CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

In this chapter a brief review of literature has been carried out under the following topics, viz Quality of groundwater for drinking, quality of groundwater for irrigation, interpretation of hydrochemical data using spatial analysis, controlling mechanism of groundwater hydrochemistry, interpretation of hydrochemical data using statistical analysis, applications of ANN in groundwater analysis, artificial recharge in improvement of groundwater quality and artificial neural network (ANN) techniques in groundwater quality prediction.

2.2 QUALITY OF GROUNDWATER FOR DRINKING

An assessment study to evaluate the groundwater quality at Phulpur Thana of Mymensingh district in Bangladesh was conducted by Shahidullah et al (2000). Groundwater samples from 14 deep tube wells were analysed for pH, EC, TDS, Na, K, Ca, Mg, Fe, P, SO$_4$, Cl and HCO$_3$. The sodium absorption ratio (SAR), soluble sodium percent (SSP) and residual sodium carbonate (RSC) were also calculated using standard methods. The range of EC was 180-380 µScm$^{-1}$ and the range of SAR was 0.22-0.80. These two parameters indicated that three samples were in low salinity-low alkali and 11 were in medium salinity-low alkali hazard classes. The chloride toxicity was also present in the area. The presence of SO$_4$, NO$_3$ and P were negligible. Except boron and SSP, all water samples were of good to excellent class.
Almost all water samples in the area were found to be fresh water with respect to TDS content. Some of the water samples may not be suitable for drinking and industrial uses due to higher values of TDS and pH. The water quality analysis for drinking purpose was conducted by Joshi and Srivastava (2006) with the water samples collected from Tarai region of Nainital district and Udham sing nagar of Uttaranchal. Physico-chemical and biological parameters including pH, alkalinity, total hardness, total dissolved solids, sulphate, nitrate, magnesium, chromium, iron and total coliform were studied. The results obtained were compared with drinking water standard IS-10500. Analysis of the results showed that iron and magnesium were slightly higher at few locations when compared with the permissible limits and Faecal contaminations were also noticed in some of the drinking water samples.

A water quality index applied to river basin of Douro River was carried out by Adriano et al (2006). A Water Quality Index (WQI) is a numeric expression used to evaluate the quality of given water, which could be easily understood by managers. In this study, a modified nine-parameter Scottish WQI was used to assess the monthly water quality of the river Douro for the period of 10-years between 1992 and 2001. It ranged from a lowest value of zero to a highest value of 100%. The Douro river basin is the international watershed and it is the largest in the Iberian peninsula. The area of Douro River basin is 98,000 km². The water received by Portugal from Spain showed the poorest quality (WQI 47.3 ± 0.7%), the quality of water increased steadily in downstream side up to 61.7 ± 0.7%. In general, the water quality at all three sites was medium to poor. Seasonally, water quality decreased from winter to summer, but no statistical relationship could be established between quality and discharge rate. Depending on the location, different parameters were responsible for the episodic decline of the quality. High conductivity and low oxygen content were found in the uppermost reservoir and faecal coliform contaminations were found in the downstream.
The study of seasonal variations in the concentrations of total solids, total dissolved solids, total suspended solids of the Sirur dam water during the year 2001-2002 was studied by Pawar et al (2006). The water transparency was recorded a maximum value during summer season while minimum during winter season. The total solids, total dissolved solids, total suspended solids were found to be maximum during monsoon season and minimum during winter season.

The study of physico-chemical characteristics of groundwater used for drinking purpose from eight different sites at Moradabad city was carried out by Sinha and Rastogi (2007) to estimate the level of contamination. It revealed that the drinking water was found to be highly contaminated with reference to most of the water quality parameters while it was moderately contaminated for some of the water quality parameters studied. The study revealed that the people using this water were prone to health hazards due to contaminated drinking water. They have suggested some urgent effective measures for the water quality management.

The physico-chemical parameters of Mulla Dam water were studied by Dhembare (2007) during July 04 to June 05. Seasonal variations in summer, rainy and winter seasons were recorded. The various parameters studied were hydrogen ion concentration, water temperature, hardness, calcium, magnesium, carbonates, bicarbonates, chloride, sulphates, phosphates, dissolved oxygen and total solids. The results revealed that there were significant seasonal variations in some physico-chemical parameters and most of the parameters were in the normal range and indicated that the Dam water was of better quality.

The impact of high concentration of TDS in groundwater used for drinking purpose with respect to medical norms were analysed by Kavita batheja et al (2007). In this study Groundwater samples were collected from different locations in Churu tehsil, Rajasthan, India for their physico-chemical
studies. Laboratory tests were performed for the analysis of samples for TDS, EC (Electrical conductivity) and major ions such as Ca, Mg, NO$_3$, Na and K. This paper has highlighted the analytical results of major ions contributing towards TDS. They have compared the results with Indian Council of Medical Research (ICMR) standards for drinking water quality and it is found that most of the water samples were non potable for human beings due to high concentration of at least any one of the parameters. Most of the samples have total dissolved solids values much higher than the maximum permissible level stipulated by I.C.M.R.

An assessment of groundwater quality in a structurally deformed granitic terrain in Hyderabad, India was carried out by Satyanarayanan et al (2007). Geochemical study of groundwater was carried out to evaluate the hydro geochemical processes and quality of groundwater. Several trace elements along with major ions and minor elements were precisely estimated in shallow and drilled wells to know the suitability of water for drinking and irrigation purposes. Analytical data have shown that pH and major ion chemistry in dug wells and bore wells did not vary significantly, while some trace elements such as Fe, Mn, Al, Pb, U and Zn varied in dug wells and bore wells. The differential mineral weathering, dissolution or precipitation reactions along fractures and joints could be taken as the cause for these variations. Although the water was not potable, it was found to be suitable for irrigation with little risk of exchangeable sodium. It was inferred that the chemical composition of the groundwater in this region was likely to have its origin from silicate weathering reactions and dissolution processes supported by rainfall and groundwater flow.

