CHAPTER I
INTRODUCTION

1.1 NATURE OF PROBLEM

Groundwater is gaining importance as a source to meet the needs of our ever increasing population for drinking as well as industry and irrigation. Groundwater exploitation generally needs smaller capital than that needed for surface water. Groundwater may, thus, rightly be providing the basic infrastructure on which edifice of modern agriculture is being built in India. Consequently, overexploitation of groundwater in certain areas has resulted in progressive lowering of the water levels and consequent decline in the yield and productivity of well. Groundwater depletion due to overexploitation has become a matter of deep concern among geographers and hydrologists. Overexploitation of groundwater does not signify total exhaustion but depletion of the stock of groundwater. A feature of such depletion is a permanent lowering of groundwater table.

Groundwater depletion appears to be the most severe crisis receiving scantiest attention both at the level of planning and management. Studies conducted in the Kolar district of Karnataka, Anantpur district of Andhra Pradesh, Amravati district of Maharashtra, Mehsana district of Gujarat, Kurukshetra, Karnal, Kaithal, Panipat, parts of Sonipat, Gurgaon, Rewari and
Mahendragarh districts of Haryana indicate falling of groundwater table (25-30 metres in the last twenty five years). Such negative trends have to be arrested. These conditions accentuate groundwater recoup studies which are necessary in affected areas to avoid harmful social, economic, and ecological consequences.

To meet ever-increasing water demand in a densely populated country like India, reliance on groundwater is constantly increasing. However, the development and use of groundwater resources have been unsystematic, unplanned and uncontrolled. As consequences, piezometric levels have been declining rapidly resulting into many undesirable and often irreversible environmental consequences. The study of groundwater, particularly where environmental considerations are important, is a multidisciplinary activity. Although, groundwater experts may brush aside the question of groundwater depletion commenting that there is nothing serious about it and the trend is confined to a few segmented pockets, the fact is that the biggest sufferers of tubewell revolution in the Indo-Gangetic plains, especially in Punjab and Haryana States, have reached an optimum stage with respect to groundwater development and land utilisation. In these areas, owing to suitability of vedose water for irrigation and drinking purpose, indiscriminate exploitation of groundwater has taken place. This wholesale exploitation of ground water has led to many environmental and socio-economic consequences. Besides, groundwater resources are increasingly recognised as a major environmental crisis in these areas.
Solutions for these consequences exist in the knowledge of the development and careful insight into management of water harvesting systems prevalent in various parts of world. Rainwater harvesting techniques have been used for agriculture in several parts since ancient times. The infrequent rain if harvested over a large area can yield considerable amount of water. The technique of ancient rainwater harvesting involves water and moisture control at a very simple level. It often consists of rows of rocks placed along the contour of slopes. Runoff captured behind these barriers also allows for the retention of soil, thereby serving as an erosion control measures on gentle slopes. The variety of water harvesting systems spreading all over the country to suit the location specificity, need proper documentations for future planning. Such valuable information may also help restoring the water policy for sustainable development. The successful story of Sukhomajari and other similar projects like Bunga in Ambala and Bajar-Ganiyar in Mahendragarh districts in Haryana have manifested the benefits of resource conservation and management. Moreover, these water harvesting projects have resulted in flood and drought modernisation, groundwater augmentation and improvement in the socio-economic conditions of the people. In addition, rainwater harvesting systems are environmentally sound. It has great potential of improving land and water resources by integrating recent developments with traditional knowledge.
1.2 OVERVIEW OF LITERATURE

Scientific studies related to rainwater harvesting are scant and disperse. Reij, Mulder and Begemann\(^1\) believed that water harvesting can significantly increase plant production in the arid and semi-arid tropics of Sub-Saharan Africa. They emphasised on those water harvesting systems which collect and concentrate rainfall runoff for the purpose of better irrigation. The study is further confined to systems in which the collected rainfall is stored in the soil profile. Huibers\(^2\) noted that water harvesting will only be effective if infiltration or the soil profile water retention capacity is significantly high to store the incidentally large amount of harvested water. Therefore, water harvesting will in general be practiced in combination with measures to increase the water application efficiency. The Middle East has been referred to by many scholars as being of outstanding importance in the history of water harvesting. Evenari, Shanan and Todmor\(^3\) explained systems in the Negev desert, which are thought to have started around 2500 years BC. Other archaeological sites of ancient water harvesting systems have been found in Libya, Iraq, Syria, Jordan and the Arabian Peninsula, especially Yamen. Brunner and Haefner\(^4\) pointed out that at the site of

