2. LITERATURE REVIEW

The entire literature review has been classified into four classes namely historical background, studies carried out at world level, studies carried out in India and studies carried out in Kutch.

2.1. HISTORICAL BACKGROUND

The importance of estimating the water availability from the available hydrologic data for purposes of planning water–resource projects was recognized by engineers even in the last century. With a keen sense of observation in the region of their activity many researchers have developed empirical formulae for estimation of runoff and groundwater recharge. However, these formulae are applicable only to the region in which they were derived.

There are several methods of estimation of runoff from known values of rainfall. The literature review for historical background for these was done from various books like Chow V. T. (1964), Ragunath H. M. (2000), Sharma R. K., Sharma T. K. (1999), Vashney R. S. (1979). Some of them are as follows:

2.1.1 Empirical methods for estimation of runoff

There are various empirical formulae available for estimation of runoff. Some of them are as follows:

Inglis and De Souza's formula:

a) Ghat areas $R = 0.85\,P - 30.5$

b) Plain areas $R = \dfrac{(P-17.8)P}{254}$

where R = average annual runoff (cm)
P = average annual rainfall (cm)

Lacey's formula:

$$R = \frac{P}{1+\frac{304.8}{P}(f/s)}$$

where R = average annual runoff (cm)
P = average annual rainfall (cm)
f = monsoon duration factor
S = Catchment factor

Khosla's formula:

$$R = P - 0.48T_m$$

where R = average annual run–off (cm)
P = average annual rainfall (cm)
T_m = mean annual temperature (°C)

Parker' formula:

Parker gave different formulae for different countries

a) British Isles R = 0.94 P – 36.5
b) Germany R = 0.94 P – 40.6
c) USA R = 0.8 P – 41.9

where R = average annual run–off (cm)
P = average annual rainfall (cm)

2.1.2 Curves and table method

Several curves and tables have also been developed by researchers for various regions. Some of them are as follows:

Binnie's Percentages

Sir Alexander Binnie was probably among the first to study the relationship of runoff to rainfall with a view to express the former as a percentage of the latter. However, in Binnie's Percentages the catchment characteristics and hydrological factors which affect runoffs are not considered.

Strange's tables and curves

Strange's curves are an improvement over Binnie's percentage because they take into account the moisture condition of the catchments. Strange has classified the catchments as dry, damp and wet depending upon initial condition of ground and good, average and bad catchments based on catchment conditions.

Barlow's table

Barlow classified the catchments into five classes and gave the runoff as percentage of rainfall for each class.

2.1.3 Runoff coefficient method

Runoff coefficient of factor is the ratio of volume of stream flow above base flow to the volume of stream flow; care is taken not to include snowmelt in runoff. Runoff (R) and rainfall (P) can be correlated by runoff coefficient, by the following expression.

$$R = k P$$

where k = runoff coefficient, depends on characteristics of catchments.
The method is applicable only for design of storm water drains and small water control projects only for urban areas and is not used for the analysis of major storms.

2.1.4 Infiltration capacity curve method

This method is used only for determining the short time runoff of small catchments. The methods are

a) f – curve method: If the rainfall intensity is always greater than the infiltration capacity (f), the surface runoff can be estimated by superimposing the infiltration capacity curve over the rainfall hyetograph and finding out the area of the hyetograph above the infiltration capacity curve.
   Surface runoff = Area of hyetograph above the f – curve
b) ∅ – Index method: if the rainfall hyetographs fluctuates above and below the infiltration capacity curve, it is more convenient to use infiltration index to estimate the runoff. A suitable value of ∅ – Index is assumed and the area of the hyetograph above that value gives the surface runoff.
   Surface runoff = Area of hyetograph above the ∅ – line

2.1.5 Watershed simulation method

A digital computer is generally used for simulation of the watershed based on the water balance equation. The method requires detailed computation and therefore tedious.

