Chapter 5

Summary and Future Perspectives

The significant findings of the present scientific study, their importance, and the scope of opportunities for future research are covered in this chapter.

- Groundwater quality was assessed in the Vadodara, Anand, Narmada, and Bharuch districts of Gujarat.

- This study developed an approach based on the Pearson Correlation coefficient, PCA, and hierarchical cluster analysis for investigating the spatial and seasonal variation of water quality governing parameters. The box plots of the water quality parameters revealed the spatial and temporal variability of groundwater quality.

- The dendrograms of HCA, Principal component analysis, and spatial distribution maps helped to identify the variables that significantly affected the groundwater quality data.

- The groundwater quality in the study area was mainly affected by: a) water-rock interactions and monsoon b) seawater intrusion in Bharuch c) agricultural activity in Anand and d) anthropogenic contamination.

- Baseline uranium data and associated parameters have been established for the study area. The Uranium content was within WHO's acceptable limit and the data will be useful for future research and study.

- Chitosan biopolymer-derived CH-DTPA and waste watermelon rind-derived 4WMB biochar have been studied for their potential as adsorbents for the removal of uranium.

- The adsorption mechanism involved complex interactions, including electrostatic attraction, ion exchange, and surface complexation.

- At pH 7, CH-DTPA has a maximum adsorption capacity of 2500.0 mg/g, which is the highest reported at neutral pH till date while the maximum adsorption capacity of 4WMB was 370.37 mg/g at pH 3 which was comparable to biochars reported in literature.

- FTIR, XPS, and XRD analyses confirmed that uranium bound with CH-DTPA through uranium-amino group chelation and complexation with oxygen and the formation of UO_2 and U_3O_8 species while with 4WMBU adsorption of uranium effectively occurred

by chemisorption at C=O functionalities and formed U_3O_8 and clarkelite uranium species confirming the presence of U (VI) species.

- The adsorption capacity of CH-DTPA was reduced to about 40-60% in the presence of bicarbonate and carbonate ions and there was no significant interference by other ions such as nitrate, sulphate, and chloride when being applied to real groundwater samples and simulated seawater.

- The adsorption capacity of 4 WMB was reduced to about 8% in the presence of bicarbonate and carbonate ions and there was no significant interference by other ions such as nitrate, sulphate, and chloride It was observed that 4WMB can effectively remove up to 87% of 150 mg/L of uranium ion from simulated sea water at optimal pH of 3.

- CH-DTPA retained 75% of its efficiency during the 4th cycle while 4WMB retained 71% of its efficiency.

- Further, Zirconium cholate (Zr-CH) and lanthanum-loaded watermelon rind biochar (3WMB-LN) adsorbents were investigated for the removal of fluoride from aqueous solutions.

- Detailed characterization studies revealed that fluoride was adsorbed on 3WMB-LN through electrostatic interaction between 3WMB-LN and F^- ions, as well as ion exchange with OH^- and COO^- groups.

- The maximum adsorption capacity of 3WMB-LN at optimum pH 3 was 35.71 mg/g, which is superior to previously reported watermelon rind biochar removal of fluoride. The Zr-CH adsorbent exhibited maximum adsorption (q_{max}=37.04mg/g) at 2 pH.

- The adsorption capacity of 3WMB-LN and Zr-CH was unaffected by common co-existing anions such as carbonate, nitrate, and chloride, however, the presence of bicarbonate and sulfate affected the adsorbent's adsorption capacity a little (~8%).

- After two cycles, the regeneration findings verified that 92.5% and 95% of the initial adsorption capacity was still retained by 3WMB-LN and Zr-CH respectively.

Future Scope of Work

▪ Cation analysis such as sodium potassium, calcium, and magnesium as well as heavy metals in groundwater of the study area is important to calculate sodium alkalinity ratio, and soluble sodium percentage, to evaluate its suitability for irrigation. This would help in plotting the Gibbs diagram and Piper diagram to show the evaporation–crystallization dominance in controlling the quality of groundwater as well as the main hydrochemical facies. It would also help in extending the PCA and HCA analysis to cluster the heavy metal ions to the anions and identify their anthropogenic origin as well as the health risk of toxic heavy metals such as chromium, arsenic, etc. PCA and HCA analysis can also be performed to cluster tehsils of identical groundwater quality parameters which would help gain a comprehensive understanding.

▪ Increasing the production of CH-DTPA, 4WMB; Zr-CH, and 3WMB-LN for large-scale water treatment applications is a crucial first step towards their practical utilization for removal of uranium from groundwater as well as recovery from seawater using CH-DTPA, 4WMB and for defluoridation using Zr-CH and 3WMB-LN.

▪ Researching the possibility of integrating adsorption with other techniques for treating water can result in fluoride and uranium removal systems that are comprehensive and more effective in the presence of interfering ions such as carbonate and bicarbonate.

▪ The applicability of Zr-CH and 3WMB-LN   can be extended to the removal of phosphate and other anions which can form a part of further study