describes preferential dissolution along the grain boundaries and is related to precipitation of second-phase particles at the grain boundaries and solute depletion in the vicinity of the grain boundaries. An e**xample of intergranular corrosion is in** austenitic Stainless Steel, in which welding can cause chromium carbides to form at grain boundaries. The nearby regions become depleted of chromium, reducing corrosion resistance and making the grain boundaries susceptible to attack

h) **Erosion Corrosion: Erosion Corrosion** is a form of corrosion that occurs when a **corrosive fluid moving at high velocity** wears away the protective surface film of a metal, exposing fresh metal to further chemical attack. It involves the combined action of **mechanical erosion** and **electrochemical corrosion. An example of erosion corrosion is i**n a water pipeline carrying sand-laden water at high speed, in which the sand particles continuously strike the pipe wall and remove the protective oxide layer. The exposed metal then corrodes more rapidly, leading to erosion corrosion.

i) **Cavitation Corrosion: Cavitation Corrosion** is a form of material damage that occurs when **vapor bubbles form and collapse rapidly in a liquid near a metal surface**. The collapse of these bubbles generates intense shock waves and high-pressure impacts that damage the metal surface and accelerate corrosion. An example is the blades of a ship's propeller may develop pits due to cavitation. As the propeller rotates rapidly, pressure changes create vapor bubbles that collapse against the blade surface, causing damage and accelerating corrosion.

j) **Fretting Corrosion: Fretting Corrosion** is a form of localized corrosion that occurs at the **contact surfaces of two materials undergoing repeated small-amplitude relative motion (vibration or rubbing)** while under load. The slight movement damages the protective oxide layer on the metal surfaces. The exposed metal then reacts with oxygen in the environment, producing oxide debris. Continued rubbing removes this debris and exposes fresh metal, leading to ongoing wear and corrosion. An e**xample of fretting corrosion is in** a bolted joint subjected to continuous vibration, tiny movements between the contacting surfaces can cause fretting corrosion, producing oxide debris and surface damage around the contact area

k) **Microbiological Corrosion: Microbiologically Influenced Corrosion (MIC)**, often called **microbiological corrosion**, is the deterioration of a metal caused or accelerated by the activity of **microorganisms** such as bacteria, fungi, algae, or other microbes. These microorganisms form biofilms on metal surfaces and produce substances that alter the local environment, making corrosion occur faster than it normally would. An e**xample of MIC is in** an oil pipeline, in which sulphate-reducing bacteria can produce hydrogen sulphide, which promotes localized corrosion and pitting of the pipe wall

l) **Atmospheric Corrosion: Atmospheric Corrosion** is the corrosion of a metal caused by exposure to the **atmosphere**, particularly in the presence of **moisture, oxygen, and airborne contaminants**. It is the most common type of corrosion and occurs when a thin film of water forms on a metal surface, allowing electrochemical reactions to take place.

m) **Fatigue Corrosion: Corrosion Fatigue (Fatigue Corrosion)** is the progressive deterioration and cracking of a material caused by the **combined action of cyclic (repeated) stress and a corrosive environment**. A metal subjected to repeated loading normally develops fatigue cracks over time. When corrosion is also present, crack initiation and growth occur much faster, reducing the material's fatigue life. An e**xample of Corrosion Fatigue (Fatigue Corrosion)** is a ship propeller shaft operating in seawater that experiences repeated rotational stresses. The seawater causes corrosion pits on the shaft surface, and these pits become starting points for fatigue cracks, eventually leading to failure.

n) **Waterline Corrosion: Waterline corrosion** is a type of localized corrosion that occurs on a metal surface **at or near the interface between air and water** (the waterline). It is common on structures that are **partly submerged and partly exposed to air. An example of waterline corrosion** is a steel ship hull left in seawater, which often shows a visible rust band along the waterline because oxygen levels differ above and below the water surface, causing accelerated corrosion at that boundary.

o) **Selective Leaching (Selective) Corrosion: Selective leaching corrosion** (also called **dealloying**) is a form of corrosion in which **one element is selectively removed from an alloy**, leaving behind a weakened, porous structure made of the more noble (less reactive) metal. An e**xample of Selective Leaching (Selective) Corrosion is in** seawater, in which brass plumbing fittings may lose zinc over time. The remaining copper structure becomes weak and porous, even though the fitting may still look intact externally.

Mechanism and Equations of Corrosion

"Metals mostly corrode when they come into contact with oxygen, moisture, acids, salts, or other substances. Electrons are transferred from the metal (anode) to an oxidizing agent (cathode) through an electrolyte in the most prevalent type, known as electrochemical corrosion". The most common mechanism is **electrochemical corrosion**, especially in the presence of moisture. Common corrosion equations (especially for rusting of iron) are as follows:

1. **Anodic Reaction (Oxidation)**

Metal loses electrons: $Fe \rightarrow Fe^{2+} + 2e^-$ (1)

2. **Cathodic Reaction (Reduction)**

In neutral or alkaline water containing oxygen: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ (2)

3. Formation of Ferrous Hydroxide

$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$ (3)

4. Oxidation to Ferric Hydroxide $4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$ (4)

5. Formation of Rust

$2Fe(OH)_3 \rightarrow Fe_2O_3 \cdot xH_2O$ (5)

where: $Fe_2O_3 \cdot xH_2O$ is hydrated iron (III) oxide (rust).

Overall Rusting Equation

$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_3$ (6)

which eventually converts to rust:

$4Fe + 3O_2 + xH_2O \rightarrow 2Fe_2O_3 \cdot xH_2O$ (7)

Electrochemical Corrosion Cell Summary

Anode: $M \rightarrow M^{n+} + ne^-$ (8)

Cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ (9)

Overall: Metal $+ O_2 + H_2O \rightarrow$ Corrosion Products (10)

Figure 3 shows the selected frequent appearance of corrosion in selected materials. Figure 4 presents the summary of mechanisms and equations in corrosion.

Corrosion Detection Techniques: Corrosion detection techniques are methods used to identify, monitor, and measure corrosion in materials and structures before serious damage or failure occurs. **Corrosion detection techniques** help in maintenance planning, safety assurance, and extending service life. Corrosion can be detected, monitored, and evaluated using several techniques. These methods and techniques are generally classified as **visual, non-destructive testing (NDT), electrochemical, and analytical techniques**. The breakdown of these techniques is as follows:

a. **Visual Inspection Technique:** Visual Inspection Technique is the simplest and most common method, which involves direct observation of rust, discoloration, pitting, or surface damage. Visual Inspection Technique can be done with the naked eye or magnifying tools.

b. **Ultrasonic Testing Technique (UT):** Ultrasonic Testing Technique (UT) utilises high-frequency sound waves to measure or evaluate material thickness. Ultrasonic Testing Technique (UT) detects internal corrosion and wall thinning without damaging the material. The technique is very useful for pipes, tanks, and pressure vessels. The technique is non-destructive testing.

Figure 3: The selected frequent appearance of corrosion in selected materials.

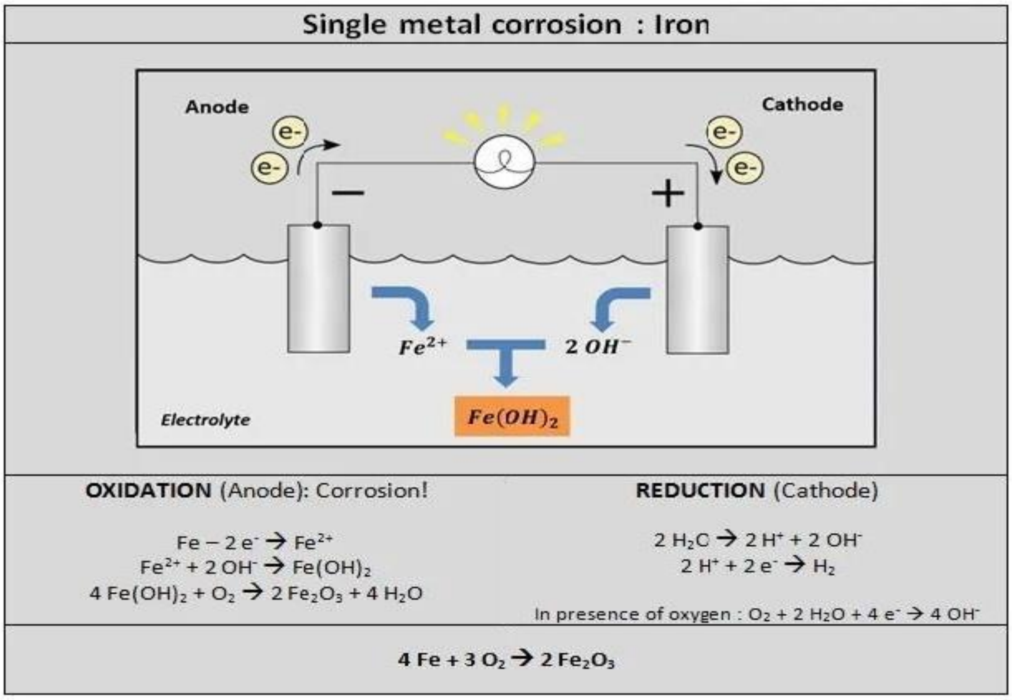

Figure 4: The summary of mechanisms and equations in corrosion (Source: Hamid and Goma 2025)