2.1.6 Hydrograph method

The runoff from catchments of a river may be estimated by direct measurements. Stream gauging is done to determine the strum hydrograph. If hydrographs are available, the runoff can be estimated from the area of the hydrograph.
Volume of runoff = Area of the storm hydrograph
The runoff can also be estimated from the unit hydrograph.

2.1.7 Rainfall runoff correlation method

Runoff can be easily computed if the rainfall runoff correlation has been established for the catchments. However, the relationship between rain fall and the resulting runoff is quite complex. The relationship depends on a large number of factors. A better method is to fit a linear regression line and to determine the correlation coefficient. If the coefficient is approximately equal to one, the regression line is accepted. The equation of the line is

$$R = aP + b$$

Where a and b are the coefficients.
For large catchments, the relationship between R and P is usually expresses as

$$R = CP^m$$

Where 'C' and 'm' are coefficients.

2.1.8 SCS method

Chow et al (1988) has described SCS method (also known as Curve number approach), developed by USDA - SCS (1972), for computing abstractions from storm rainfall.

Method gives curve numbers, which are related to potential maximum retention S, by equation,

$$S = \frac{1000}{CN} - 10$$

SCS has given hydrologic soil group table for classifying soil type and land use in different Group from A to D, ranging A for deep sand, deep losses, aggregated silts, to D for soil that swells significantly when wet, heavy plastic clays, and certain saline soils.
SCS has given table which given Runoff curve numbers for Antecedent Moisture Condition II (AMC–II) i.e. for normal condition, depending on land use and hydrologic soil group.

2.1.9 Rainfall Runoff Modeling

There are various analysis done for the rainfall runoff co-relationship and the various model studies are available. The different types of models available are

1) Rainfall Runoff Model
2) HYSM Model
3) Simple Nonlinear Rainfall Runoff Model
4) Watershed Runoff Modeling
5) Simple Watershed Model

2.2 STUDIES CARRIED OUT AT WORLD LEVEL

Several researchers have carried out studies at world level, some of which have been mentioned here.

Africa
Esteves M. et al. (2000) carried out studies of overland flow and infiltration modeling for small plots during unsteady rain and compared the numerical results with the observed values in West Africa for small experimental plots of $100m^2$.

Argentina
Coronato F.R. et al. (1996) studied the precipitation and landscape related effects on soil moisture in semi-arid rangelands of Patagonia in Media Luna Ranch (45^o 35'S, 71^o 25'W, 700 m from msl.) The region is a semi-arid grassland having area of 5300 km^2 of Argentina which is similar to the Banni Grassland area of Kutch.

Austria
Study in Austria for the period 1981 to 2001 has been carried out by Mrez. R. et. al. (2006). He collected rainfall information of hourly rainfall data from 143 recording stations and were combined with the daily rainfall data from 1066 stations. He developed runoff coefficients.

China
Huang M. et al (2007) used soil moisture data and curve number method for estimating runoff in the Loess Plateau of China.

Jinquan Wu et al (1996) carried out studies for analysis of rainfall-recharge relations for northern China. In-situ lysimeters experiments and numerical simulations were used to study the relationships between rainfall and recharge by infiltration at different groundwater depths and groundwater systems were classified into three categories i.e shallow water table, intermediate water table and deep water table.

Xin-Ping Wang et al. (2008) studied the effect of rainfall characteristics on infiltration and redistribution patterns in re-vegetation – stabilized desert eco-system in the semi-arid sand dune area of north western China in the Tengger desert.

Zhi-Hua Shi et al. (2009) determined the initial abstraction ratio in Wangjiaqiao watershed (31° 5' N-31°9'N, 110°40'E-110°43' E) which lies in the Zigui county of Hubei Province in China. It is about 50 km northwest of the Three Gorge Dam and covers an area of 1670 ha. The elevation within the watershed ranges from 182 m to 1180 m with slopes ranging from 2° to 58° and average of 28°.

