CHAPTER 2

LITERATURE REVIEW

This chapter provides a literature review on various aspects of groundwater management and current state of groundwater in the arid and semi-arid regions. The objectives of the chapter are to (i) assess both quantitative and qualitative aspects of groundwater development, particularly in arid and semi-arid regions; and (ii) identify the research gap.

2.1 INTRODUCTION

The groundwater is considered as blue gold of vital social and economic importance. Deteriorating quality of groundwater affects the human health and agriculture sector severely. The sustainability of groundwater quality and quantity is essential for its domestic and agricultural uses, so that it can be utilized effectively for a long time in an optimal manner without damaging to the environment. Research community has contributed towards groundwater quality and quantity issues, and applied various modern tools and techniques like multi criteria decision making techniques, remote sensing and geographical information system, life cycle assessment to address these issues in day to day life. Various indicators and factors affecting the groundwater quantity and quality and its environmental impacts have been identified and analyzed in detail. In this chapter, the contribution made by the research community in the assessment of various aspects of groundwater has been carefully reviewed. The literature encompassing different approaches, tools and techniques to address groundwater quality and quantity issues has been reviewed and classified. The research gaps are identified based on the critical analysis of the literature reviewed in this chapter, followed

by formulation of research objectives of this research work in the northwestern hyper-arid region located in Rajasthan.

2.2 GROUNDWATER QUALITY

It is observed from the contemporary literature that groundwater quality assessment in terms of hydro-geochemical parameters is a common approach to understand the hydrology and status of groundwater.

This section of study presents a brief overview of the existing literature studies on groundwater quality assessment. Table 2.1 depicts the major research work carried out in terms of contribution, location, parameters, methodology, and regional aspects. It is observed from the contemporary literature that a groundwater quality assessment in terms of hydro-geochemical parameters is a common approach to understand the hydrology and status of groundwater. The list of studies selected for the review are found close to the research aim of the current study and towards assessment of groundwater quality in a hyper arid to arid region.

Table 2.1 A summarized existing literature review of groundwater/ surface water quality analysis

S. No.	Author	Contribution	Location	Parameters	Methodology	Region
1	Tafreshi & Tafreshi (2020)	Determined the origins and sources of changes in the ions dissolved in the groundwater	Golpayegan Plain aquifer, Iran	Major ions	PCA analysis, Piper diagram, & geochemical plotting	N/A
2	Worsa-Kozak et al. (2020)	Investigated the groundwater level fluctuations, seasonal behavior and the interdependencies of the process	Wroclaw, Poland		Statistical Methods and Data Mining	N/A
3	Ates et al. (2020)	Applied multivariate statistical techniques to evaluate the water quality and pollution sources	Sapanca Lake Watershed, Sapanca Basin, Turkey	Physico-chemical parameters	multivariate statistical techniques	N/A
4	Karunanidhi et al. (2020)	Examined the risk of fluoride-rich groundwater in the	Hard Rock Terrain, South India	Physico-chemical parameters	geochemical plotting	N/A