The hydro chemical investigation conducted by Tatawat and Singh (2008) was restricted to the major ions concentrations, distributions, their relative abundance and their pattern of the variability in groundwater chemistry. 11 ground water samples were collected from Jaipur City,
Rajasthan, India from different hand pumps to study the chemical parameter, such as pH, EC, Total Hardness (TH), Ca, Mg, Na, K, CO$_3^{2-}$, HCO$_3^{-}$, SO$_4^{2-}$, and Cl with the help of standard methods of American public health associations (APHA) during premonsoon season (April 2006 to June 2006). It was observed that about 36% of groundwater exceeded the permissible limit of EC, TDS and TH. The groundwater quality of Jaipur city experienced degradation due to rapid urbanization and industrialization.

WQI and its suitability of water for human and cattle consumptions from Kohargaddi dam in Balrampur district, India were carried out by Mishra et al (2008). The physico-chemical characteristics of Kohargaddi dam water were studied during July 06-07. Seasonal variations in water quality parameters during rainy, winter and summer seasons were studied. The results revealed that there were significant seasonal variations in some physico-chemical parameters and WQI. The results indicated poor status of water during rainy and winter seasons and very poor status during the summer season. They concluded that the water of Kohargaddi dam was not suitable for human or cattle consumption.

The environmental impact assessment and seasonal variation study of the groundwater in the vicinity of river Adyar, Chennai, India was carried out by Venugopal et al (2008). From the geochemical results, it has been found that the seasonal effect does not change the order of abundance of both cations and anions, but it had changed the concentration of various ions present in the groundwater. Na and Cl were found to be the most predominant ions in their study. The nitrate concentration in the groundwater ranged from 4.21 to 45.93 mg/l in premonsoon and it ranged from 1.02 to 75.91 mg/l in postmonsoon. The nitrate concentrations in the postmonsoon season were high in some places especially in the upper stretch of the river. The intense agricultural activities near the upper stretch of the river were an important factor for the higher concentration of nitrates in these aquifers. In order to
determine the geochemical nature of water, the data were interpreted using the piper diagram and found Na-Cl and Ca-Mg-Cl types of water. Equiline diagrams were used to evaluate the affinity of ion relationship between various ions present in these waters. A comparison of the groundwater quality in relation to drinking water quality standards have shown that most of the water samples were not suitable for drinking purpose during postmonsoon period. US Salinity Laboratory’s diagram, Wilcox’s diagrams, Kelly’s ratio and magnesium ratio were used to evaluate the water quality for irrigation. It was found that majority of the groundwater samples were not good for irrigation in postmonsoon season. The sources of the ions in the water were examined and classified accordingly using Gibb’s diagram. The TDS values of the premonsoon samples were lower than the postmonsoon samples.

The hydrochemical characteristics and groundwater quality assessment were carried out by Arumugam and Elangovan (2008) in Tirupur Region of Tamil Nadu, India. Groundwater samples from 62 locations have been collected. The extensive agricultural, industrial activities and urbanization resulted in the contamination of the aquifer. Most of the locations were contaminated by higher concentration of EC, TDS, K and NO$_3$. Majority of the samples were not suitable for domestic purposes and far from drinking water standards.

The assessment of groundwater quality of Bhavana nagar region was carried out by Deepti Mishra et al (2009) for determining its suitability for drinking purposes. Groundwater samples collected from 12 different locations of Bhavana nagar region for winter, summer and postmonsoon seasons revealed that pH of all samples were neutral to slightly alkaline. Turbidity of all samples were within the permissible limit. TDS, TH, Fl, Cl and Cr were beyond the permissible limit in some samples. In most of the samples iron was beyond the permissible limit. Zn, Cu and Mn were within the permissible limit.
2.3 QUALITY OF GROUNDWATER FOR IRRIGATION

The assessment of regional water quality for the irrigation use from Jilh aquifer in Saudi Arabia was carried out by Saeed et al (2001). Water quality data from 72 wells in the study area were collected and analyzed for 14 different water quality parameters. The hydrochemistry of the Jilh aquifer was studied in detail to evaluate the aerial distribution of major ions. The results showed that the overall concentrations of all the ions were very high and the sodium hazard in the aquifer was low. The classification showed that 7 percent of wells had waters of permissible quality for agriculture use without any hazard, 22 percent of the wells had waters of moderate quality and 71 percent of the wells had unsuitable water quality. Low SAR and high EC in all the wells showed that the water from these wells could be used for irrigation purposes with proper leaching.

The analysis of geochemistry of groundwater in Burdwan district of West Bengal, India was carried out by Gupta et al (2008). The hydrogeochemical investigations were carried out in different blocks of Burdwan district in order to assess its suitability for drinking and irrigation purposes. 49 groundwater samples were collected from the bore wells and their water chemistry of major cations and anions were analyzed. The chemical relationships in Piper and Gibb’s diagram had suggested that the groundwater was mainly belonging to alkali type and Cl group and were controlled by rock dominance. A comparison of groundwater quality in relation to the drinking water quality standards proved that most of the water samples were suitable for drinking whereas groundwater in some areas of the district had high salinity and high sodium adsorption ratio (SAR), indicating their unsuitability for irrigation.
The assessment of groundwater quality from some parts of Gwalior, India was carried out by Singh and Singh (2008). The groundwater of Gwalior region was assessed for its irrigational suitability. Fourteen water samples were collected from dug and bore wells. The Groundwater samples were analyzed for major cations such as Na, Ca, Mg, K and anions such as Cl, HCO$_3^-$, CO$_3^{2-}$, SO$_4^{2-}$ and NO$_3^-$.