c. **Radiographic Testing (X-ray/Gamma Ray) Technique:** The radiographic testing (X-ray/Gamma Ray) technique utilises radiation to create or produce images of internal structure. Radiographic Testing (X-ray/Gamma Ray) helps in detecting internal corrosion, cracks, and voids. Radiographic Testing (X-ray/Gamma Ray) is common or frequently found in weld inspection and thick components. The technique is a non-destructive test.
d. **Eddy Current Testing Technique:** Eddy Current Testing Technique utilises electromagnetic induction to evaluate or detect surface and near-surface corrosion. Eddy Current Testing Technique is effective for conductive materials such as aluminium and copper alloys. Eddy Current Testing Technique is often utilised in aircraft inspection. The technique is a non-destructive test.
e. **Magnetic Particle Inspection (MPI) Technique:** The Magnetic Particle Inspection (MPI) Technique is used for ferromagnetic materials (like steel). Magnetic Particle Inspection (MPI) Technique reveals surface and slightly subsurface corrosion cracks and corroded particles gather at defect locations under a magnetic field. The technique is a non-destructive test.
f. **Electrochemical Methods or Techniques:** This technique measures or evaluates corrosion rate utilising electrical signals. The technique includes other techniques such as Linear polarization resistance (LPR) and Potentio-dynamic polarization. The technique is useful for real-time monitoring in pipelines and tanks. The technique is a non-destructive test.
g. **Weight Loss (Coupon Test) Technique:** In the Weight Loss (Coupon Test) Technique, metal samples (coupons) are exposed to the environment for a specific period, and the corrosion rate of the metal is calculated by measuring weight loss or change in weight over time. The technique is simple and easy to utilise but the technique is a time-consuming method. The technique is a destructive test.
h. **Acoustic Emission Monitoring Technique: The Acoustic Emission Monitoring Technique d**etects sound waves produced by crack growth and corrosion activities. The technique is **u**seful for real-time structural health monitoring. The technique is a non-destructive test.
i. **Infrared Thermography Technique:** Infrared Thermography Technique **d**etects temperature differences caused by corrosion activities or material loss by the metal in a specific environment. **The** Infrared Thermography Technique is useful for corrosion level evaluation of large structures and electrical systems. The technique is a non-destructive test.
j. **Corrosion Probes and Sensors Technique:** Corrosion Probes and Sensors are installed in pipelines and tanks for continuous monitoring of the corrosion rate. Corrosion Probes and Sensors Technique **m**easures corrosion parameters such as corrosion rate, pH, oxygen, and conductivity. Figure 5 presents the corrosion forms with the required monitoring techniques. The technique is non-destructive testing.

Overview and summaries of publications on Corrosion and Corrosion Science

A summary and overview of corrosion and corrosion science is as follows:

- "**Corrosion** is the gradual deterioration of a material, usually a metal, due to chemical or electrochemical reactions with its environment. It converts metals into more stable radicals, groups, or compounds such as oxides, hydroxides, or sulphides". Examples of corrosion are the rusting of iron in the presence of oxygen and water, tarnishing of silver. and corrosion of steel pipelines, ships, and bridges.

  The major effects of Corrosion are loss of material strength and structural integrity, increased maintenance and replacement costs, safety hazards and equipment failures and reduced efficiency of industrial systems. The key types of Corrosion are uniform corrosion (occurs evenly over the surface), galvanic corrosion (happens when two dissimilar metals are electrically connected in an electrolyte), pitting corrosion (localized attack forming small holes or pits), crevice corrosion (occurs in narrow gaps where stagnant solution accumulates), intergranular corrosion (Attacks grain boundaries of metals), stress corrosion cracking (combined effect of tensile stress and a corrosive environment) and erosion-corrosion (accelerated by fluid movement).
- **Corrosion Science** is the branch of science and engineering that studies the mechanisms of corrosion, factors affecting corrosion rates, and methods for preventing and controlling corrosion. It combines principles from chemistry, electrochemistry, materials science, metallurgy, and engineering. The major **key concepts are**

a. **Electrochemical Nature:** Most corrosion occurs through electrochemical reactions. In which a metal surface develops:
   - **Anode:** where metal dissolves (oxidation).
   - **Cathode:** where reduction reactions occur.

b. **Corrosion Cell Components**: The major components of corrosion are anode (positive electrode), Cathode (negative electrode), electrolyte (aqueous solution or water containing dissolved salts) and electrical connection between anodic and cathodic areas

c. **Factors Affecting Corrosion**: The major factors that have significant effects on corrosion are temperature, humidity and moisture, pH of the environment, presence of salts and pollutants
   - Metal composition and microstructure
   - Mechanical stresses

a. Desktop Review on Corrosion and Corrosion Science

Figure 6a presents the outcome of the desktop review, search, and findings on corrosion and corrosion science. The results of the desktop review provide 1,091,722 journal articles, conference proceedings, reviewed journal articles, and edited books with an overall average of 4831 articles per year between 1800 and May 2026. The figure established that the growth of publications on corrosion and corrosion science between

1800 and May 2026 can be grouped into three phases of linear phase between 1800 and 1945, logarithm-linear phase between 1945 and 1993 and exponential phase between 1993 and 2026. In the growth, between 1800 and 1945 the number of publications rose from 1685 to 4090 articles; between 1945 and 1993, it was from 4090 to 58200 articles and between 1993 and 2026, the number increased from 58,200 to 358000 articles. In the case of publications per year, the figure established that the growth of publications per year on corrosion and corrosion science between 1800 and May 2026 can be grouped into three phases like publications growth of linear phase between 1800 and 1945, logarithm-linear phase between 1945 and 1993 and exponential phase between 1993 and 2026. In the publication growth per year, between 1800 and 1945 the number of publications rose from 20 to 372 articles per year; between 1945 and 1993, it was from 372 to 5291 articles per year and between 1993 and 2026, the number increased from 5291 to 34095 articles per year. It is well known that the correlation coefficient is a measure of the **strength and direction** of the linear relationship between two variables.