S. No.	Author	Contribution	Location	Parameters	Methodology	Region
		Shanmuganadhi River basin, south India on human health		and major ions		
5	Mukate et al. (2020)	Studied the impact of different land use practices on groundwater	Chincholi MIDC area, Solapur, India	Physico-chemical parameters and major ions	PCA analysis	Semi-arid
6	Maroufpoor et al. (2019)	To predict the spatial distribution of groundwater EC. The study utilized geo-statistic based Kriging and Co - Kriging methods and compared with data-driven ANN and ANFIS models for predicting spatial distribution of groundwater EC	Kerman Province, Iran	EC	ANN and ANFIS	Arid
7	Pandey et al. (2019)	Evaluated the pre-monsoon and post-monsoon concentrations of several important physico-chemical parameters and heavy-metal contents of groundwater samples	Koradi Thermal Power Plant, Nagpur	Physico-chemical parameters and major ions	Hydro geochemical analysis	N/A
8	Singh et al. (2019)	Evaluated the spatial variation of groundwater quality parameters	Block level study, Jhunjhunu	Physico-chemical parameters and major ions	GIS, Fuzzy inference technique	N/A
9	Jain and Vaid (2018)	Analyzed water quality parameters to observe the suitability for drinking and irrigation purposes in Nalbari district of Assam	Eastern India	Cations and anions	Hydro-chemical analysis, SAR, USSL diagram, Gibb's scatter diagram	Sub-tropical humid (dry winter)
10	Singh and Singh (2018)	Analyzed the groundwater samples for arsenic contamination and also plotted the observation using Piper diagrams for groundwater samples	Northeast India	Major ions, Arsenic contamination	Multivariate statistical analysis, Geo-chemical plotting	Sub-tropical humid (dry winter)
11	Ahamad et al. (2018)	Analyzed the geochemistry of groundwater samples from Varanasi using various geochemical plots such as Gibb's plot and Piper plots	Northern India	Cations and anions	Water quality index, Gibb's plot and piper plot	Sub-tropical humid (dry winter)
12	Jasrotia et al. (2018)	To evaluate the groundwater quality parameters to assess the geochemistry of the groundwater in the Western Doon valley region	Northern India	Cations and Anions	Piper's diagram, Expanded durov diagram, Kelley's ratio index &permeability index	Sub-tropical humid (dry winter)

S. No.	Author	Contribution	Location	Parameters	Methodology	Region
13	Dandautiya et al. (2018)	Assessed contamination levels in groundwater owing to leaching effects of fly ash under different scenarios	Suratgarh thermal power plant, Sri Ganganagar	Fly ash leachates	Elemental analyses and field emission gun scanning electron microscope	N/A
14	Bhuiyan and Ray (2017)	To identify and demarcate zones and levels of pollution. The study has revealed that groundwater in many parts of the region is unsuitable either for drinking or for irrigation by using a comparison of the obtained values with BIS and WHO.	Rajasthan, India	Major ions, pH, EC	GIS	Arid
15	Singh et al. (2017)	To study major hydrogeochemical processes and to decipher the impact of anthropogenic activities using multivariate statistical techniques and conventional graphical plots.	Delhi, India	Major ions, EC	PCA, HCA and DA	Arid/semi-arid
16	Sheikh et al. (2017)	To infer hydrogeochemical processes.	Haryana, India	Major ions	Stable isotopes, GIS, Piper plots	Arid
17	Ahada and Suthar (2017)	To discuss the hydrochemistry of the groundwater.	Rajasthan, India	Major ions, pH, EC, TDS, TH	Hydro-chemical analysis, piper plot	Arid
18	Tiwari et al. (2017)	To provide an overview of the spatial variation of groundwater quality parameters.	Rajasthan, India	Major ions, pH, EC, TDS, TH	Hydro-chemical analysis, piper plot, GIS	Arid
19	Lapworth et al. (2017)	To explore the hydrochemistry of the top 160m aquifer systems.	Northwest India	Major ions, trace elements	Hydro-chemical analysis	Arid
20	Chintalapudi et al. (2017)	To assess the groundwater quality contamination threat around industrial cluster at Rajasthan State Industrial Development and Investment Corporation (RIICO) in Jaipur.	Jaipur, Rajasthan, India	Major ions, pH, EC, TDS, TH, SAR	Hydro-chemical analysis, piper plots, Gibbs plots	Arid
21	Singh et al. (2017)	To evaluate the geochemical mechanism of fluoride enrichment in groundwater of western India.	Western India	Major ions	Hydro-chemical analysis, x-ray diffraction, geo-chemical plots	Arid region
22	Tirkey et al. (2017)	To identify the groundwater quality status in peri-urban agglomeration of Ranchi city.	Northeast India	Cations and anions; heavy metals	Hydro-chemical analysis, Water quality index (WQI)	Tropical Savana