The important constituents that influence the water quality for irrigation were TDS, EC, SAR, RSC, sodium percentage (Na %) and permeability index (PI). These parameters were compared with standard limits and were found to be within the safe limit recommended for irrigation purpose. TDS in ground water was ranging between 256-1324 mg/l during the investigation period. It revealed that groundwater of the study area would not cause any salinity hazard.

The hydro chemical analysis and evaluation of groundwater quality in Tumkur taluk, Karnataka State, India was carried out by Sadashivaiah et al (2008). The Taluk spreads over an area of 1043 sq.km in the semi-arid region and frequently facing water scarcity as well as quality problems. Water samples were collected from 269 stations during premonsoon season and from 279 locations during postmonsoon season of the year 2006. The water samples were tested for chemical characteristics. Based on hydro chemical facies, the type of water that predominates in the study area was Ca-Mg-HCO$_3^-$ during both premonsoon and postmonsoon seasons. The suitability of water for irrigation was evaluated based on SAR, RSC, Na %, EC and USSL classification.

The hydro chemical characteristics and the effects of irrigation on groundwater quality in Harran Plain, GAP Project, Turkey was carried out by Yesilnacar and Gulluoglu (2009). Their aim was to determine the groundwater quality after the use of surface irrigation in semi-arid Harran Plain. Physical and chemical parameters of the groundwater including pH,
temperature, EC, Na, K, Ca, Mg, Cl, HCO$_3^-$, SO$_4^{2-}$, NO$_3^-$, NH$_4^+$, P, total organic carbon and turbidity were determined monthly during the year 2006. The quality of the groundwater in the study area was assessed to determine its suitability for human consumption and agricultural purposes. In the general plain, the EC values measured were considerably above the guide level of 650$\mu$Scm$^{-1}$, while nitrate was found almost in all groundwater samples and its values were significantly above the maximum admissible concentration for human consumption with respect to international and national standards. Majority of the groundwater were of very hard water category. Interpretation of analytical data has shown that Ca–HCO$_3^-$ and Ca–SO$_4^{2-}$ were the dominant hydrochemical facies in the study area.

The surface and subsurface water quality appraisal for irrigation was carried out by Isaac et al (2008). Use of irrigation water available from various sources in agriculture was justified on agronomic and economic grounds. For this study 44 water samples were collected from the various resources such as canal, sewage pipe line, tube wells in confined aquifers and unconfined aquifers of Chaka block in Allahabad district. The water samples were chemically analyzed to check its suitability for irrigation and to classify them according to the amount of salts present. The analysis revealed that most of the samples were within the lower alkalinity limit except sewage water. The EC of the samples ranged from 0.26 to 1.37millimhos/cm. P, Na, Ca and PO$_4^{3-}$ were all found to be in permissible range except one sample in the village Kuria, where the Na percentage was found in doubtful category. The other parameters like SAR, RSC and soluble sodium percentage (SSP) were also found below the permissible limit.

A study was conducted in 20 villages of Lahore district to assess the suitability of ground water for irrigation by Ali et al (2009). 60 water samples were collected from 20 villages and they were analyzed for EC, SAR, RSC and
Cl concentrations. Out of 60 water samples, 7 were fit, 7 were marginally fit, and remaining 46 were unfit for irrigation. 28 samples had EC higher than the permissible limit, 19 samples had high SAR, 44 samples had high RSC and 10 samples were found unfit for irrigation due to high concentration of Cl. It was understood that the quality of ground water in most of the villages was not suitable for sustainable crop production and soil health.

The quality of groundwater in the shallow aquifers of a paddy dominated agricultural river basin of Kerala, India was assessed by Kannan and Joseph (2009). The groundwater from the shallow aquifers in Palakkad and Chittur taluks of Bharathapuzha river basin of Kerala had been selected where paddy is the dominant crop. The water samples were collected from various seasons such as monsoon (August, 2005), postmonsoon (December, 2005) and premonsoon (April, 2006) and they were analyzed for important physico-chemical parameters. Spatial and temporal variation of attributes existed in the study area and different hydro chemical facies have been identified. Using Gibb’s diagram, rock dominance has been identified as the mechanism controlling groundwater chemistry. Further, the suitability of water for irrigation was determined by analyzing salinity hazard indicated by SAR, RSC and Na%. Finally, stress zones in the study area were delineated using Arc GIS spatial analysis software and various management options were recommended to restore the ecosystem.

The hydro chemical appraisal of groundwater and its suitability in the intensive agricultural area of Muzaffarnagar district, Uttar Pradesh, India was carried out by Tyagi et al (2009). Muzaffarnagar is a district situated in the most fertile plains of two great rivers Ganga and Yamuna in the Indo-Gangetic plains, with agricultural land irrigated by both surface water and groundwater. An investigation has been carried out to understand the hydrochemistry of the groundwater and its suitability for irrigation uses.
Groundwater in the study area was neutral to moderately alkaline in nature. Chemistry of groundwater suggested that alkaline earths (Ca + Mg) significantly exceed the alkalis (Na + K) and weak acids exceed the strong acids (Cl + SO$_4$), suggesting the dominance of carbonate weathering followed by silicate weathering. Majority of the groundwater samples (62%) had Ca–Mg–HCO$_3$ type of hydro chemical facies followed by Ca–Na–Mg–HCO$_3$, Na–Ca–Mg–HCO$_3$, Ca–Mg–Na–HCO$_3$–Cl and Na–Ca–HCO$_3$–SO$_4$ types. A positive high correlation ($R^2 = 0.928$) between Na and Cl suggested that the salinity of groundwater was due to intermixing of two or more groundwater bodies with different hydro chemical compositions. Most of the groundwater samples were suitable for irrigation uses. Chemical fertilizers, sugar factories and anthropogenic activities were contributing the sulphate and chloride concentrations in the groundwater of the study area.