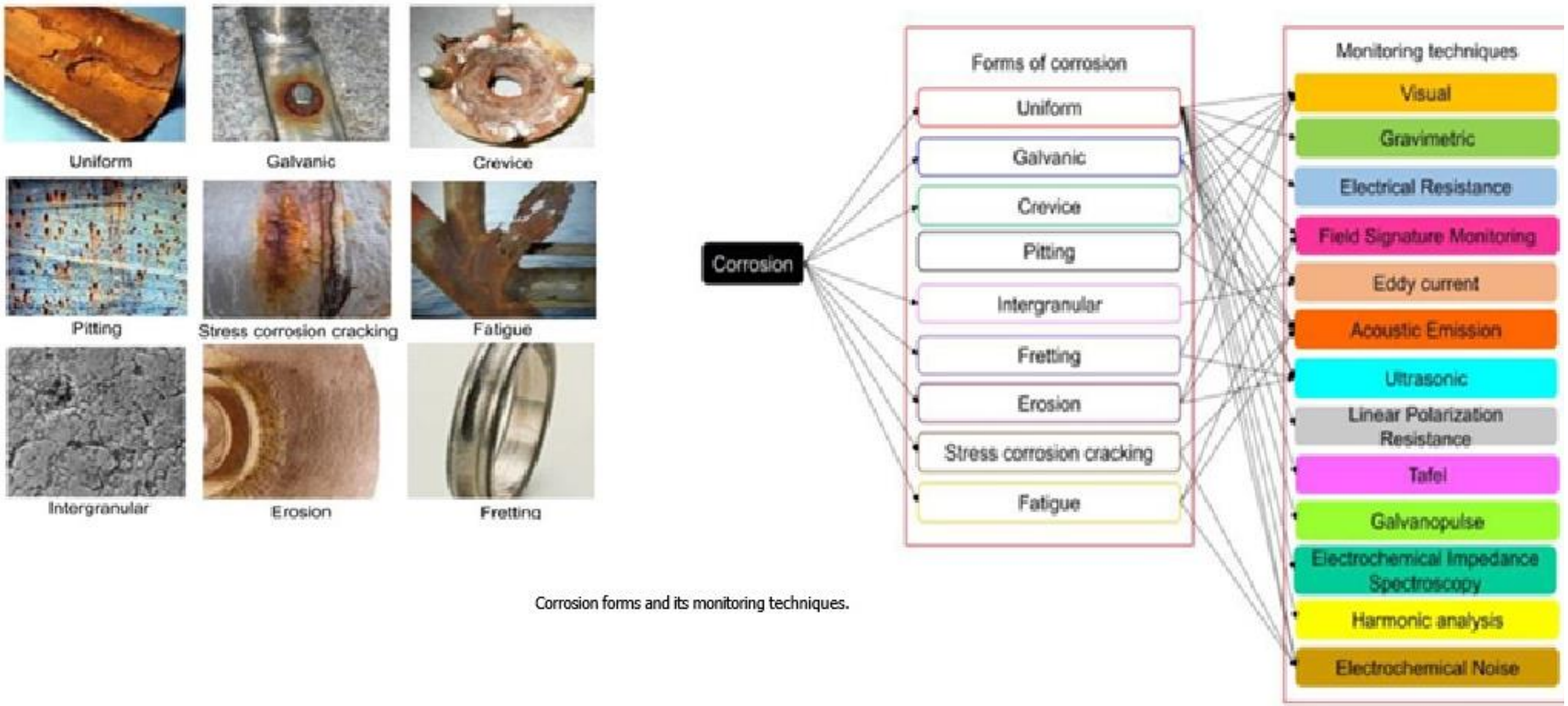

Figure 5: The corrosion forms with the required monitoring techniques. (Source: Rajendran and Subbian 2025)

It ranges from **−1.00 to +1.00**, as a perfect positive linear relationship, from 0.700 to 0.900 as a strong positive relationship, from 0.400 to 0.600 as a moderate positive relationship, from 0.100 to 0.300 as a weak positive relationship, and less than 0.100 as no linear relationship. The figure revealed 0.8700 and 0.8858 as the correlation coefficient for publication growth and the rate of publication growth per year. The results established that as the year increases, the publications and rate of publication per year on corrosion and corrosion science tend to increase. In addition, these results show an increase in the study and its applications. The differences in publications per year revealed that there is more understanding, research, experiments, and studies on the subject of corrosion and corrosion science applications in the environment (Ibrahimi et al., 2021, Imran et al., 2023, Jawad et al., 2026, Jones 1996, Jumbo-Egwurugwu et al., 2026, Khalaf et al., 2024, Khalilov et al., 2026; Kucharlapati et al., 2025, Kurtz et al., 2023, Li et al., 2015 Lin et al., .2023, Lin et al., 2023, Liu et al., 2021; Ma et al., 2021, Mubeen et al.,2026, Nrior et al., 2026.Odeyemi and Alaba 2025. Ogu et al.,2023 , Ogunwole et al., 2022 , Okeke et al.,2022 , Okeke et al., 2022 , Okeke et al., .(2023d, Okeke et al., 2023c , Okeke et al., 2023b).

b. Desktop Review on Application of AI, ANN, and ML in predicting Corrosion and in Corrosion Science

Figure 6b presents the outcome of the desktop review, search, and findings on the applications of AI, ANN and ML in predicting Corrosion and in Corrosion Science. The results of the desktop review provide 1,091,722 journal articles, conference proceedings, reviewed journal articles, and edited books with an overall average of 324 articles per year between 1800 and May 2026. The figure established that the growth of publications on corrosion and corrosion science between 1800 and May 2026 can be grouped into three phases: a linear phase between 1800 and 1945, a logarithm-linear phase between 1945 and 1993, and an exponential phase between 1993 and 2026. In the growth, between 1800 and 1945, the number of publications rose from 327 to 487 articles; between 1945 and 1993, it was from 487 to 10600 articles, and between 1993 and 2026, the number increased from 10600 to 18300 articles. In the case of rate publications per year, the figure established that the growth of publications per year on the application of AI, ANN, and ML in predicting Corrosion and in Corrosion Science between 1800 and May 2026 can be grouped into three phases like publications growth of linear phase between 1800 and 1945, a logarithm-linear phase between 1945 and 1993, and an exponential phase between 1993 and 2026. In the publication growth per year, between 1800 and 1945 the number of publications rose from 4 to 44 articles per year; between 1945 and 1993, it was from 44 to 964 articles per year and between 1993 and 2026, the number increased from 964 to 1743 articles per year. It is well known that the correlation coefficient is a measure of the **strength and direction** of the linear relationship between two variables. It ranges from **−1.00 to +1.00**, as a perfect positive linear relationship, from 0.700 to 0.900 as a strong positive relationship, from 0.400 to 0.600 as a moderate positive relationship, from 0.100 to 0.300 as a weak positive relationship, and less than 0.100 as no linear relationship. The figure revealed 0.8196 and 0.8383 as the correlation coefficient for publication growth and the rate of publication growth per year. The results established that as the year increases, the publications and rate of publication per year on corrosion and corrosion science tend to increase. In addition, these results show that there is an increase in the study and its applications. The differences in publications per year revealed that there is more understanding, research, experiments, and studies on the subject of corrosion and corrosion science applications in the environment (Okeke et al., .2023a , Okeke et al., 2022d, c , b, and a , Okeke et al., 2023c , 2023b , Okeke et al., 2023a, b, c and d; 2022a , Okuma et al., 2026, ,Oladosu et al., .2021a and b, Olisakwe et al., 2022a; b and c, 2023a and b, 2011 Onukwulu et al.,2022, 2023a and b, Ossai, 2019). Figure 7 shows the more on the applications of AI, ANN and ML in predicting corrosion and in corrosion science.

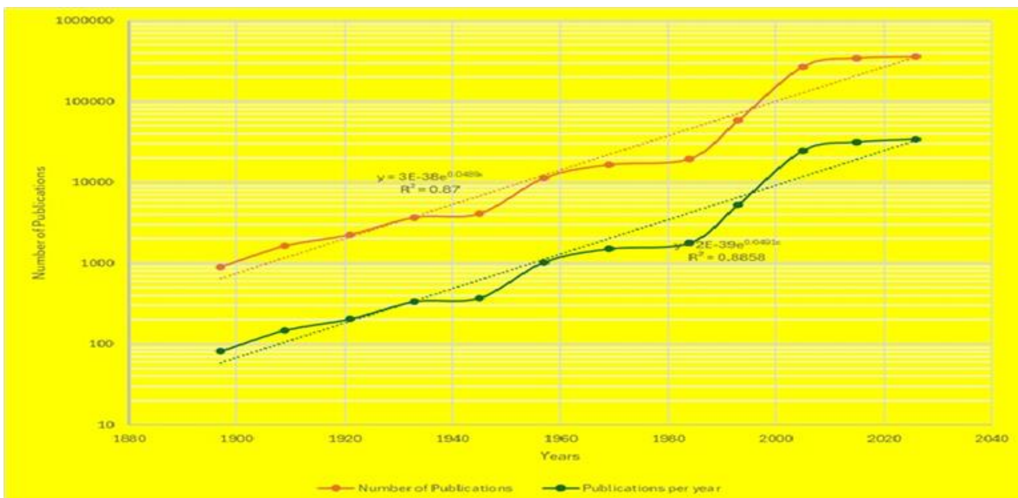

Figure 6a: the outcome of the desktop review, search, and findings on corrosion and corrosion science.