S. No.	Author	Contribution	Location	Parameters	Methodology	Region
23	Chabukdhara et al. (2017)	Assessed the groundwater quality and health risk associated with it using hydro geochemical methods and multivariate techniques	Northern India	Heavy metals and major ions	fuzzy comprehensive assessment (FCA)&PCA	Sub-tropical humid (dry winter)
24	Li et al. (2016)	To provide a clear picture of status and extent of groundwater pollution for the purpose of policy and decision makers the groundwater quality was assessed.	Hua County, China	SAR and RSC,	Wilcox and USSL (Statistical and hydro-geochemical plotting)	Arid
25	Yang et al. (2016)	To evaluate the hydrogeochemical processes that probably affect the groundwater quality.	Ordos basin, China	Cations and anions	Piper trilinear diagram plotting	Arid
26	Patel et al. (2016)	To evaluate hydrogeochemical parameters	Andhra Pradesh, India	Major ions, TDS	Piper trilinear diagram plotting, PCA	Arid
27	Bencer et al. (2016)	To highlight the hydro-chemical processes of groundwater	Eastern of Algeria	Major ions	CA and PCA	Arid
28	Mondal et al. (2016)	To identify major impacting physio-chemical parameters of groundwater quality.	Rajasthan, India	Major ions, pH, EC, TDS, TH	Standard hydro-chemical analysis	Semi-arid
29	Kumar et al. (2016)	To understand the effect of canal recharge on groundwater and subsurface movement of recharge pathways.	Bikaner, Rajasthan, India	Major ions, pH, EC	Hydro-chemical analysis	Hyper arid
30	Sharma et al. (2016)	To identify useful pollution indicators of groundwater.	Rajasthan, India	Major ions	Factor analysis	Arid
31	Hosseinifard and Aminiyan (2015)	To evaluate the factors regulating groundwater quality.	Rafsanjan plain, Iran	Major ions, pH, SAR, EC, TDS	Hydro-chemistry diagrams	Arid
32	Marghade et al. (2015)	To assess the spatial controlling processes of groundwater contamination using PCA. The PCA helps as a tool to assess the controlling processes of the groundwater quality	Nagpur, India	Major ions, pH, EC, TDS, TH	PCA	Arid/ semi-arid
33	Nazzal et al. (2015)	To map groundwater quality. It is observed that both natural and anthropogenic processes contribute to the groundwater quality, but anthropogenic impacts are more important and results in further deterioration of groundwater quality.	Central Saudi Arabia	Major ions, pH, EC	PCA	Arid
34	Ma et al. (2014)	To understand the controlling factors of groundwater quality. This work can help to identify the	North China	Major ions, heavy metals	DA and Factor analysis	Arid/Semi-arid

S. No.	Author	Contribution	Location	Parameters	Methodology	Region
		main controlling factor of groundwater quality in North China plain, to make better and more informed decisions for achieving sustainable groundwater development.				
35	Singh (2014)	Presented an overview of major issues and methods for the conjunctive use of both groundwater and surface water resources for sustainably irrigated agriculture	Wide spread	Conjunctive use of water	Review paper	N/A
36	Avtar et al. (2013)	Conducted a hydro-chemical study in order to establish the suitability of groundwater for drinking, agricultural and industrial purposes.	Central India	Major ions	PCA analysis, Piper diagram, & geochemical plotting	Sub-tropical humid (dry winter)
37	Jalali (2012)	To assess the controlling factors of groundwater chemistry	western Iran	Major ions	PCA, Graphical plots, chemical analysis	Arid/semi-arid
38	Vijay et al. (2011)	Assessed and evaluate the deterioration of groundwater quality due to anthropogenic activities in the Puri city, India	Eastern India	Physicochemical and Bacteriological	Hydro-chemical analysis, Bacteriological analysis, Water level fluctuations	Tropical Savana
39	Singh et al. (2011)	To ascertain the presence of heavy metals in groundwater samples and used Piper and other graphical methods to represent the groundwater geochemistry.	Northern India	Major ions	PCA, Piper diagram, &geochemical plotting	Sub-tropical humid (dry winter)
40	Brandsegg et al. (2010)	To investigate the structure of variations within highly heterogeneous data.	Mid-Norway	Wireline well log data	structured PCA	-
41	Praveena et al. (2010)	To evaluate the groundwater quality of unconfined aquifer.	East Malaysia	Major ions	Hydro-chemical analysis	-
42	Singh (2010)	The study explains the feasibility of conjunctive use of surface water and groundwater for sustainable irrigation for agricultural crop production	Northwest India	Soil moisture and salinity	Model based simulation of conjunctive water use, management of saline water	N/A
43	Vasanthavigar et al. (2010)	To develop a water quality index by understanding hydrogeochemical parameters for Thirumanimuttar sub-basin of Tamilnadu, India	South India	Cations and anions Na, Mg, Ca, K Cl, HCO3, SO4	Hydro-chemical analysis, geo-chemical plots	Tropical Savana/semi-arid