2.4 INTERPRETATION OF HYDROCHEMICAL DATA USING SPATIAL ANALYSIS

The spatial and temporal variations of groundwater chemistry in Pettyjohns cave, Northwest Georgia, USA was done by James Mayer (1999). A longitudinal study of water chemistry in Pettyjohns Cave, Georgia, revealed a wide range of major ion water chemistry at different sampling points within the cave and pronounced seasonal water chemistry variations at some locations. The cave occurs in the Mississippian Bangor limestone on the east side of Pigeon Mountain in the Appalachian Plateaus physiographic province of northwest Georgia, USA. 4 sampling points within the cave were monitored at approximately 2-3 month intervals for 22 months. They were a major conduit stream, a small conduit tributary, water dripping into the cave through a small fracture and the water dripping from active speleothems. Surface water was also sampled as available and was analyzed for temperature, pH, specific conductance, alkalinity, and major ions. Most
spatial water chemistry trends within the cave appeared to be the result of rock-water interaction along distinct subsurface flow paths. Temporal variations were most pronounced in conduit streams and resulted primarily from mixing of distinct waters in varying ratios. Results illustrated the inherent spatial and temporal variability of water chemistry in karst aquifers and pointed the need to design sampling programs carefully.

The groundwater quality mapping using Geographical Information System (GIS) was carried out by Anbazhalagan and Nair (2004) in Panvel basin Maharashtra, India. A GIS based groundwater quality mapping has been carried out in the region with the help of data generated from chemical analysis of water samples collected from the basin. Groundwater samples showed the quality deterioration due to excess level of chloride, hardness, TDS and salinity. These parameters indicated the level of quality of groundwater for drinking and irrigation purposes. Idrisi 32 GIS software was used for generation of various thematic maps and for the spatial analysis and integration to produce the final groundwater quality map. The groundwater quality map showed fragments representing groundwater zones that were desirable and undesirable for drinking and irrigation purposes.

A spatial analysis of groundwater quality of Gulbarga city, Karnataka state, India using GIS technique was attempted by Mise et al (2006). This work pertained to quality analysis and spatial variation in groundwater quality with GIS techniques. The analysis included the study of spatial and temporal variations of quality of groundwater in the region. The groundwater samples were collected from 55 wards of the city. The samples were analysed for physico-chemical parameters. The results were used for inter elemental correlation analysis which indicted some of the element showing good correlation. With map overlay technique, various thematic maps were generated showing the distribution of concentrations of chemical
parameters in different wards. The water quality parameters were depicted by various colour combinations for different ranges of concentrations. Groundwater quality map showed the poor quality of groundwater primarily due to its hardness.

Groundwater quality suitable zone identification with the application of GIS in Chittoor area, Andhra Pradesh, India was done by Yammani (2007). The analytical results of the groundwater samples showed that the groundwater was alkaline. Sodium and bicarbonate were the dominant cation and anion present in the study area. Gibb’s diagram showed that the control of the chemistry of groundwater in the study area was the weathering of granitic gneisses and also the leaching of evaporated and crystallized ions from the topsoil of the irrigated areas and improperly treated industrial effluent ponds. GIS has been applied and analyzed for identification of groundwater quality suitable zones for domestic and irrigation purposes. 30.06 % of the area was with suitable quality, 67.45% of the area was with moderately suitable quality and 2.45% of the area was with unsuitable quality of groundwater for domestic purpose. 46% of the area was with suitable quality, 53.36% of the area was with moderately suitable quality and 0.64% of the area was with unsuitable quality of groundwater for irrigation purpose.

A study on geo environmental quality assessment in Jharia coalfield, India has been attempted by Bhabesh et al (2007) using multivariate statistical analysis and GIS modeling techniques. Water quality Index was calculated for each sample network station in the study area to assess the suitability of water for human consumption. It revealed the presence of very poor to poor quality surface water and mine water. The role of various geo environmental parameters such as quality of groundwater, surface water, mine water etc., together with village population densities has been emphasized for delineation of the environmentally stressed villages in Jharia coalfield.
2.5 CONTROLLING MECHANISM OF GROUNDWATER HYDROCHEMISTRY

The hydro geochemical evaluation of Western Anatolian mineral waters was carried by Barut et al (2004). There are numerous mineral waters in Anatolia where geological and tectonic activities are intense. Archeological studies conducted in Anatolia, which is the cradle of various civilizations, revealed the fact that mineral water has been used in many areas. The scope of this study was to evaluate mineral waters in Western Anatolia and their use in thermal resorts for balneological purposes. In this respect, 50 thermal waters used in spa centers were analyzed for various physical, chemical and bacteriological parameters. Among the 50 waters tested, 40 were thermo mineral waters while 10 were acrato thermal waters. Some of these waters have distinct chemical compositions. Various types of mineral water sources occur in this region. 5 of these were sulphurous, 1 has carbon dioxide, 29 have fluorine, 1 has iodine and 3 are saliferous. The thermo mineral sources with saline characteristics have balneotherapy potential for treating skin illnesses including psoriasis and rheumatological illnesses. Some waters with appreciable bicarbonate and sulfate concentrations were used for balneotherapy. They were also used as a cure for prophylactic and metaphylactic treatment of urolithiasis. However, among 38 sampling sites, 12 sites were bacteriologically contaminated. This indicated that regulations governing the protection of such zones were not properly enforced and that water sources within these regions were not sufficiently protected or inspected.