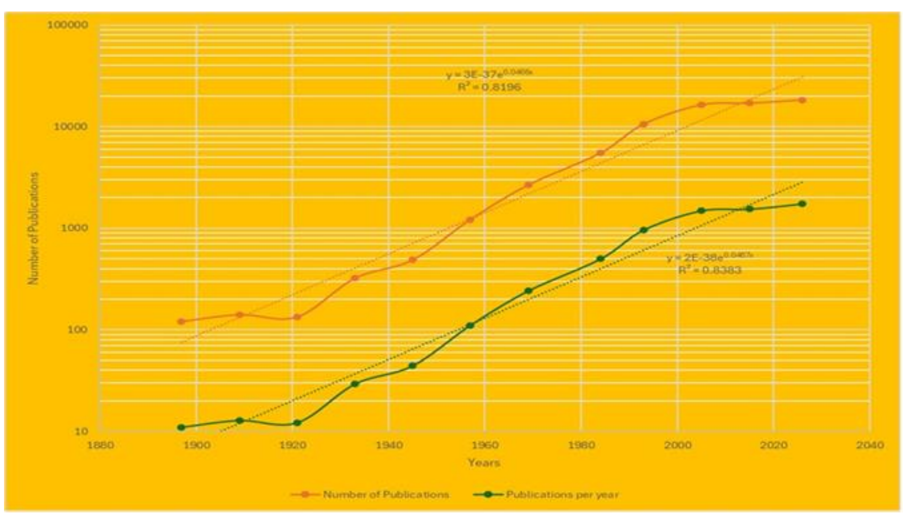

Figure 6b: the outcome of the desktop review, search, and findings on Application of AI, ANN and ML in predicting Corrosion and in Corrosion Science.

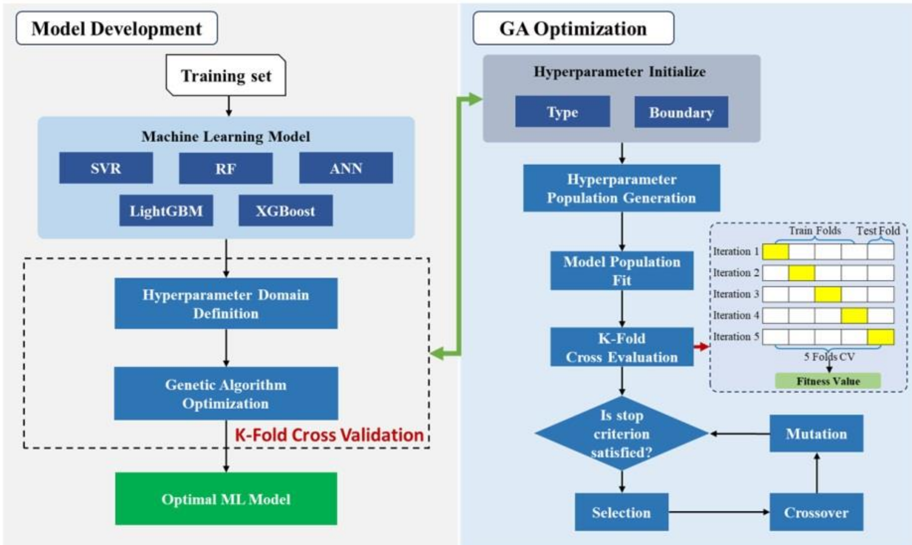

Figure 7a: Flow chart ofeveloped ML model (Source: Chen et al., 2025)

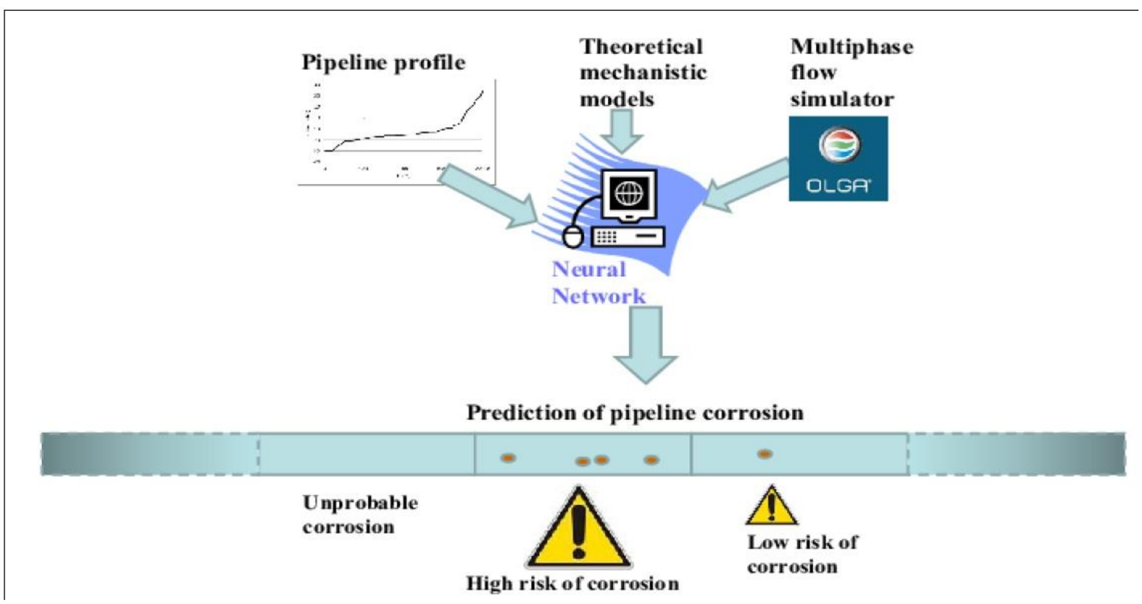

Figure 7b: Schematic diagram AI model (Source: Adewoyin et al., 2025)

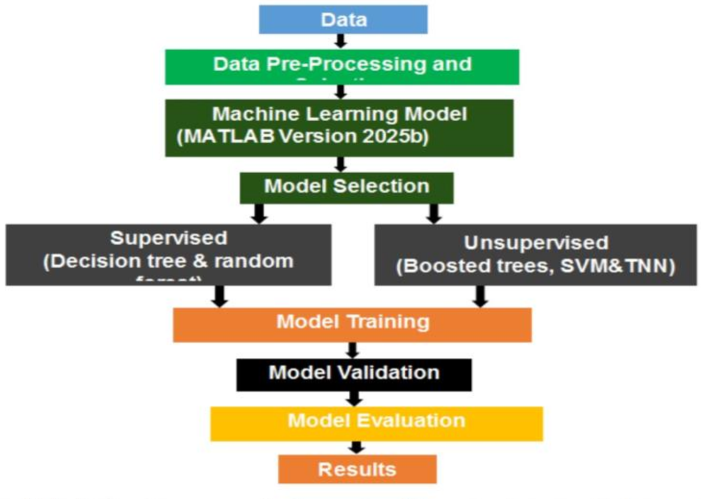

Figure 7c: ML Flow Chart for corrosion detection techniques (Source: Usman et al., 2025)

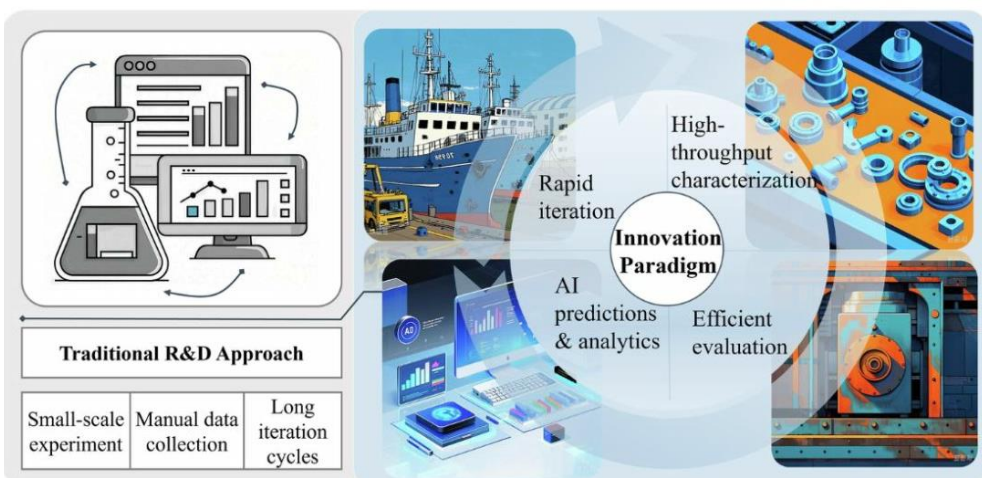

Figure 7d: Conventional research and AI approaches to corrosion detection (Source: Hamid and Goma 2025)