S. No.	Author	Contribution	Location	Parameters	Methodology	Region
44	Arumugam and Elangovan (2009)	To assess the groundwater contamination due to anthropogenic activities using various geochemical plots and various hydro geochemical methods for Tirupur Region of Coimbatore District, Tamil Nadu, India.	South India	Major ions	PCA analysis	Tropical Savana/semi-arid
45	Srivastava and Ramanathan (2008)	To assess the impacts of landfills on groundwater quality using various hydrogeochemical methods and multivariate statistical tools	Northern India	Major ions and heavy metals	Hydro geochemical plots, Multivariate statistical techniques	Sub-tropical humid (dry winter)
46	Raju (2007)	Estimated SAR, RSC, permeability index (PI) using Chadha rectangular diagram for geochemical classification and hydro chemical processes	South India	Major ions	Chadha Rectangular diagram, & geochemical plotting	Tropical Savana
47	Voudouris et al. (2000)	Assessment of groundwater hydrochemistry, especially in situations where numerous samples are available.	Peloponnese, Greece	Major ions, pH, EC, TDS, TH	Simple and multiple regression, factor, and trend-surface analyses	Semi-arid

SAR - Sodium absorption ratio; RSC - Residual sodium carbonate; PCA - Principal Component analysis; DA - Discriminant Analysis;ANFIS - Adaptive neuro-fuzzy inference system; EC -Electrical conductivity; ANN - Artificial neural network

In recent years, the research activities in groundwater quality studies have been promoted due to rapidly deteriorating groundwater quality caused by intensified human activities and fresh water needs (Li et al. 2016). Another study by Li et al. (2017) discussed the contemporary research on groundwater quality levels and its deterioration due to fast economic and anthropogenic activities in an arid region in Western China.

Li et al. (2016) provided a research work on the Hua county of China. The study attempted to visualize the status and extent of groundwater pollution in the region to support policymaking. The study mainly considered SAR (Sodium absorption ratio) and RSC (residual sodium carbonate) as parameters and utilized statistical and hydro-geochemical plotting methodology to report the issues. The Hua county of China is an arid region. The study presented the analysis using Wilcox diagram and USSL diagram (US Salinity Laboratory Staff).

Similarly, Maroufpoor et al. (2019) predicted the spatial distribution electrical conductivity of groundwater. In this study, geo-statics based kriging and co-kriging methods were used and then compared with data-driven ANN and ANFIS models for predicting spatial distribution of electrical conductivity in an arid environment of Kerman province in Iran. Yang et al. (2016) evaluated the hydrogeochemical processes that probably affected the groundwater quality in Ordos basin, China. They considered cations and anions; and plotted the results using Piper trilinear plots. Another study was conducted by Hosseinifard and Aminiyan (2015) to evaluate the factors regulating groundwater quality by plotting major ions, pH, SAR, EC (electrical conductivity), and TDS (total dissolved solid) with the help of various hydro-chemistry diagrams in an arid environment of Rafsanjan plain, Iran. Patel et al. (2016) conducted water quality study in Andhra Pradesh, India to evaluate various parameters such as major ions and TDS with the help of Piper trilinear diagram and PCA (Principal Component Analysis). In another study by Marghade et al. (2015) conducted in Nagpur, India major ions, pH, EC, TDS and TH were analysed using PCA technique. The authors made the assessment of the spatial controlling processes of groundwater contamination. The PCA is an effective tool to assess the various governing processes of groundwater quality. Bhuiyan and Ray (2017) attempted to identify and demarcate zones and level of contamination. The outcomes of the study revealed that groundwater in many parts of the region is unsuitable for both drinking and irrigation based on the prescribed values by WHO (World Health Organization) and BIS (Bureau of Indian Standards). Geographical information system (GIS) technique was applied for analyzing various ions, pH and EC in the study. The study was conducted in an arid environment of Rajasthan, India. Ma et al. (2014) conducted a study in North China applying DA and factor analysis to understand the controlling factors of groundwater quality.