The analysis of hydro chemical processes controlling the urban groundwater system in Seoul area, Korea was studied by Kim (2004). Urban activities cause a number of hydro geological environmental problems. The aim of his study was to undertake a hydro chemical evaluation of the urban
aquifer system in Seoul. Well monitoring, hydro chemical analysis, identification of contamination sources and an assessment of the mechanisms of hydro geological impact were undertaken. The aquifer quality was affected by several processes of groundwater contamination. Hydraulic conductivity in the Seoul aquifer varies from $2.3 \times 10^{-9}$ to $1.5 \times 10^{-3}$ m/sec. Interpretation of the hydro chemical data indicated that pollution created a general decline of the quality. Sliding stiff diagrams illustrated the mixing effect between polluted water and background fresh groundwater. Groundwater of the Seoul area was affected by diffuse pollution from industrial complexes, seepage from oil storage tanks, infiltration of sewage, and leachate percolation from abandoned landfills.

The process of water–rock interaction in the Turonian aquifer of Oum Er-Rabia Basin, Morocco was studied by Ettazarini (2005). Possible water-rock interaction processes in the Moroccan basin of Oum Er-Rabia were discussed by a geochemical study of groundwater from the Turonian limestone aquifer, the most important water resource in this region. Different types of water according to the classification of Piper were defined. Waters have shown an evolution from dominant $\text{CHO}_3$–Ca–Mg type mixed to $\text{SO}_4$–Cl–Ca–Mg type. The use of geochemical diagrams and chemical speciation modeling method has shown that water–rock interaction was mainly controlled by carbonate and anhydrite dissolution, ion exchange and reverse ion exchange processes. Water–rock equilibrium conditions were favorable for the precipitation of calcite, dolomite, kaolinite and magnesian smectite.

The water quality in weathered limestone in upper Mahanadi basin, India was studied by Panigrahy and Raymahashay (2005). Stromatolitic limestone and calcareous shale belonging to Chattisgarh supergroup of Proterozoic age dominate the upper part of the Mahanadi river basin. X-ray diffractogram of limestone rocks has shown the presence of a significant
amount of calcite, dolomite and ankerite. Shales of various colours contain calcite and dolomite. It was observed that congruent dissolution of carbonate minerals in the Charmuria pure limestone has given rise to typical karst topography. On the other hand, limestones were also seen to support red and black soil profiles. This indicated that the limestone bedrock has undergone a parallel incongruent weathering. The XRD analyses revealed that the limestone soils thus formed contain quartz, clays and iron-oxides. Also silicate component trapped during the deposition of stromatolitic limestone weathered incongruently resulting in diverse soil profiles. Carbonate and silicate mineral weathering schemes have been worked out to explain the soil formation, fixation of Al in clay minerals and Fe in goethite. The mineral stability diagrams indicate that kaolinite and Ca-smectite were stable in the river water environment. Hence they occur in suspended sediments and soils. The dominant influence of carbonate weathering on the water quality was observed even in the downstream part of the river outside the limestone terrain.

The study of water-rock interaction induced by contaminated groundwater in a karst aquifer, Greece was carried out by Panagopoulos et al (2005). The karst system is composed of a thick sequence of carbonate sediments, which have experienced two types of dolomitization and dedolomitization processes and comprise an extended aquifer. The application of fertilizers in the region have not only caused the degradation of the groundwater quality but also induced hydrochemical changes exerting major control on dolomitization processes. Factor analysis indicated high correlation coefficient between NH$_4$, NO$_3$, Ca and Mg. These parameters could be attributed to cation-exchange processes involving clay minerals. The application of conservative mixing model showed that the calculated groundwater types indicated a cation exchange process between NH$_4$ derived from fertilizers and Ca, Mg. Mg released from smectite inter-layers, exchanged for NH$_4$ in the groundwater and favoured a dolomitization process.
through the partial replacement of Ca in the lattice of calcite contained in precursor dolomites. This recent stage dolomitization occurred near the water level and within the phreatic zone and had not influenced the whole karst massif. It also resulted in low Mg / Ca values found in the zone characterized by intensive application of nitrogen-based fertilizers and the absence of overlying impermeable strata.

The controlling factors of groundwater hydrochemistry in a small island’s aquifer were studied by Aris et al (2007). The factor analysis was applied to the hydrochemical data set of Manukan Island in order to extract the principal factors corresponding to the different sources of variation in the hydrochemistry. The application of varimax rotation was used to ensure the clear definition of the main sources of variation in the hydrochemistry. The geochemical data of dissolved major, minor and trace constituents in the groundwater samples indicated the main processes responsible for the geochemistry evolution. By using Kaiser normalization, principal factors were extracted from the data for each location. The analysis revealed that there were four sources of solutes: (1) seawater intrusion (2) leaching process of underlying rock mediated by pH (3) minerals weathering process and (4) dissolution of carbonate minerals characterized by high loadings of Ca, Zn and Mg. Such processes were dominated by the significant role of anthropogenic impact from over abstraction of fresh water from the aquifer. Those factors contributed to the changes of the groundwater geochemistry behavior and explained the effect of rising extraction of freshwater from the aquifer.