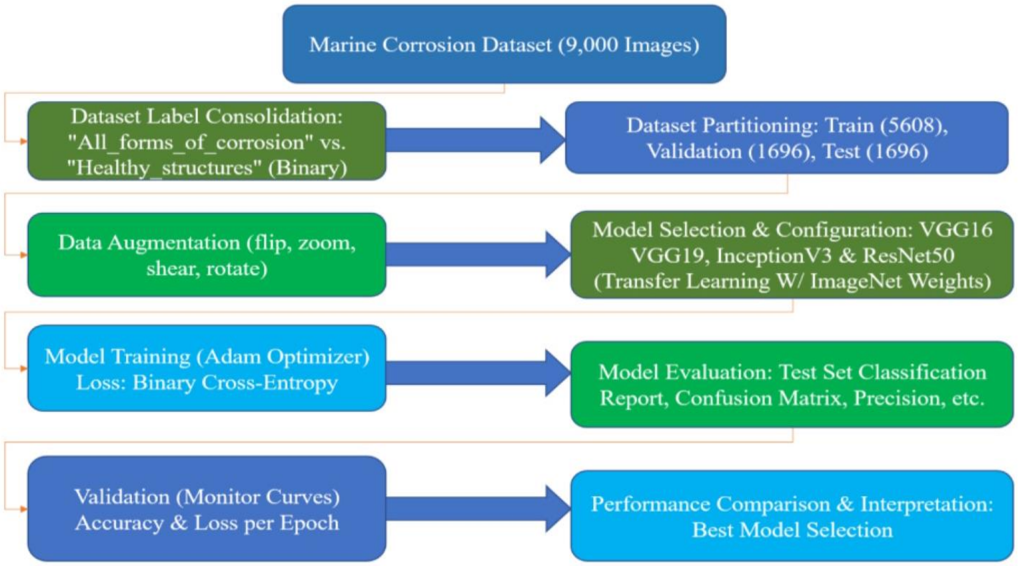

Figure 7e: Outline of dataset for model using ML (Source: Khalilov et al., 2026)

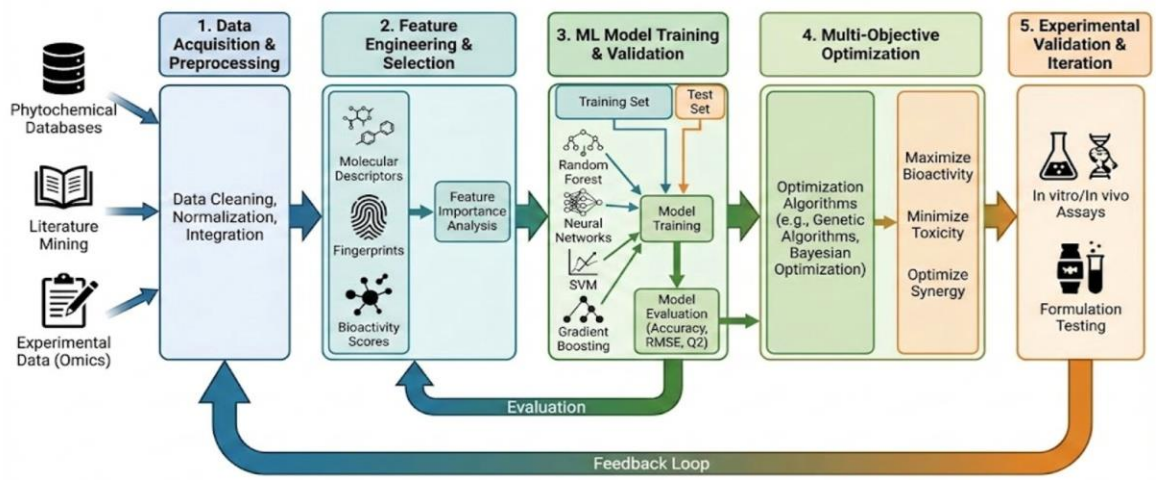

Figure 7f: Enhanced ML flow chart for model optimization of multi-photochemical (Source: Oyetola, 2025)

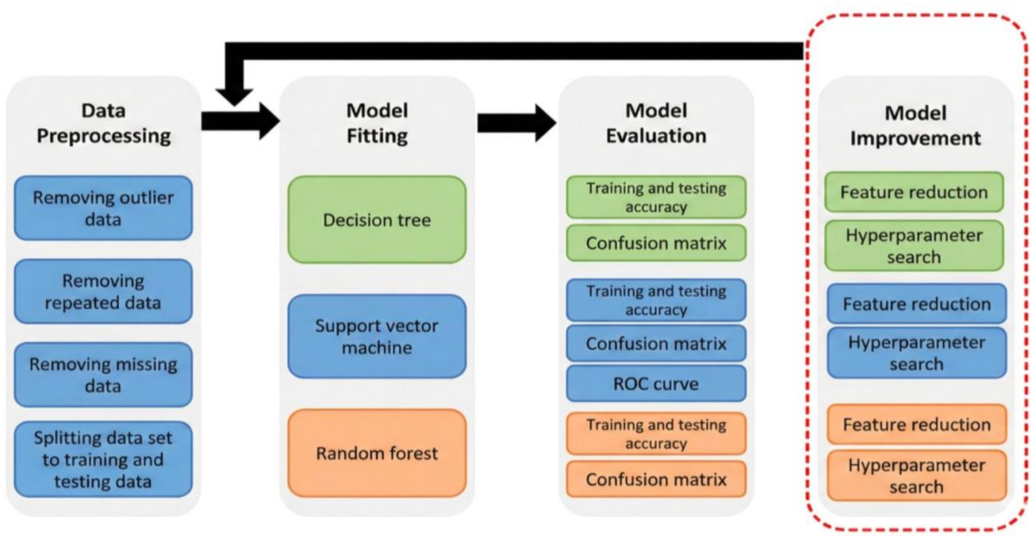

Figure 7g: Schematic flow chart of a typical ML model for corrosion electrochemistry, data analysis (Source: Guo and Rong, 2026)

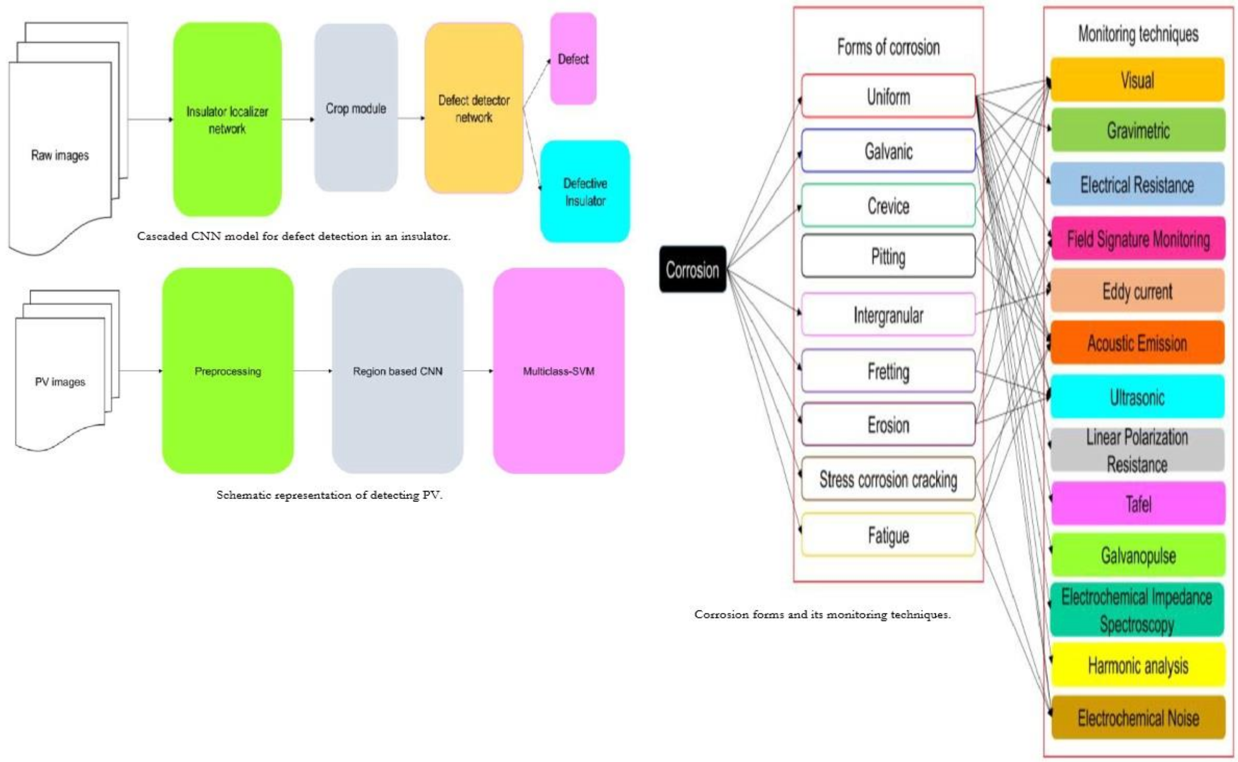

Figure 7h: Corrosion classification and applicable detection techniques (Source: Rajendran and Subbian