They identified the main controlling factors of groundwater quality in North China plain considering major ions and heavy metals to make better and more informed decisions for achieving sustainable groundwater development. Another study conducted by Nazzal et al. (2015) in Central Saudi Arabia considered major ions, pH and EC; and applied PCA technique to map groundwater quality. Their results inferred that both natural and anthropogenic actions contribute to the groundwater quality; but anthropogenic activities are more impactful and are an important factor in deterioration of groundwater quality. In Eastern part of Algeria, Bencer et al. (2016) conducted a study to highlight the hydro-chemical processes related to groundwater by applying CA and PCA techniques. Singh et al. (2017) used PCA, HCA and DA techniques to study major hydro-geochemical processes and decipher the anthropogenic activities using major ions and EC in Delhi, India. Jalali (2012) attempted to assess the controlling factors of groundwater chemistry in western Iran by applying chemical analysis of the samples, PCA and plotting the various parameters via graphical plots. In Mid-Norway, Brandsegg et al. (2010) used wire line well log data and applied structured PCA technique investigated the structure of variations within highly heterogeneous data of water quality. Praveena et al. (2010) conducted hydro-chemical analysis using major ions in water in East Malaysia to evaluate the groundwater quality of an unconfined aquifer. A study conducted by Voudouris et al. (2000) using simple and multiple regression, factor and trend-surface analyses considering major ions, pH, EC, TDS and TH assessed groundwater hydrochemistry, especially in situations where numerous samples are available in Peloponnese, Greece. Sheikh et al. (2017) inferred hydro geochemical processes and their subsequent impacts upon water quality in Haryana, India by using stable isotopes, GIS and Piper plots. In order to identify the pollution indicators of groundwater in Rajasthan, India, Sharma et al. (2015) used factor

analysis while considering the major ions in the groundwater samples. Mondal et al. (2016) carried out their research work using standard hydro-chemical analysis to identify major impacting physic-chemical parameters of groundwater quality in Rajasthan, India. Ahada and Suthar (2017) plotted major ions on Piper plot and carried out hydro-chemical analysis considering pH, EC, TDS and TH in Rajasthan, India, to discuss the hydrochemistry of groundwater. Lapworth et al. (2017) explored the hydrochemistry of the top 160 m aquifer systems in northwest India, using hydro chemical analysis. Tiwari et al. (2017) provided an overview of the spatial variation of the groundwater quality parameters in Rajasthan, India, using hydro-chemical analysis, Piper plots and GIS. Chintalapudi et al. (2017) conducted a study using Piper plots, Gibbs plot and hydro-chemical analysis techniques to assess the groundwater quality contamination threat around industrial cluster at Rajasthan State Industrial Development and Investment Corporation (RIICO) in Jaipur city considering major ions, pH, EC, TDS, TH and SAR. Kumar et al. (2016) conducted hydro-chemical analysis of the groundwater samples in Bikaner, Rajasthan, India, to understand the effect of canal recharge on groundwater and subsurface movement of recharge pathways. Singh et al. (2017) evaluated the geochemical mechanism of fluoride in groundwater of western India using various techniques such as hydro-chemical analysis, x-ray diffraction and geo-chemical plots. Vasanthavigar et al. (2010) developed a water quality index by understanding hydro geochemical parameters for Thirumanimuttar sub-basin of Tamilnadu, India while considering the major ions and various other physic-chemical parameters of groundwater quality.Tirkey et al. (2017) assessed the groundwater quality status in peri-urban agglomeration of Ranchi city in northeast India using hydro-chemical and water quality index (WQI) techniques. Jain and Vaid (2018) analyzed water quality parameters to observe the