The identification study of major sources controlling groundwater chemistry from a hard rock terrain was carried out by Srinivasamoorthy (2008). The study area Mettur forms an important industrial town situated in north-west of Salem district, Tamilnadu, India. The geology of the area is mainly composed of Archean crystalline metamorphic complexes. To identify
the major process activated for controlling the groundwater chemistry has been made by collecting a total of 46 groundwater samples during premonsoon and postmonsoon seasons. The groundwater chemistry was dominated by silicate weathering. Na, Mg, Cl and SO$_4$ account about 90% of cations and anions. The contribution of Ca +Mg and Na + K to total cations and HCO$_3$ indicated the domination of silicate weathering as major sources for cations. The plot for Na to Cl indicated higher Cl in both seasons, derived from anthropogenic sources from fertilizer, road salt, human wastes, animal wastes and industrial applications. Minor representations of Na also indicated the sources from weathering of silicate-bearing minerals. The plot for Na / Cl to EC indicated that Na was released from silicate weathering process and it was also supported by higher HCO$_3$ values in both the seasons. Ion exchange process was also activated in the study area. The plot of Na, Cl to Ca, Mg, HCO$_3$, SO$_4$ confirmed that Ca, Mg and Na concentrations in groundwater were derived from aquifer materials. Saturation index of silicate and carbonate minerals indicated over-saturation during premonsoon and under-saturation during postmonsoon, conforming dissolution and dilution process. In general, water chemistry was guided by complex weathering process, ion exchange along with influence of Cl ions from anthropogenic impact.

2.6 INTERPRETATION OF HYDROCHEMICAL DATA USING STATISTICAL ANALYSIS

Assessing ground-water vulnerability using logistic regression was done by Anthony et al (1998). Groundwater vulnerability has been assessed using largely qualitative methods and expressed as relative measures of risk. A statistical approach was used to quantify the likelihood of elevated concentration of nitrate or a detectable concentration of atrazine in a well. The occurrence of elevated nitrate concentrations or detectable concentrations of atrazine in ground water was related to both natural and anthropogenic
variables using logistic regression. The variables that explain the occurrence of elevated nitrate concentrations were well depth, geology and the percentages of urban and agricultural land within a radius of 3.2 kilometers of a well. Well depth and roadside application of atrazine explained the occurrence of detectable concentrations of atrazine. From these relations, multiple logistic regression models were developed to predict the probability of elevated nitrate concentrations or a detectable concentration of atrazine in groundwater of a well.

Characterization by factor analysis of the chemical facies of groundwater in the deltapic plain sands aquifer of Warri, western Niger delta, Nigeria was carried out by Olobaniyi and Owoyemi (2006). 60 water samples were collected from wells tapping the aquifer of Warri and its environments. Various parameters like pH, TDS, K, Na, Ca, Mg, Cl, HCO$_3$ and SO$_4$ were analyzed by standard procedures. The data obtained were subjected to R-mode factor analysis. Three factors were extracted. Factor 1 included K, Na, Cl, and EC and reflected the signature of saline water intrusion resulting from seepages. Factor 2 had high loading values of Mg, Ca, HCO$_3$ and pH. It represented the processes of natural rainwater recharge and water-soil / rock interaction. Factor 3 included SO$_4$ and it could be related to the dissolution of sulphides from the geological formation, heavy vehicular activity and the petroleum refining process in the town. The areal distributions of the various factor scores indicated that the factors 1 and 2 were enhanced close to the banks of river Warri and decreases away from them. Factor 3 was enhanced in the southeastern portion of the town where it was deemed to be caused by the dissolution by groundwater of sulphur bearing minerals within the geological formation and also in the central and northwestern portions of the town. This paper demonstrated the effectiveness of factor analysis in evaluating hydrochemical processes in coastal and industrial areas.
The controlling factors of groundwater hydrochemistry in a small island’s aquifer were studied by Aris et al (2007). Factor analysis was applied to the hydrochemical data set of Manukan Island in order to extract the principal factors corresponding to the different sources of variation in the hydrochemistry. The application of varimax rotation was used to ensure the clear definition of the main sources of variation in the hydrochemistry. The geochemical data of dissolved major, minor and trace constituents in the groundwater samples indicated the main processes responsible for the geochemistry evolution. By using Kaiser normalization, principal factors were extracted from the data for each location. The analysis revealed four sources of solutes were seawater intrusion, leaching process of underlying rock mediated by pH, minerals weathering process and dissolution of carbonate minerals characterized by high loadings of Ca, Zn and Mg. Such processes were dominated by the significant role of anthropogenic impact from the over extraction of fresh water from the aquifer. The changes of the groundwater geochemistry behavior explained the effect of rising extraction of freshwater from the aquifer.

The groundwater quality of Gulbarga district was extensively monitored for two years of study period from October 1999 to September 2001 by Majagi et al (2008). 25 different sampling stations were selected for the study purpose in the city and five selected villages in the district. Gulbarga districts lies in the northern plains of Karnataka State, covers an area of 16,244 sq km. The study revealed that the water sources in the area were heavily polluted. The major water quality parameters exceeding the permissible limits during all the seasons were TH, Ca hardness, Mg hardness, alkalinity and MPN (Bacterial count) and the other parameters have shown distinctive variations in different stations and seasons. Most of these parameters were correlated with one another.
A correlation study of the ground water quality in the Manali Petroleum Industrial Region in Tamil Nadu, India was studied by Arul Antony et al (2008). The increased prominence of the petroleum industry in Manali at North Chennai has given rise to an upsurge of ecological disturbances together with groundwater pollution. 10 groundwater samples were collected from various parts of the industrial region in the monsoon, winter and summer seasons during 2006-2007. 20 water quality parameters were taken into account for the correlation analysis. Significant positive correlation was found to exist between the pairs of parameters; turbidity-alkalinity, turbidity-iron, EC-Na, TDS-EC, TDS-TH, EC-TH and TH-K. It was also observed that some of the parameters were found to have weak correlation and some parameters had negative correlation.