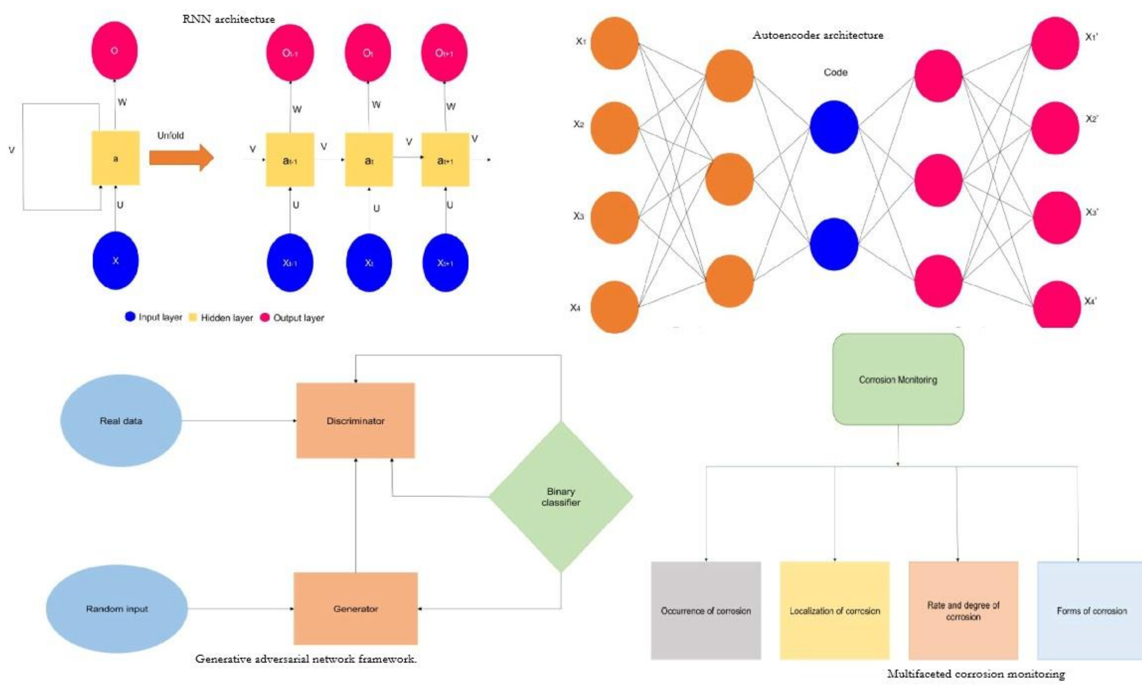

Figure 7i: Flow chart for applicability of detection techniques using ANN (Source: Rajendran and Subbian 2026)

Conclusion

It can be concluded based on the findings that:

a. corrosion is a natural process,
b. there is more understanding, research, experiments, and studies on the subject of corrosion and corrosion science applications in the environment
c. as the year increases, the publications and rate of publication per year on corrosion and corrosion science tend to increase.
d. there is an increase in the study and its applications.
e. corrosion can be controlled.
f. understanding the causes, types, and prevention methods is essential to protect materials from corrosion, ensure safety, and reduce economic losses

REFERENCES

Abdulmutaali, A., Aldrich, C., and Lepkova, K. (2025). Unsupervised process monitoring of corrosion based on electrochemical noise and multivariate image analysis. *npj Materials Degradation*, *9*(1), 43.

Adebisi B, Aigbedion E, Ayorinde OB, and Onukwulu EC. (2023) A Conceptual Model for Optimizing Asset Lifecycle Management Using Digital Twin Technology for Predictive Maintenance and Performance Enhancement in Oil and Gas. International Journal of Advances in Engineering and Management. 2023;2(1):32–41. https://doi.org/10.35629/.IJAEM.2025.7.1.522-540.

Adebisi B, Aigbedion E, Ayorinde OB, and Onukwulu EC. (2023). A Conceptual Model for Integrating Process Safety Management and Reliability-Centered Maintenance to Improve Safety and Operational Efficiency in Oil and Gas. International Journal of Social Science Exceptional Research. 2023;2(1):32–41. https://doi.org/10.54660/.IJSSER.2023.2.1.32-41.

Adebisi B, Aigbedion E, Ayorinde OB, and Onukwulu EC.(2021) A Conceptual Model for Predictive Asset Integrity Management Using Data Analytics to Enhance Maintenance and Reliability in Oil and Gas Operations. International Journal of Multidisciplinary Research and Growth Evaluation. 2021;2(1):534–54. https://doi.org/10.54660/.IJMRGE.2021.2.1.534-541.

Adebisi B, Aigbedion E, Ayorinde OB, Onukwulu EC. A Conceptual Model for Implementing Lean Maintenance Strategies to Optimize Operational Efficiency and Reduce Costs in Oil and Gas Industries. International Journal of Management and Organizational Research. 2023;2(1):32–41. https://doi.org/10.54660/.IJMOR.2022.1.1.50-57.

Adeleke A, and Peter O. (2021) Effect of Nose Radius on Surface Roughness of Diamond Turned Germanium Lenses. 2021

Adewoyin, M. A., Ogunnowo, E. O., Fiemotongha, J. E., Igunma, T. O., and Adeleke, A. K. (2023). Systematic review of AI-augmented corrosion modeling techniques in infrastructure and manufacturing systems. *Journal of Frontiers in Multidisciplinary Research*, *4*(1), 362-380.

Aljibori, H. S., Alamiery, A., and Kadhum, A. A. H. (2023). Advances in corrosion protection coatings: A comprehensive review. *Int. J. Corros. Scale Inhib*, *12*(4), 1476-1520

Aljibori, H. S., Alamiery, A., and Kadhum, A. A. H. (2023). Advances in corrosion protection coatings: A comprehensive review. *Int. J. Corros. Scale Inhib*, *12*(4), 1476-1520

ASTM International (2002). ASTM G15-02. Standard Terminology Relating to Corrosion and Corrosion Testing. West Conshohocken: ASTM International; Submarine Groundwater Discharge. Stanford University. pp. 131 – 150.

Chen, Q., Cai, Y., Zhu, Y., Ji, H., Ma, X., and Wang, H. (2025). An Integrated Approach Using GA-XGBoost and GMM-RegGAN for Marine Corrosion Prediction Under Small Sample Size. *Materials*, *18*(16), 3760.

Chouhan, J. S., Dixit, A., and Gupta, D. (2013). Green inhibitors for prevention of metal and alloys corrosion: an overview. *Chem. Mat. Res*, *3*(6), 16-24.

Coelho, L. B., Zhang, D., Van Ingelgem, Y., Steckelmacher, D., Nowé, A., and Terryn, H. (2022). Reviewing machine learning of corrosion prediction in a data-oriented perspective. *npj Materials Degradation*, *6*(1), 8.

De Masi G, Gentile M, Vichi R, Bruschi R, Gabetta G. Machine learning approach to corrosion assessment in subsea pipelines. In: OCEANS 2015-Genova. IEEE; 2015:1-6.

Elmas F, Rios M, Lima E, Caiado R, and Santos R.(2023) Prediction of external corrosion rate in oil and gas platforms using ensemble learning. Brazilian Journal of Operations and Production Management. 2023;20(3):1952. https://doi.org/10.14488/bjopm.1952. 2023.

Fehintola, E.O. (2021). Corrosion inhibition of *Acalypha wilkesiana L.* leaves, *Acalypha godseffiana J.* Leaves and *Cola nitida A.* husk extracts in acidic medium. *Unpublished PhD. Thesis* .Federal University of Technology, Akure

Guma, T. N., and Dele, D. O. (2025). Advances in Corrosion Monitoring Techniques. *The Challenges of Corrosion Control on Metallic Surfaces*, 53.