suitability for drinking and irrigation purposes in Nalbari district of Assam in eastern India, considering major ions in the groundwater. Vijay et al. (2011) assessed and evaluated the deterioration of groundwater quality due to anthropogenic activities in Puri city, India using various techniques such as hydro-chemical analysis, bacteriological analysis and water level fluctuations. Singh and Singh (2018) analyzed the groundwater samples for arsenic contamination and also plotted the observations using Piper plots for groundwater samples in northeast India using multivariate statistical analysis and geo-chemical plotting. Ahamad et al. (2018) analyzed the geochemistry of groundwater samples from Varanasi, northern India, using various geo-chemical plots such as Gibb's plot and Piper plots. Srivastava and Ramanathan (2008) assessed the impacts of landfills on groundwater quality using various hydro-geochemical methods and multivariate statistical tools in northern India, considering major ions and heavy metals. Jasrotia et al. (2018) evaluated the groundwater quality parameters to assess the geochemistry of the groundwater in the western Doon valley region using hydro geochemical techniques such as Piper diagram, expanded Durov diagram, kelley's ratio index and permeability index. Chabukdhara et al. (2017) assessed the groundwater quality and health risk associated with it using hydro geochemical methods and multivariate techniques in northern India, using heavy metals and major ions in the groundwater samples. They applied fuzzy comprehensive assessment and PCA in conducting their research work. Arumugam and Elangovan (2009) assessed the groundwater contamination due to anthropogenic activities using various geochemical plots and hydro geochemical methods for Tirupur region of Coimbatore district in Tamil Nadu, India. They used PCA technique to analyze major ions in the study. Another study by Avtar et al. (2013) in central India, used PCA analysis and hydro geochemical plotting in order to establish the

suitability of groundwater for drinking, agricultural and industrial purposes. Raju (2007) estimated SAR, RSC and permeability index (PI) using Chadha rectangular diagram for geochemical classification and hydro-chemical processes in South India considering the major ions. Singh et al. (2011) ascertained the presence of heavy metals in groundwater samples and used Piper and other graphical methods to represent the groundwater geochemistry in northern India using PCA with major ions in the water samples. Singh (2010) explained the feasibility of conjunctive use of surface water and groundwater for sustainable irrigation for agricultural crop production in northwest India. They considered soil moisture and salinity as parameters for their study and simulated the conjunctive water use. Singh (2014) presented an overview of major issues and methods for the conjunctive use of both groundwater and surface water resources for sustainably irrigated agriculture.

Few important observations made from the literature studies are given below:

- Most of the literature studies found that the quality of groundwater is deteriorating due to fast economic and anthropogenic growth.
- It is also observed that in many of the regions (from reviewed studies) the groundwater quality is not drinkable especially in arid and semi-arid regions.
- The studies assess the major factors of groundwater quality deterioration.
- Research community believes that both anthropogenic and natural processes affects the groundwater quality.
- Research community argues that recharge of groundwater and its contaminations are two major problems.

2.3 REMOTE SENSING, GIS, AND FUZZY MULTICRITERIA DECISION MAKING

Scholars from different parts of the world have offered various tools and techniques for investigating groundwater quantity as well as quality. The older techniques like lithologs, non-destructive tests and field survey consume a lot of time, labour and cost as compared to the recent and trending remote sensing and GIS.