Colorado

Tokar A. S., Markus M. (2000) applied the ANN technique to model watershed runoff in three basin with different climate and physiological characteristics – the Fraser river in Colorado, Raccoon Creek in lowa, and Little Patuxent River in Maryland. In the Frazer river watershed, the ANN technique was applied to model monthly stream flow and was compared to a conceptual water balance model. The ANN technique was used to model the daily rainfall – runoff process and was compard to the Sacramento soil moisture accounting (SAC – SMA) model in the Raccoon river watershed. The daily rainfall runoff process was also modeled using the ANN technique in the Little Patuxent River basin and the training and testing results are compared to those of the simple conceptual rainfall runoff model. In all cases, the ANN model provide higher accuracy, a more systematic approach and shortened the time spent in training of the model.

Iraq

Hussein M.H. (1996) made an analysis of rainfall, runoff and erosion in the low rainfall zone of northern Iraq. He experimented on six natural runoff plots situated on 6 % uniform slope area. Three plots were 30m long and remaining three plots were 10 m long. He used the observed runoff in soil loss record to test the validity of USDA-SCS curve number method and universal soil loss equation in the region.

Italy

Rainfall runoff relationship developed by Kottegoda N.T. et al.(2000) using simple statistical daily streamflow generated for three river basins in Italy. River basins are

1. Arizino basin with a catchment area of 123 km^2 with the highest elevation at 1914m above the mean sea level situated in the north-eastern Veneto region. Arizino is a tributary of the Tagliamento river that flows into the Adriatic sea noth of Venice.
2. Argentina basin with a catchment area of 192 km^2 with the highest elevation of 2166 m above the mean sea level. The argentina is in the Liguria region and flows into the Mediterranian Sea near Arma di Taggia.
3. Tevere basin has a catchment area of 934 km^2 and highest elevation of 2487m above the mean sea level. It discharges into the Mediterrian Sea near Rome on the central west coast of Italy.

Korea
Moon Sang Ki et al (2004) conducted statistical analysis of hydrographs and water table fluctuations to estimate ground water recharge. He used the water level monitoring data of 66 wells in water table aquifers at national ground water monitoring stations and daily precipitation data from Korea water resources corporation. He prepared hydrographs for ground water for 66 monitoring stations by using water level data.

Malaysia
Abdullah Rozi et al. (2004) made the re-adjustment to the variables of the SCS method to suit Malaysia. He used the stream flow record of Sungai Tasoh catchment in Negeri Perlis. He found co-relation coefficient factors for local use.

Netherlands
Overeem Aart (2008) focuses on the effects of dependence between the maximum rainfalls for different durations on the estimation of DDF curves and the modeling of uncertainty of the curves. Hourly rainfall depths from 12 stations in the Netherlands had been analyzed for this study.

Oman
A metric conceptual IHACRES model is applied to hourly data from a 734 km^2 catchment area in Oman using a semi-distributed representation of rainfall input. Sensitivity analysis was used to guide reduction of the model from a nine parameter version to a simpler version. The performances of the alternative versions for predicting flow volumes and peaks at the catchment outlet are inter-compared. Performances are also compared with those achieved using lumped versions of IHACRES, a physically based model and a two parameter regression model. (Neil Mclntyre et al- 2009)

Neil Mclntyre et al(2007) Runoff volumes and peaks were regressed against descriptors of rainfall characteristics and antecedent conditions for 36 rainfall-runoff events in Wadi Ahin river which is situated in the northern region of Oman with elevation above the sea level ranging from 300m to 1300m having a catchment area of 734 km^2. The controls o runoff were found to be rainfall volume, rainfall peak, rainfall spatial location and variability, and antecedent wetness.

Qurashi Aisha Al et al. (2008) carried out studies to evaluate the distribution model Kineros2 for establishment of rainfall-runoff relationship to an arid catchment in Oman using rainfall runoff data from 27 storm events. The study was for the model sensitivity, uncertainty and performance based on uniform random sampling. As per their study, prediction performance was generally poor and estimated runoff was very high. A study was carried out for Wadi Ahin river which is situated in the northern region of Oman with elevation above the sea level ranging from 300m to 1300m having a catchment area of 734 km^2.