Guo, R., and Rong, J. (2026). Machine learning in corrosion electrochemistry: a critical review of prediction and corrosion-type identification. *International Journal of Electrochemical Science*, *21*(4), 101324.

Hamid, Z. A., and Gomaa, M. H. (2025). Introductory Chapter: The Challenges of Corrosion Control. *The Challenges of Corrosion Control on Metallic Surfaces*, 1.

Harsimran, S., Santosh, K., and Rakesh, K. (2021). Overview of corrosion and its control: a critical review. *Proc. Eng. Sci.* 3: 13–24.

Ibrahimi, B.E L, Nardeli, J.V., and Guo, L. (2021). An overview of corrosion. *ACS Symp. Ser.* 1403: 1–19.

Imran, M. M. H., Jamaludin, S., Ayob, A. F. M., Ali, A. A. I. M., Ahmad, S. Z. A. S., Akhbar, M. F. A., . and Mohamed, S. B. (2023). Application of artificial intelligence in marine corrosion prediction and detection. *Journal of Marine Science and Engineering*, *11*(2), 256.

Jawad, M. N., Thami, K. H., Abbas, W. F., Qasim, H. H., Aliedane, H. A., and Saleh, O. J. (2026). A Comprehensive Review of Advances and Challenges in Sacrificial Anode Cathodic Protection Systems for Storage Tanks. *Archives of Current Research International*, *26*(1), 179-192.

Jones, D.A. (1996). Principles and Prevention of Corrosion, Second Edition, New Jersey: Prentice Hall. 336 - 362 ISO (2015). Corrosion of metals and alloys – Basic terms and definitions 8044:2015; 2015.

Jumbo-Egwurugwu, P., Ridha, S., Rasool, M. H., Ekwe, O. A., and Krishna, S. (2026). Corrosion Inhibitors in Drilling Mud: Advances, Challenges, and Future Directions. *Petroleum Research*.

Khalaf, A. H., Xiao, Y., Xu, N., Wu, B., Li, H., Lin, B., . and Tang, J. (2024). Emerging AI technologies for corrosion monitoring in oil and gas industry: A comprehensive review. *Engineering Failure Analysis*, *155*, 107735.

Khalilov, J. A., Otamuradov, F. A., Toshov, K. T., Khodjamkulov, S. Z., Chorieva, N. B., Urakov, N., . and Kurbonova, Z. M. (2026). Recent advances in machine learning for the design and performance prediction of corrosion inhibitors. *Int. J. Corros. Scale Inhib*, *15*(3), 1-26.

Kucharlapati, R. N. V., Sangal, A., Shirazi, S. A., and Nassef, A. S. (2025). Predictive Analytics in Corrosion Monitoring Using AI/ML: Empowering the Oil and Gas Industry. In *MECC 2025* (pp. 1-16). Association for Materials Protection and Performance.

Kurtz, M. A., Yang, R., Elapolu, M. S., Wessinger, A. C., Nelson, W., Alaniz, K., . and Gilbert, J. L. (2023). Predicting corrosion damage in the human body using artificial intelligence: in vitro progress and future applications. *Orthopedic Clinics*, *54*(2), 169-192.

Li, X., Zhang, D., Liu, Z., *Zhong Li, Cuiwei Du and Chaofang Dong* . (2015) Materials science: Share corrosion data. *Nature* **527**, 441–442 (2015). https://doi.org/10.1038/527441a

Lin Z, Zhang W, Li J, Yang J, Han B, and Xie P. (2023) Application of artificial intelligence (ai) in the area of corrosion protection. Anti-Corrosion Methods and Materials. 2023;70(5):243-251. https://doi.org/10.1108/acmm-03-2023-2769.

Lin, Z., Zhang, W., Li, J., Yang, J., Han, B., and Xie, P. (2023). Application of artificial intelligence (AI) in the area of corrosion protection. *Anti-Corrosion Methods and Materials*, *70*(5), 243-251.

Liu Q, Li N, Yongga A, Duan J, and Yan W. (2021) The evaluation of the corrosion rates of alloys applied to the heating tower heat pump (hthp) by machine learning. Energies. 2021;14(7):1972. https://doi.org/10.3390/en14071972.

Ma S, Du Y, Che K, Qin H, and Su Y. (2021) Research on corrosion assessment model for buried steel pipelines under dynamic dc stray current based on machine learning. Materials and Corrosion. 2021;73(4):540-549. https://doi.org/10.1002/maco.202112791.

Mubeen, M., Khalid, S., Tabish, M., Bibi, F., Ilyas, H. A., Chen, S., . and Yang, C. (2026). Performance evolution, predictive modeling and smart nanocomposite strategies for organic corrosion protection coatings. *Corrosion Communications*.

Nrior, M. M., Nitonye, S., Adumene, S., and Orji, C. U. (2026). Probabilistic Finite Element Analysis of Temperature-Dependent Corrosion in Oil and Gas Pipelines. *Scientific Journal of Engineering Research*, *2*(2), 248-257.

Odeyemi, O. O., and Alaba, P. A. (2025). Efficient and reliable corrosion control for subsea assets: Challenges in the design and testing of corrosion probes in aggressive marine environments. *Corrosion Reviews*, *43*(1), 79-126.

Ogu E, Egbumokei PI, Dienagha IN, and Digitemie WN. (2023) Economic and environmental impact assessment of seismic innovations: A conceptual model for sustainable offshore energy development in Nigeria. 2023.

Ogunwole O, Onukwulu EC, Sam-Bulya NJ, Joel MO, and Ewim CP. (2022) Enhancing risk management in big data systems: A framework for secure and scalable investments. International Journal of Multidisciplinary Comprehensive Research. 2022;1(1):10– 16. https://doi.org/10.54660/IJMCR.2022.1.1.10-16.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO.(2023d) A conceptual model for standardized taxation of SMES in Nigeria: Addressing multiple taxation. International Journal of Frontline Research and Reviews. 2023;1(4):1–017.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO (2023a). A service delivery standardization framework for Nigeria's hospitality industry. International Journal of Frontline Research and Reviews. 2023;1(3):51–65.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2022) conceptual model for standardizing tax procedures in Nigeria's public and private sectors. International Journal of Frontline Research in Multidisciplinary Studies. 2022;1(2):14–26.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2022) A conceptual framework for enhancing product standardization in Nigeria's manufacturing sector. International Journal of Frontline Research in Multidisciplinary Studies. 2022;1(2):1–13.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2022) Modeling a national standardization policy for made-in-Nigeria products: Bridging the global competitiveness gap. International Journal of Frontline Research in Science and Technology. 2022;1(2):98–109.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2022a) A service standardization model for Nigeria's healthcare system: Toward improved patient care. International Journal of Frontline Research in Multidisciplinary Studies. 2022;1(2):40–53.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2022a) Developing a regulatory model for product quality assurance in Nigeria's local industries. International Journal of Frontline Research in Multidisciplinary Studies. 2022;1(02):54–69.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2022b) A theoretical model for standardized taxation of Nigeria's informal sector: A pathway to compliance. International Journal of Frontline Research in Science and Technology. 2022;1(2):83–97.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2023a) A theoretical model for harmonizing local and international product standards for Nigerian exports. International Journal of Frontline Research and Reviews. 2023;1(4):74–93.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2023b) A digital financial advisory standardization framework for client success in Nigeria. International Journal of Frontline Research and Reviews. 2023;1(3):18–32.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2023b) A policy model for regulating and standardizing financial advisory services in Nigeria's capital market. International Journal of Frontline Research and Reviews. 2023;1(4):40–56.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO. (2023c) A conceptual model for Agro-based product standardization in Nigeria's agricultural sector. International Journal of Frontline Research and Reviews. 2023;1(3):1–17.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO.(2022b) A model for wealth management through standardized financial advisory practices in Nigeria. International Journal of Frontline Research in Multidisciplinary Studies. 2022;1(2):27–39.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO.(2022c) A model for foreign direct investment (FDI) promotion through standardized tax policies in Nigeria. International Journal of Frontline Research in Science and Technology. 2022;1(2):53–66.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO.(2023a) A digital taxation model for Nigeria: standardizing collection through technology integration. International Journal of Frontline Research and Reviews. 2023;1(4):18–39.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO.(2023b) A theoretical framework for standardized financial advisory services in pension management in Nigeria. International Journal of Frontline Research and Reviews. 2023;1(3):66–82.