Present-day advancements in remote sensing and GIS has proven their effectiveness and diligence for groundwater studies. Jha et al. (2007) reviewed remote sensing and GIS technology to focus their effectiveness in covering the groundwater hydrology and revealed six key areas which can be addressed using remote sensing integrated with GIS. They also discussed about the constraints in the field of remote sensing and GIS for the developing nations. The study concluded that remote sensing GIS techniques have a great potential to address the problems related to groundwater resources. Machiwal and Singh (2015) developed thematic maps of soil, LULC (Land use and Land Cover), slope, drainage density, water level fluctuation and transmissivity maps, using remote sensing and GIS technique, of the Aharriver catchment located in Udaipur, Rajasthan, India. Oikonomidis et al. (2015) attempted to assess the groundwater potential areas situated in Thessaly in central Greece, with the help of integrated remote sensing and GIS and compared the results with the field data. Senanayake et al. (2016) conducted a research study in Ambalantota, Sri Lanka in order to delineate potential artificial recharge zones for groundwater. They adopted a weight linear combination method for integrating various thematic layers developed for the study using remote sensing and GIS. Jenifer and Jha (2017) carried out a study in Tiruchirappalli district, Tamil Nadu,

India and observed the effectiveness of remote sensing and GIS techniques in delineating the groundwater potential zones. With the help of satellite imagery, they developed various thematic maps and applied weights to each layer based on AHP, Catastrophe and Entropy multi-criteria decision analysis (MCDA) techniques.

Manap et al. (2014) generated groundwater potential zone maps with the help of frequency ratio (FR), which is a probability based model, in Langat basin area in Malaysia. They utilized the GIS tool to generate groundwater potential zone maps. Naghibi et al. (2018) conducted a study in Mashhad Plain, Iran to identify potential artificial recharge areas through floodwater spreading (FWS). They generated suitability maps with the help of GIS for this study. Iqbal et al. (2015) used GIS based fuzzy pattern recognition model for vulnerability assessment of groundwater towards pollution. Their model considered the DRASTIC approach which affects and checks the contamination of groundwater.

2.4 GROUNDWATER SUSTAINABILITY INDEX

Sustainable development of the natural resources has now become a global need of the hour and is of critical importance. Sustainability is a comprehensive concept which incorporates many factors. Generally, sustainability in a domain of interest covers social, environmental and economic effects. Considering these effects, water resources sustainability implies uses and future developments of water resource sector logically to guarantee development of economy, environment and community sustainably (Wang et al., 2019). According to Flint et al. (2004), sustainable development mainly focuses on well-being of community, healthy economy, water quality and quantity, and finally on national security. Scholars from all over the world have contributed extensively on the sustainability of water resources. Cortes et al.

(2018) worked on improving the sustainability of a basin and developed a watershed sustainability index. Konar et al. (2016) offered a blueprint for better understanding the sustainable water use for a social hydrological model. Mekonnen and Hoekstra (2016) observed the scarcity and status of water resources on monthly basis and revealed four key factors to achieve water use sustainability. Another study by Chaves and Alipaz (2007) developed watershed sustainability index and incorporated key factors affecting the water resource sustainability in the study area. Mititelu-Ionus (2017) developed a robust watershed sustainability index by emphasizing the dynamic evolution of watershed sustainability and offered further advancement in water resources sustainability. While evaluating and assessing the condition, performance and responses of natural and anthropogenic activities, indicators play a key role for policy–makers, administrators, mangers and stakeholders to respond fittingly. Water resources sustainability studies based on indicators offer a sound theoretical base for follow up scholars to address the concept in a scientific manner and review its usefulness. Sullivan et al. (2017) described the significance of attaining water resource management sustainability by studying the water resources of the Colorado River Basin, United States. After analyzing the management aspects of water resources in four river basins, Jacob et al. (2016) inferred that sustainable development of water resources can be better understood by merging action and knowledge together. Kong et al. (2016) proposed an interdisciplinary research methodology by incorporating the use of GIS to analyze and assess the water resource sustainability. A blueprint indicator framework was proposed by Koop and Leeuwen (2015) in order to evaluate the urban water resources sustainability. Kasim et al. (2014) suggested a water management framework incorporating strategies and case studies to address how water management can be utilized in hotels of varying sizes and diversified