The interpretation of groundwater quality using multivariate statistical technique in Moradabad City, Western Uttar Pradesh State, India was carried by Pathak et al (2008). 58 water samples were collected from different localities on the basis of various land use patterns. The higher values of most of the parameters were found in the area of old settlement, while lower values observed in new settlements. This showed clear impact of land use on groundwater. Water quality data collected from different localities were used in conjunction with multivariate statistical technique to identify key variables. The first four components were chosen for interpretation of the data, which accounts for 77.38 % of the total variance in the data set. The first component was characterized by Ca, Na, TH, TDS, BC and salinity while second component was characterized by DO and Mg. The third and fourth components were characterized by Ca, SiO$_2$, HCO$_3$ and K respectively. Hydrochemical constituents of the groundwater were mainly controlled by TDS and EC. For cluster analysis single linkage method was used. The findings of the cluster analysis were presented in the form of dendrogram of the sampling stations as well as hydrochemical variables, which produced
four major groupings. It suggested that groundwater monitoring could be consolidated.

Characterization of groundwater quality in Kinmen Island using multivariate analysis and geochemical modeling was done by Chen-Wuwing Liu et al (2008). This work characterized the quality of groundwater in Kinmen using factor analysis (FA), cluster analysis (CA) and geochemical simulation. The factor scores were plotted spatially to illustrate the groundwater quality and were used to discuss the grouped relationship using CA. Salinization, redox and organic matter factors were identified from 17 hydrochemical measurements in 18 wells. Acidic and oxidizing groundwater with nitrate-N pollution was distributed mainly in the west of Large Kinmen. Saline groundwater was distributed to the north-east of Large Kinmen and in the south of Leiyu. Groundwater with organic matter was present throughout Leiyu. Five groups of the groundwater quality divided by CA could be interpreted according to one to three factors. The grouped characteristics of the groundwater quality helped the local government and industries to plan the use and protection of groundwater resources. Furthermore, a geochemical simulation was used to demonstrate the formation processes of the acidic and oxidizing groundwater properties in granitic sediments. A large amount of the precipitation of the kaolinite and magnetite released the concentrations of hydrogen ion and raised the redox potential in the aquifers.

Regression analysis of ground water quality data of Sunamganj district, Bangladesh was carried out by Joarder et al (2008). Ground water samples from different Upazilas of Sunamganj District have been analyzed for drinking and irrigation purposes. Correlation coefficients among different parameters were determined. An attempt has been made to develop linear regression equations to predict the concentration of water quality constituents having significant correlation coefficients with EC. Ca and EC, HCO$_3$ and EC were highly correlated but not perfect. Their findings showed that Ca, NO$_3$, 

and HCO₃ were significantly related with EC at 1% level of significance. Except for the TDS, all the other variables were significant at a conventional level (i.e. 5%) with expected sign. The author said that the usefulness of these linear regression equations in predicting the ground water quality was an approach and it could be applied at any locations.

The ground water quality characteristics correlation and regression study on Coimbatore city west zone was done by Bathusha and Saseetharan (2009). Groundwater samples were collected from 18 wards of Coimbatore city west zone. 2 samples were collected from each ward and the total numbers of samples were 36. Water quality assessment was carried out for the parameters like temperature, odour, taste, colour, turbidity, pH, EC, TDS, Cl, TH, alkalinity, Ca, Na and K. Correlation coefficients were determined to identify the highly correlated and interrelated water quality parameters. Regression equations relating these identified parameters were formulated in this work. Comparison of observed and estimated values of the different parameters revealed that the regression equations developed in this study could be used for making water quality monitoring.

The evaluation of ground water quality using multiple linear regression and structural equation modeling was done by Chenini and Khemiri (2009). A methodology for characterizing ground water quality of watersheds using hydrochemical data that mingle multiple linear regression and structural equation modeling was presented. Hydro chemical data was analyzed in order to explore the composition of phreatic aquifer, the composition of groundwater samples and the origin of water mineralization using mathematical method and modeling in Maknassy basin, central Tunisia. Principal component analysis was used to determine the sources of variation between parameters. These components showed that the variations within the dataset were related to variation in sulphuric acid and bicarbonate, sodium
and chloride, calcium and magnesium which were derived from water-rock interaction. An equation was explored for the sampled ground water. Using Amos software, the structural equation modeling allowed testing the entire system of variables in order to determine the extent to which it was consistent with the data. The integrated result provided a method to characterize ground water quality using statistical analyses and modeling of hydro chemical data in Maknassy basin to explain the ground water chemistry origin.

2.7 APPLICATIONS OF ANN IN GROUNDWATER ANALYSIS

The forecasting techniques of groundwater contamination using artificial neural network was studied by Shamim et al (2004). He has said that the groundwater contamination has long been a deep concern to environmentalists due to its harmful effects on human health. He has also said that the presence of different effluents in groundwater should be known as accurately as possible so that necessary arrangements could be made to provide water treatment. He has used ANN model for the prediction of quantities of different effluents. The model was applied to real data from groundwater in Faisalabad, the largest industrial city of Pakistan. The city has more than 8000 big and small industrial units. The city was receiving effluents of a large number of textile mills, laundries and other factories. He has proposed the same method for the future prediction of quantities of heavy metals such as Fe, Cu and Pb in groundwater due to seepage. The data for both the lined and unlined channel was obtained from Pakistan Council of Research for Water Resources. The results obtained from the model were compared with actual values as well as the WHO Standards.

The prediction of mine water quality by physical parameters was done by Khandelwal and Singh (2005). This work was an attempt to predict the chemical parameter in mine water using ANN by incorporating the pH, temperature and hardness. The prediction by ANN was also compared with
multivariate regression analysis. For the prediction of chemical parameter of mine water, 30 data sets were taken for the training of network while testing and validation of network was done by 10 data sets with 923 epochs. The predicted results of chemical parameters of mine water by ANN were very satisfactory and acceptable as compared to MVRA and seem to be good alternative for pollution prediction.