San Antonia
Jain A. and Prasad I.S.K.V. (2003) analysed two unit hydrograph models, four regression models, and two ANN models were developed. Data derived from Salado Creek at Bitters Road, San Antonio were employed. It was found that the ANN models

Consistently outperformed conventional models, barring a few exceptions, and provided a better representation of an event–based rainfall–runoff process in general, and better prediction of peak discharge and time to peak discharge, in particular.

Spain

Lazaro R et al. (2000) studied the analysis of a thirty year rainfall record (1967 – 1997) in semi-arid Almeria area (37o 3' 10" N, 2o 23'27" W) of Tabernas basin in Spain to study the effect of rain on vegetation.

Nicolau J.M. et al. has found out the effect of soil and vegetation on runoff in semi arid region of Spain during fifteen month study of natural rainfall and by rainfall simulation. The study was on three pairs of plots each of size 10x2 m.

A simple physically based distribution model has been developed to study the role of antecedent soil water content on runoff in semi arid catchments of Spain located in Murcia Region (1°10' W, 38° 23' N) by Castillo V.M. et. al. (2003). As inputs, the model requires the parameters hydraulic conductivity, effective matric potential at the wetting point, soil porosity and value of the Manning's roughness coefficient.

South Korea

Park Eungyu et al (2008) tried to develop a simple model for water table fluctuations in response to the precipitation for the area Hongcheon of South Korea. The area has a temperate climate with an average annual precipitation of 1508 mm of which, more than half falls in July and August. The model was calibrated for the year 2001 and used to predict ground water table fluctuations for the year 2002 – 2004. The results indicate that parameters are stable over the time.

Taiwan

Chyan-Deng Jan et al. (2007) studied the effect of rainfall intensity and distribution on groundwater level fluctuations for the Donher well station (23o 40' 6"N, 120o 6' 37" E) at the Donher Elementary School at Guken village, Yulin County in central Taiwan. He collected rainfall data from seven rain gauge stations nearby the well station.

United Kingdom

Finch J.W. (1998) tried to estimate direct groundwater recharge using a simple water balance model. His study shows that the most crucial land surface parameters required by simple water balance models for estimating ground water recharge are those required by the soil water component of the model.

2.3 STUDIES IN INDIA

Anuraga T.S. et al (2006) have carried out study for groundwater recharge using landuse and soil data for south India using Soil-Water-Atmosphere-Plant (SWAP) model.

Central Arid Zone Research Institute (CAZRI) Jodhpur (1990) has published a report titled "Water : 2000 AD - The scenario for arid Rajasthan".

Chatterjee S.b. et al (1953) carried out studies for the Climostatical regions - Geographical review of India including arid and semi-arid parts of India and prepared maps based on his study.

Dhruvanarayana V.V. (1965) conducted study for analyzing the water potential for Luni Basin of Rajasthan. He compared the figures obtained by various methods like Khosla's formula, Blaney's method and Strange's tables to get reliable figures for surface and groundwater potential of Luni basin.

Kothyari Umesh C. (1995) carried out study for estimation of monthly runoff from small non-snowfed catchments having areas less than 1515 km^2 from the states of Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan, West Bengal and Tamilnadu. The data for 20 catchments was used for calibration of the model which was further used to predict the runoff for 11 catchments.

Kumar C.P.(1995) has tried to study the effect of water table depth on the recharge due to rainfall using finite difference solutions considering one-dimensional vertical flow of water in un-saturated zone.

Malik Deepak (2008) has studied the traditional water harvesting technologies and made changes in them as per the environment and demographic changes in the region, a case study of Thar Desert in north western India, Rajasthan.

Murthy K.N.K. et al (1978) developed interrelationship between rainfall and runoff for treated catchments of Central Research Farm at Central Arid Zone Research Institute (CAZRI) at Jodhpur in Rajasthan using both linear and quadratic regression equations for each catchment

Ramakrishna Y.S. et al (1984) carried out studies for the prediction of droughts in the Indian arid region through application of the theory of conditional probabilities based on first order Markov chain model for the climatic fluctuations during the years 1901-1970. They observed that the occurrence of extreme arid conditions in the succeeding year could be predicted with 92 percent confidence while climatic types can be predicted with 83 percent confidence.

