The ultimate goal of the present research work was to synthesize graphene oxide (GO), and the fabrication of composite materials through the integration of metal oxides represents a pivotal step toward the development of advanced materials with multifaceted applications. The integration of surfactants and deep eutectic solvent (DESs) into these nanocomposites (NCs) adds a layer of sophistication, promising enhanced properties and improved environmental compatibility. Their unique features make them suitable candidates for various applications such as wastewater treatment, gas separation/purification, fluorescent sensors, green hydrogen production, antimicrobial, photocatalytic, energy storage, and adsorbent applications.

Findings based on the present work concluded that graphene-based composites of metal oxides functionalized by surfactants and DESs NC have enormous potential for various environmental, energy, and sensor applications. This chapter covers the key findings based on the experimental work. This study outlines the futuristic prospects that emerged from a thorough analysis of different types of graphene-based composites of metal oxide functionalized by surfactant and DES NCs, including their synthesis, surface modification, morphologic features, and potential applications.

In concluding remarks, the thesis comprises **seven chapters**, which are outlined as follows:

In **Chapter 1** introduces the field of nanotechnology and nanocomposites, placing particular emphasis on the carbon-based two-dimensional material known as GO. This chapter includes a brief description of graphene oxide and an exploration of its properties. In addition, it emphasizes the advantages associated with the functionalization of GO-metal oxide NCs.

In **Chapter 2** delves into the discussion of synthesis routes, principles, and applications of the characterization techniques utilized. For the synthesis of nanocomposites with metal-oxides, graphite oxide was prepared in the laboratory using a previously reported route. In addition, the functionalization of the graphene-metal oxide nanocomposite with surfactants and DESs is discussed. Subsequently, major characterization techniques for the structural, chemical, microscopic, and physical evaluations of nanocomposites were developed. The techniques discussed include Fourier transform infrared spectroscopy (FTIR), X-ray diffraction studies (XRD), UV-visible absorption spectroscopy (UV-Vis), Thermogravimetric analysis (TGA), Differential scanning calorimetry (DSC), Field emission scanning electron microscopy (FESEM), Transmission electron microscopy (TEM), energy dispersive X-ray (EDX), Contact angle, and Tensile strength.

In **Chapter 3 and Chapter 4**, the synthesis of nanocomposites continued with graphene oxide–zirconium oxide (GO@ZrO_2) and graphene oxide–titanium oxide nanocomposites (GO@TiO_2), respectively. Following synthesis, these nanocomposites underwent modification using a cationic gemini surfactant (CGS, butanediyl-1,4, bis (N, N-hexadecyl ammonium) dibromide (16-4-16)), dodecyl trimethyl ammonium bromide (DTAB), or DES (reline, ChCl; urea, 1:2 molar ratio). The resulting adsorbent materials were thoroughly characterized using various physicochemical techniques. To assess their efficacy, methylene blue (MB) was employed as a model adsorbate to investigate its adsorption and removal from aqueous solutions utilizing the modified nanocomposites. The adsorption data were then compared with those of other similar reported adsorbents. Remarkably, the DES-based advanced material demonstrated ultrafast MB adsorption compared to the surfactant-modified nanocomposites. These findings highlight the promising potential of the developed nanocomposites for efficient and rapid adsorption applications.

Chapter 5 explores the photophysical behavior of rhodamine B (RB) within deep eutectic solvents (DESs), both with and without the presence of GO or ionic surfactants. The impact of GO, surfactant, or the combination of GO and surfactant on controlling the movement of RB at various sites, including the GO surface, surfactant micelle, DES surface, or background solvent, is extensively discussed through fluorometric analysis. Moreover, the modifications inspired by reline in DESs have been observed to alter the interactions between RB and GO, sodium dodecyl sulfate (SDS, an anionic surfactant), or Cetyltrimethylammonium bromide (CTAB, a cationic surfactant). The DES-controlled cationic vs. zwitterionic form of RB plays a pivotal role in its interaction and sustained movement towards the GO surface, micellar surface, or the formation of negatively charged ion pairs with SDS monomers. These insights contribute to a deeper understanding of the intricate interplay between DES components, surfactants, and GO in influencing the photophysical behavior of RB, providing valuable information for potential applications in controlled-release systems and sensing devices.

In **Chapter 6**, the fabrication of Mixed Matrix Membranes (MMMs) unfolded through the utilization of a standard phase inversion technique, renowned for its cost-effectiveness and time efficiency. This process involved the combination of polycarbonate (PC) and polystyrene (PS) with nanofillers, including GO and ZrO_2, at concentrations ranging from 2 wt% to 20 wt%. Additionally, membranes were crafted using DES. The resulting MMMs underwent comprehensive characterization utilizing various techniques. Benefiting from the excellent surface characteristics of ZrO_2, the heightened sorption capacity of GO, and the enhanced thermal stability attributed to DES, MMMs exhibited significantly improved gas permeability and gas

selectivity beyond the capabilities of conventional membrane materials. Permeability data with various environmental gases, such as CO_2, N_2, O_2, and CH_4, were acquired and used to determine selectivities, showcasing the potential of these MMMs for advanced gas separation applications.

In **Chapter 7** provides a comprehensive summary of the research, highlighting key findings and outcomes. It concludes by discussing potential future research directions in related areas, offering insights into the possibilities for further exploration.