

# CHAPTER 8 CONCLUSIONS

## 8.1 Conclusion

Following are the conclusion drawn from this study;

1. The multivariate statistical analysis methods PCA, FSA and HCA and 10 parameters are used to determine 3 PCs based on the inter correlation of water quality parameters. A composite PC map reveals that majority of the well having factor scores higher than 1 are located in cluster 2, 3 and 4, indicating part of Kalol and Savli Taluka are affected by anthropogenic sources.
2. Out of 50 wells, 32 wells fall under cluster 1 having negative factor scores and considered as non-polluted. These wells are located in Southern and Western parts of the alluvial region.
3. Cluster 2 primarily covers the central region of the study area, with the 9 wells exhibiting similar characteristic of high Alkalinity indicated by Factor Scores greater than 1 in majority of the wells in this area. The contamination source in this area has been attributed to the substantial presence of improper solid waste disposal activities.
4. Cluster 3 predominantly comprises upper North zone of the study area having 8 wells. Hierarchical Cluster Analysis (HCA) indicates that the primary component influencing cluster 3 includes variables Total Dissolved Solids (TDS) and Total Hardness (TH). It was also observed that the 8 wells in cluster 3 share a common characteristic of high Total Hardness direct indicative of influence of its proximity to industrial areas. Significant number of these wells exhibit high levels of Nitrate concentration also.
5. Well number 24 of Cluster 4, exhibit a highly contaminated zone in the Northern part. It is verified that the usage of Urea is excessive in this region. Excessive usage of Urea coupled with practices related to animal husbandry and disposal of domestic waste in nearby pond could be the reason of high contamination in this region.
6. Rapid growth of Petroleum and Mineral based industrial manufacturing units and improper disposal of industrial wastes into small drains including Mini river, especially in the Northern parts of the alluvial region is another key anthropogenic source of contamination.
7. Based on the validation outcomes, it is evident that the conventional DRASTIC model is not effective in assessing the groundwater vulnerability in the study area. To enhance these model, two separates' models, namely DRASTIC-FS and DRASTIC-EI have been proposed

by introduction of new parameters, Factor Score (FS) and External Influence (EI) respectively.

8. DRASTIC-FS and DRASTIC-EI analysis, reveals that each model operates on a distinct conceptual framework relating anthropogenic activities. Hence, it is essential to recognize that no direct comparison can be drawn between these two models due to their fundamentally different approaches and objectives. DRASTIC-FS gives idea about level of susceptibility to contamination by indirect way of assessment using integrated effect of various causes of ground water quality deterioration. DRASTIC-EI gives susceptibility to contamination by direct integration and analysis of apparent sources like high industrialization and urbanization.
9. From the study it is concluded that the weights of variable parameters (D, R, I, C, FS, EI) can be determined more accurately using ANN technique, instead of accepting its values recommended by Delphi committee of Aller Linda in 1987. Delphi committee's weights were recommended without any technical base whereas ANN weights are optimized based on hydrogeological criteria and technical base which make the ANN weights more accurate and appropriate compared to the conventional weights given by Aller Linda.
10. This study successfully validated the DRASTIC-FS and DRASTIC-EI models against Groundwater Nitrate concentration data for three consecutive years (2018, 2019, 2020) using Pearson's correlation analysis. The results consistently showed reasonably higher correlation coefficients ('r') ranging between 0.54-0.63 for DRASTIC-EI and 0.50-0.69 for DRASTIC-FS compared to the Conventional method. This leads to conclude that conventional DRASTIC is not proper approach for assessment of vulnerability and for accurate assessment of vulnerability conventional DRASTIC should be modified considering influences of local significant factors and using calibrated weights of different parameters.
11. A good correlation between Vulnerability parameters outcomes and groundwater Nitrate concentrations suggests the influence of anthropogenic activities such as excessive use of fertilizers, seepage from effluent systems of STP and Industrial units. These are the leading contributors making the groundwater vulnerable.
12. The vulnerability index, indicates considerable increase in its values during the post-monsoon season which is contradicting conventional understanding of improvement of water quality in post monsoon period due to dilution of concentrations of contaminants. The main reason for this is rise of groundwater levels during post monsoon period and the

recharge from industrial wastewater which plays significant role in increasing vulnerability of the groundwater to potential contamination. This suggests the need for severe management practices and monitoring measures to safeguard groundwater quality and prevent adverse environmental impacts associated with industrial discharge.

13. The Nitrate concentrations in the groundwater increases up to 283 mg/l in pre monsoon. There are total three critical areas identified in the Northern, Western and Central parts of the study area indicating high health risk.
14. The AHP approach in Multi-Criteria Decision Analysis (MCDA) is based on eight key evaluation criteria. To enhance the effectiveness of the AHP analysis, additional criteria related to hydrogeological variables are introduced. These includes groundwater table (GWT), aquifer material (AM), location-specific characteristics (LSC) and contamination level (CL). Because of inclusion of these hydrogeological parameters AHP outcomes for each well works out to be more accurate both logical and scientifically.
15. Majority of population in the Northern region, is involved in agricultural activities. Also some industries are located nearby Kalol city area. Groundwater table is between of 30 to 50 ft (fbgl) and soil is mostly sand or clay hence use of Chemical Reduction (CHEM) is the most suitable method for denitrification in this part of the study area.
16. In the Western region also, the population is involved mainly in agricultural activities however in addition to it there are other sources of Nitrate injection in groundwater like rural sanitation consisting of soak pits. Aquifer of this region mainly consist clay formation and groundwater level is near the surface hence combination of Pump And Fertilizer (PAF) and Phytoremediation (PHYTO) methods are recommended for denitrification in this part of the study area.
17. The Central region consists Makarpura industrial area and sub-urban area of Vadodara city, Danteshwar, Tarsali having high density of population. Groundwater level in these area is also high ranging between 15 to 75 (fbgl) hence Chemical Reduction (CHEM) and Pump And Treat (PAT) methods are suggested for denitrification of groundwater. Efficiency of Pump and Treat (PAT) method can be increased by the cost-benefit analysis.
18. The spatial distribution of Nitrate concentration in study area shows the groundwater is highly contaminated in the Northern region as well as in upper part of central region. 22.22 % of this area is contaminated due to Nitrate concentration. Vulnerability index obtained by DRASTIC-FS indicates 32.49 % of area covered in Northern, Central and Western Zones is highly and severely vulnerable to contamination. From this it is concluded that remaining

10.27 % area is highly susceptible to contamination with passage of time if proper remediation strategy for reduction of Nitrate concentration is not adopted.

## **8.2 Future Scope**

The following points can be considered based on above conclusions to enhance present study in future.

- (1) Groundwater model can be employed for accurate assessment and calculation of Nitrate reduction in the study area.
- (2) Specific groundwater management strategy in the form of denitrification approach/method at particular well location using simulation groundwater model can be suggested.
- (3) Further, such model may be refined to apply it globally instead of specific location.