Rao A. R. et al (1973) carried out stochastic modeling for the interaction of rainfall and groundwater levels. They gave two conclusions, one that valid univariate models with excellent one step-ahead prediction capabilities can be developed for modeling the groundwater level process and second that in their study, rainfall did not appear to be very significant in modeling of groundwater due to its random nature.

Sarma J. V.V. et al (1973) carried out studies for Rainfall and ground water recharge in Chandrampalem Basin located in the Visakhapatnam and Srikakulam districts in the eastern ghats hill ranges of Andra Pradesh.

Shakir Ali et al ((2008) made an attempt to estimate the evaporation from water surface in semi-arid Bundi district of south eastern part of Rajasthan geographically located at 25o

36' N latitude and 75o 15' E longitude having an elevation of 252m above mean sea level with an average rainfall of 750mm.

Sharda V.N. et al (2006) carried out studies for estimation of groundwater recharge from water storage structures in semi-arid climate of Kheda district (73o 10' E longitude and 23o 0'N latitude) of Gujarat state.

Sharma K.D. and Singh H.P. (1981) carried out study for analysis of rain-water infiltration in relation to rainfall intensity, depth, antecedent soil moisture and slope length for the design of in-situ water harvesting structures.

Sharma K.D. and Singh Surendra (1992) have estimated runoff using Landsat Thematic Mapper Data and SCS model for Johri basin in Northwest India.

Sharma K.D. et al (1994) developed a lumped model for streamflow routing in arid ephemeral channels in Indian Arid Zone. The model is simple and requires minimum observed data for calibration and can also be used for ungauged basins in arid regions through parameterization.

Sharma K.D. and Murthy J.S.R. (1998) collected data for a period of nine years (1979-1987) for nine sub-basins in Luni river basin located in arid region of north west Rajasthan. They have developed a discrete event model appropriate for simulating the rainfall-runoff process in the upland Luni basin.

Verma R. D. (1979) has developed a physical model in which the main drainage basin is divided into small homogeneous zones with uniform intensity of rainfall and can be used for predicting runoff at the point of interest in the basin. He has conducted the study for various semi-arid regions of India.

Yadav R.C. et al (1976) carried out studies for the evaluation of runoff potential and analysis of rainfall data for drought years, deficit years, normal years, surplus years and flood years for the Kolavat and Nal catchments of Bikaner District in Rajasthan.

2.4 STUDIES IN KUTCH

Baskaran, M. (1989) conducted a study for establishing the geochronology of the Miliolitic rocks of Kutch.

Biswas, S.K. (1980) conducted several geological studies for Kutch region of Gujarat. One of the is the study for structure of Kutch – Kathiawar Region.

The statistical data for the district has been collected from District Census Handbook, Kutch, Census of India (1961, 1971, 1981, 1991 and 2001). Director of Census Operation, Gujarat.

Environmental Planning Collaborative (EPC) (2001), Ahmedabad carried out a study under Kutch Ecology Fund (KEF) and prepared a report titled "Water Resources Action Plan", Volumes 1,2 & 3.

Narmada and Water Resource Department, Gandhinagar, Government of Gujarat (1999) published a report of the Committee on Estimation Groundwater Resource and Irrigation Potential in Gujarat State.

Gujarat Ecology Commission (GEC) (1995), Gandhinagar has carried out a study and published a report titled "Curent Ecological Status of Kutch".

Ground Water Resources Development Corporation (GWRDC) (1999) published a report titled "Hydrogeological data of Gujarat State", Gandhinagar, Gujarat which includes the data for Kutch district.

Gujarat Water Supply and Sewerage Board (GWSSB) (2005) has published a report titled "Reference Manual for Hydrogeologists" which was also referred for this study.