Daily groundwater level fluctuation forecasting using soft computing technique was done by Azhar et al (2007) using ANN. The study presented here deals with forecasting of daily groundwater level fluctuation (GLF). The calculation model was based on the adaptive neuro-fuzzy inference system (ANFIS) and two algorithms of ANN models. The objective in this study was to predict daily GLF monitoring purpose. The first step was to investigate the effect of the number time lags as inputs for one-day-ahead prediction using the ANFIS algorithm. It was found that three input nodes containing three time-lag of well-studied gave good prediction results. The second experiment was to predict the GLF one to seven steps ahead using the three input nodes. In this experiment, the three soft computing techniques were applied. The results indicated that the performances were decreasing by increasing the time step ahead and in general there was no significant difference between the three techniques used. The best accuracy was for one-day-ahead prediction. The results obtained in this study suggested that GLF monitoring could be conducted by a forecasting model with considering time-lag as inputs.

River flow forecasting using ANN was studied by Akhtar et al (2009). This paper explored the use of flow length and travel time as a pre-processing step for incorporating spatial precipitation information into ANN models used for river flow forecasting. ANN models for flow forecasting were frequently developed only with 10 precipitation and discharge as inputs.
An analysis of the flow length and travel time as a basis for pre-processing remotely sensed rainfall data was presented here. 15 pre-processed rainfall data were used together with local stream flow measurements of previous days as input to ANN models. The case study for this modeling approach was the Ganges river basin. A comparative analysis of multiple ANN models with different hydrological pre-processing was presented. The ANN showed its ability to forecast discharges 3-days ahead with an acceptable accuracy. Within this forecast horizon, the influence of 20 pre-processed rainfall data was marginal, because of dominant influence of strongly auto-correlated discharge inputs. For forecast horizons of 7 to 10 days, the influence of the pre-processed rainfall was noticeable, although the overall model performance was deteriorating.

The forecasting of groundwater level using ANN was done by Sreekanth et al (2009). The performance of ANN model was trained with Levenberg–Marquardt algorithm in standard feed-forward neural network and it was examined for forecasting groundwater level at Maheshwaram watershed, Hyderabad, India. The model efficiency and accuracy were measured based on the root mean square error (RMSE) and regression coefficient \( R^2 \). The model provided the best fit and the predicted trend followed the observed data with RMSE = 4.50 and \( R^2 = 0.93 \). The author suggested that precise and accurate groundwater level forecasting could be done using ANN and it would be a promising tool also.

The determination of relationship between hardness and groundwater quality parameters by neural networks was done by Balkaya (2009). In this study, groundwater hardness quality at Samsun Incesu-Derekoy region was modeled by the use of ANN structure. In the data set arrangement effective input variables were five different water quality parameters. They were pH, chlorine, calcium, magnesium and total hardness.
Their concentrations in the time “\( t \)” and the output variable (TH) was the concentrations in the time “\( t + 1 \)”. For the model 10,000 epochs were performed and the learning rate was equal to 0.1, and correlation coefficient (R) that achieved in this study was found 0.591. As a result, the authors concluded that ANN was the effective modeling technique on estimation of environmental complex water quality problems.

2.8 ARTIFICIAL RECHARGE IN IMPROVEMENT OF GROUNDWATER QUALITY

A case study of artificial recharge pilot projects in Gujarat, India was done by Rushton and Phadtare (1989). They claimed that artificial recharge was a possible means of alleviating the over exploitation of aquifers. This work described artificial recharge experiments in both alluvial and limestone aquifers using spreading channels, percolation tanks and injection wells. The importance of understanding the conditions in the aquifer was stressed and the economic viability of the alternative techniques was considered. Intensive exploitation of an aquifer frequently leads to deteriorating conditions, especially in highly progressive agricultural areas where the quantity of water withdrawn for irrigation purposes was usually several times the recharge. This over-exploitation could lead to declining water levels and severe falls in pumping levels. In other situations, the consequence was the ingress of poor quality water. In areas of acute water shortage even small amounts of artificial recharge could greatly improve the reliability of the supply.

A detailed study on artificial recharge of groundwater was carried out by Herman Bouwer (2002). Artificial recharge of groundwater was achieved by putting surface water in basins, furrows, ditches, or other facilities where it infiltrated into the soil and moved downward to recharge aquifers. Artificial recharge was increasingly used for short or long term
underground storage. It has several advantages over surface storage, and in water reuse. Artificial recharge required permeable surface soils. Where these were not available, trenches or shafts in the unsaturated zone were used. Or water could be directly injected into aquifers through wells. To design a system for artificial recharge of groundwater, infiltration rates of the soil had to be determined and the unsaturated zone between land surface and the aquifer had to be checked for adequate permeability.

An overview of recharge and groundwater models was done by Ward Sanford (2002). He said that recharge was a fundamental component of groundwater systems and in groundwater-modeling recharge was either measured and specified or estimated during model calibration. The most appropriate way to represent recharge in a groundwater model depends on both the physical factors and the study objectives. A constant-head boundary condition was used where the water table was close to the land surface. Flux observations had to be incorporated in order to estimate the rates of recharge. Flux measurements were based on either Darcian velocities or seepage velocities. In regions that tend to be arid or have high topographic relief, the water table was usually deep and the rate of recharge was controlled by the amount of water that the climate provided and the soil delivered to the water table.

2.9 SUMMARY

The literature reviews have been carried out under the following topics towards the aim of this work. They are, evaluation of quality of groundwater for drinking and irrigation purposes, study of controlling mechanism of groundwater hydrochemistry, statistical analysis of groundwater quality parameters and application of artificial neural network in groundwater studies. Literatures to improve the groundwater quality have also been surveyed.