managerial capabilities. Enormous research has been carried out worldwide on sustainability indicators which are of prime importance and play a major role for water resource management. Juwana et al. (2010) proposed a framework employing Delphi technology for analyzing the water sustainability indicators in West Java. Kefayati et al. (2018) explored the sustainability of watershed by using a comprehensive water resource indicator framework. Naubi et al. (2017) developed a sustainability index for Skudai river for analysing the river water sustainability. Vollmer et al. (2016) proposed a review of nearly 95 indicators for the assessment of freshwater resources sustainability. In order to assess the sustainability of urban waters, Gonzales and Ajami (2015) formulated a water management indicator framework on a regional scale. In a study by Singhal et al. (2015), water resource sustainability indicator system was used to assess the urban groundwater sustainability in northern India. In order to assess the sustainability of world water resources, researchers have proposed a blue water sustainability index (Wada and Bierkens, 2014). Shilling et al. (2013) studied the water resources of California with the help of a framework based on water resources sustainability indicators.

2.5 LIFE CYCLE ASSESSMENT

Worldwide researchers are incorporating life cycle management tools in order to study freshwater resources and their environmental impacts as well as socio-economic aspects. Koehler (2008) highlighted the critical aspects of water use in LCA and also pointed out the issue of water scarcity in Asia, particularly in India and China. According to Bayer et al. (2009), LCA of groundwater extraction is a potential research topic. It stated that LCA as a tool needs further consideration beyond its industrial applications. Boulay et al. (2011),

focused on categorizing the type of water and water users for LCA inventory. The study categorized two types of agricultural water users: one is good quality irrigation water user and another is relatively poor-quality water users. Milà et al.(2009) focused on assessment of freshwater use impacts, development of inventory model, and characterization factors for impact assessment. A few studies have applied LCA in agricultural sector. Birkved and Hauschild (2006) used LCA to estimate the environmental impacts due to use of pesticide in agricultural and illustrated the capability of the model through two real time Danish case studies. Dijkman et al. (2012) focused on impacts related to use of pesticides in agricultural sector in Europe. In this sequence, few studies have been conducted in the context of water footprint assessments in India. Bhakar et al. (2015), focused on assessing the environmental impacts associated with water supply system of a university campus. Another study by Bhakar et al.(2016), focused on treatment and purification of freshwater supplied to the residents of a university campus for drinking purposes. Ghazi et al. (2008) evaluated the environmental impact associated with the mud generated in drilling operations.

2.6 RESEARCH GAP

The important research gaps assessed from the literature studies are given below:

- No studies have been found in the contemporary literature addressing quality as well as quantity of groundwater resources in the study area, especially in context to hyper arid regions located in India.
- No studies have been found assessing the groundwater sustainability in single score in the study area and also environmental vulnerability due to use of groundwater for irrigation purpose.

- Appropriate groundwater withdrawal policies are missing for the study area as the total habitation and agricultural water needs are fulfilled by groundwater only.
- Indicator based studies which govern the groundwater resources of the region have not been addressed in the research domain.
- Addressing the groundwater resource management issues with the help of remote sensing and GIS in the study area is also lacking. Remote sensing and GIS integrated approach has proven capabilities in assessing the quantitative as well as qualitative aspects of the groundwater at the regional as well as national levels.

The literature review provides a brief summary of the existing studies in terms of major parameters assessed and research methodology used. It can be beneficial for researchers and practitioners to identify correct set of parameters and research methodology for the selected area of research. The literature review investigations illustrated in this chapter reflects that there is a need for an accelerated pace of research, which can address different aspects of groundwater management systems in an accurate and effective manner. The crucial and fundamental findings of the contemporary research include that there is a need to develop comprehensive models which not only takes into account the qualitative and quantitative aspects of groundwater but also deals with uncertainty aspect associated with the data. To provide a suitable solution in the best possible way, a rigorous attempt has been made in the present study by focusing and addressing issues mentioned above. These are presented in subsequent Chapters of this thesis work.