Gujarat Water Supply and Sewerage Board (GWSSB) (2007), carried out a study and prepared a report titled "Water resources management in Kutch district".

Jadeja Y.J (2005) has carried out Ph. D research work on "Studies On Water Resource Development And Planning Of The Pachchham Area Kachchh District – Gujarat" under the guidance of Tiwari K.C at Department of Geology, Faculty of Science, The M.S.University of Baroda. He has conducted study for one of the islands in the Great Rann of Kutch.

Mistry J.F. (1988) has studied the rainfall and drought analysis with respect to surface water resources for the Kutch region. As per his opinion, Kutch has only 2% net available utilizable October Storage for surface water potential of the total water potential of Saurashtra and Kutch districts.

Merh, S.S. (1995) authored a book titled "Geology of Gujarat" published by Geological Society of India. The book includes the detailed geology of Kutch.

Raju, K.C.B. (1984) prepared a report titled "Status of Groundwater Resources-Kutch District, Gujarat" for Shree Vivekanand Research Training Institute(VRTI), Mandvi, Kutch.

Raju K.C.B. (1989) prepared a report titled "Groundwater Resources of Kutch District and Necessity for its proper management" for Shree Vivekanand Research Training Institute (VRTI), Mandvi, Kutch.

Raju, K.C.B. (1998) conducted a study for the importance of recharging depleted aquifers with focus on Kutch region along with the study of state of the art of artificial recharge in India.

Shankar, R. and Pande, P. (2001) carried out geoseismological studies of Kutch (Bhuj) Earthquake of 26 January 2001.

Singh Y.D. et al (1996) of Gujarat Ecological commission, Vadodara has carried out a detailed investigation for the Process of Desertification in Kutch and Banaskantha Districts of Gujarat for the period 1961 to 1991. Based on their report, GUIDE has been planned to identify few representative sample villages in the two districts and conduct intensive studies to evolve site specific eco-friendly packages which would be important for better management of fragile eco-systems.

Singh R.S. et al (1990) prepared a report on "Agro-climatology of Kutch District (Gujarat State). It covered topics like landuse, soils and cropping pattern, rainfall distribution, climate and agriculture for Kutch. The report was published by Division of Resource Management, Central Arid Zone Research Institute (CAZRI), Jodhpur.

Singh R.S. et al (1991) carried out analysis of rainfall characteristics for Kutch district of Gujarat. They used 12 stations for rainfall data from 1901 to 1989. Their analysis revealed that the rainfall has a decreasing pattern from southwest to northeast for the region. They also worked out the probabilities for weekly distribution of the rainfall.

Singh, S. and Kar, A. (1996) carried out studies and prepared a report titled "Integrated natural and human resource appraisal for sustainable development of Kutch district" which was published by Central Arid Zone Research Institute, Jodhpur.

Thakkar, M.G. et al (1999) carried out study for quaternary tectonic history and terrain evolution of the area around Bhuj, Mainland Kutch, Western India.

2.5 JUSTIFICATION OF STUDY

The detailed studies carried out by various researchers for the Kutch region mainly cover the aspects of geology of the region, rainfall analysis, groundwater recharge methodology, agro-climatology, ecology and the process of desertification. A comprehensive study for inter-relationship of the parameters like rainfall, runoff and groundwater recharge has not yet been carried out for the region.

Kutch being an arid region with scanty and erratic rainfall pattern, the importance of such a study increases manifold. The relations between rainfall and runoff can be used efficiently for design of surface water storage structures.

No studies have been carried out for the evaluation of draft pattern for the region. The values of draft based on this study can be utilized in formulating the extraction pattern keeping in mind the rainfall pattern of the past years.

Also, although there are studies regarding the groundwater for artificial recharge, there is no study which suggests the relation between rainfall and groundwater recharge or the quantity of recharge due to surface storage structures for the region.

The author therefore endeavors to carry out this comprehensive study for developing relations between rainfall-runoff, rainfall-groundwater recharge, component of recharge due to surface storage and development of an equation for obtaining values of draft for the region.