Okeke IC, Agu EE, Ejike OG, Ewim CP, and Komolafe MO.(2023c) A technological model for standardizing digital financial services in Nigeria. International Journal of Frontline Research and Reviews. 2023;1(4):57–073.

Okuma, S. O., Nwaeju, C. C., and Ofuyekpone, O. D. (2026). The Role of Carbon Steel as a Fundamental Material in Oil and Gas Industry Applications: Exploring the Properties, Performance, and Protection Strategies for Enhanced Durability in Harsh Environments. In *Carbon Nanomaterials-Latest Trends in Synthesis, Properties and Applications*. IntechOpen.

Oladosu SA, Ike CC, Adepoju PA, Afolabi AI, Ige AB, and Amoo OO.(2021) Advancing cloud networking security models: Conceptualizing a unified framework for hybrid cloud and on-premises integrations. Magna Scientia Advanced Research and Reviews. 2021. https://doi.org/10.30574/msarr.2021.3.1.0076.

Oladosu SA, Ike CC, Adepoju PA, Afolabi AI, Ige AB, and Amoo OO. (2021) The future of SD-WAN: A conceptual evolution from traditional WAN to autonomous, self- healing network systems. Magna Scientia Advanced Research and Reviews. 2021. https://doi.org/10.30574/msarr.2021.3.2.0086.

Olisakwe CH, Ekengwu EI, and Ehirim VI. (2022a) Determining the effect of carburization on the strain hardening behaviour of low carbon steel. International Journal of Latest Technology in Engineering, Management and Applied Science. 2022;11(2):12-18. IJLTEMAS.

Olisakwe CH, Ikpambese KK, and Tuleun LT. (2022b) Modelling and optimization of corrosion rates of mild steel inhibited with Ficus thonningii bark extract in 1 M HCl solution. Int J Res Trends Innov. 2022;7(10):630–6.

Olisakwe H, Ikpambese K, Ipilakyaa T, and Ekengwu I. (2022c) The Inhibitive Effect of Ficus thonningii leaves extract in 1M HCl solution as corrosion inhibitors on mild steel. Int J Innov Sci Res Technol. 2022;7(1):769–76

Olisakwe H, Ikpambese KK, Ipilakyaa TD, and Qdeha CP. (2023a) Effect of ternarization on corrosion inhibitive properties of extracts of Strangler fig bark, Neem leaves and Bitter leave on mild steel in acidic medium. Int J Res Trends Innov. 2023;8(7):121–30.

Olisakwe HC, Bam SA, and Aigbodion VS. (2023b) Impact of processing parameters on the superhydrophobic and self-cleaning properties of CaO nanoparticles derived from oyster shell for electrical sheathing insulator applications. Int J Adv Manuf Technol. 2023;128(9):4303–10.

Olisakwe HC, Tuleun LT, and Eloka-Eboka AC. (2011) Comparative study of Thevetia peruviana and Jatropha curcas seed oils as feedstock for grease production. Int J Eng Res Appl. 2011;1(3).

Onukwulu EC, Dienagha IN, Digitemie WN, and Egbumokei PI. (2022) Advances in digital twin technology for monitoring energy supply chain operations. IRE J. 2022 Jun 30. Available from: https://www.irejournals.com/index.php/paper- details/1703516

Onukwulu EC, Fiemotongha JE, Igwe AN, and Ewim CP-M. (2023a) Marketing strategies for enhancing brand visibility and sales growth in the petroleum sector: Case studies and key insights from industry leaders. Int J Manag Organ Res. 2023;2(1):74–86.

Onukwulu EC, Fiemotongha JE, Igwe AN, and Ewim CP-M. (2023b) Mitigating market volatility: Advanced techniques for enhancing stability and profitability in energy commodities trading. Int J Manag Organ Res. 2023;3(1):131–48.

Ossai C. (2019) A data-driven machine learning approach for corrosion risk assessment—a comparative study. Big Data Cogn Comput. 2019;3(2):28. doi:10.3390/bdcc3020028

Oyetola, E. O. (2026). Machine Learning-Enhanced Optimization of Nanoscale Phytochemical Synergistic Films for High-Temperature Industrial Corrosion Protection: A Review. *Nanoparticle*, *7*(1), 21.

Palit, S. (2018). Recent advances in corrosion science: a critical overview and a deep comprehension. Direct synthesis of metal complexes, 379-411.

Pedeferri, P., and Ormellese, M. (2018). Corrosion science and engineering.

Qamar, R., and Zardari, B. A. (2023). Artificial neural networks: An overview. *Mesopotamian Journal of Computer Science*, *2023*, 124-133.

Rajendran, M., and Subbian, D. (2026). Deep learning in corrosion assessment and control: a critical review of techniques and challenges. *Corrosion Reviews*, *44*(1), 20240060.

Ridwan M, Ko J, Leung CK and Ming W-K (2026) The green potential of artificial intelligence: revisiting energy consumption, growth, and ecological footprint in the United States. Front. Environ. Sci. 14:1717269. doi: 10.3389/fenvs.2026.1717269

Rodrigo E, Litskas VD, Mairata A, Martínez Vidaurre JM and Pou A (2026) Effect of organic mulches in vineyards: CH4 and N2O emissions and their contribution to the GWP and carbon balance. Front. Environ. Sci. 14:1846259. doi: 10.3389/fenvs.2026.1846259

Ruiz, D., Casas, A., Escobar, C. A., Perez, A., and Gonzalez, V. (2024). Advanced machine learning techniques for corrosion rate estimation and prediction in industrial cooling water pipelines. *Sensors*, *24*(11), 3564.

Ryl, J. (2020). Recent advances in corrosion science. *Materials*, *13*(8), 1927.

Saminathan, R., Nashali, A. Y. A., Haqawi, A. A. A., Marappan, S., Natesan, S. P., and Shakeel, F. (2024). Role of artificial intelligence (AI) and machine learning (ML) in the corrosion monitoring processes. Zastita Materijala, 65(3), 473-480.

Sastri S A (1998). Corrosion inhibitors : principles and applications Chichester ; New York : Wiley

Sheldon (2018). R.A. Metrics of Green Chemistry and Sustainability: Past, Present, and Future. ACS *Sustain. Chem. Eng., 6, 32–48*.

Singh, H., Singh, J., Kaushal, P., and Singh, G. (2025). Advances and Challenges. *Fabrication of Wear and Corrosion Resistant Materials: Surface Processing Techniques*, 23.

Singh, H., Singh, J., Kaushal, P., and Singh, G. (2025). Advances and Challenges in Corrosion Research. *Fabrication of Wear and Corrosion Resistant Materials*, 23-43.

Souza, M. D., Moro, G., Melo, R. S., Moretto, L. M., Brasil, S. L., and Zanardi, C. (2025). Carbon steel corrosion monitoring: Why opting for an electroanalytical approach. *Journal of Electroanalytical Chemistry*, *995*, 119312.

Talbot, D. E., and Talbot, J. D. (2018). *Corrosion science and technology*. CRC press.

Tan Y, Zhang Y, Wan F and Han Y (2026) Study based on machine learning on the impact of fluoride-contaminated farmland remediation on farmers' income structure and rural economic revitalization. Front. Environ. Sci. 14:1805611. doi: 10.3389/fenvs.2026.1805611

Thakur, A., Quadri, T. W., Anadebe, V. C., Msagati, T. A., and Ebenso, E. E. (2026). Surface science perspectives on eco-friendly corrosion inhibitors. *Next Materials*, *11*, 101782.

Ulhaq Toor, I. (2025). Artificial intelligence and machine learning in corrosion inhibitor design and development: Advances, challenges, and future perspectives. *International Journal of Electrochemical Science*, 101274.

Usman, A., Sulaiman, A. D. I., Hassan, U., and Inuwa, A. M. (2025). Systematic Corrosion Prediction Techniques in Oil and Gas Pipelines Using Machine Learning Methods.

Yang, Z., Long, Z., and You, L. (2026). Interpretable corrosion rate prediction and rational design of amorphous alloy coatings: a deep learning framework with DenseLoss and SHAP interpretability. *Applied Physics A*, *132*(5), 393.

Yuldashova, S. G., Muzaffarova, N. S., Nomozov, A. K., Shaymardanova, M. A., Durmanova, S. S., Esanov, A. M., . and Nazirov, S. S. (2026). Nanocoatings and anti-corrosion strategies: anti-corrosion solutions in medical devices. *Int. J. Corros. Scale Inhib*, *15*(3), 58-88.