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the Great Dam near Marib in north Yemen flow diversion exists although on a modest scale than in the past. They observed that water harvesting is widespread and of great importance in Yemen, there is little mention of these systems in the available literature. In the report of UNEP\(^1\) during 1983 it is observed that China with its vast population is actively promoting rain and storm water harvesting. One very old but still common flood diversion technique is called Warping (harvesting water as well as sediments) and is extensively applied in China's Loess areas. It was observed in a case study in Shanxi province that silt trap is another technique commonly applied in China. Pacey and Cullis\(^2\) indicated that in Australia water harvesting is widely practiced phenomenon. Hollick\(^3\) gave a detailed account of one widely adopted technique since the early fifties in western Australia. This technique is referred to as roaded catchments. These roaded catchments are constructed to harvest water and collect it into tanks for livestock water supply. Finkel, and Finkel and Naves\(^4\) while serving the Agriculture Department of Israel discussed various techniques for rainwater harvesting. They examined that third world countries are developing their own approaches and solutions which are more compatible with their needs and circumstances. Nasri,

\(^1\) UNEP, (1983) Rain and Storm water Harvesting in Rural Areas, Tycooly, Dublin.
Albergel, Cudennec and Berndtsson\(^1\) explained that traditional rainwater harvesting system like the \textit{Tabia} displays many advantages to large scale water projects. Moreover, they observed that rainwater harvesting also allows farmers to choose different crops depending on the catchment size. Oosterbaan\(^2\) described that in the mountainous and dry province of Baluchistan, bunds are traditionally constructed across the slope of the land to force the runoff to infiltrate in the soil (Khuskaba system). Similarly, Sailaba system depends on floods in natural water courses which are captured by earthen bunds.

Some research has also been conducted by Sheikh, Shah and Aleem\(^3\); Sheikh\(^4\) in Pakistan’s desert on artificial catchments for rainwater harvesting on the establishment of tree species. It is now widely believed that water harvesting, which involves collection of runoff plays a significant role in the arid and semi-arid tropics. In these regions the limited availability of water is the major constraint to rainfed agriculture. In the arid regions the amount of rainfall is usually not sufficient to sustain the crops whereas in semi-arid regions it is not so much the quantity, but the uneven distribution of

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rainfall in time and space which makes all agricultural practices risky enterprises.

In India, it has been estimated that out of the total precipitation of around 400 million hectare metres in the country, the surface water availability is about 178 million hectare metres. Out of this, about 50 per cent can only be put to beneficial use because of the topographical and other constraints. The availability of water is highly uneven in both time and space. The precipitation is confined to only 3 to 4 months in the year and varies from 10 cm in the western parts of Rajasthan to over 1100 cm at Cherrapunji in Meghalaya. Consequently, due to this erratic nature of rainfall various traditional rainwater harvesting systems are common in different parts of the country since time immemorial. Apathani in Arunachal Pradesh, Jabu method of farming in Nagaland and bamboo drip irrigation system practiced in Meghalaya are good examples of local water harvesting1.

Barah2 made an attempt to trace out the tradition of numerous water harvesting systems and discussed their functions and values. He elaborated that traditional systems were excellent source of water resource development. The water structures were constructed and developed in such a way to suit the location specificity, topographical adaptability and community requirements. Not only the State, even chieftains, service workers and women patronised and promoted the

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water harvesting systems all over the country. Kittu,1 examined the status of groundwater development in India and indicated that Punjab has more or less utilised the entire groundwater potentials. Similarly, States like Haryana, Tamil Nadu, Rajasthan, Gujarat and western Uttar Pradesh have registered a high status of groundwater development, which ranges from 60 to 97 per cent. He suggested that during monsoon, surplus runoff offers scope for conservation and alleviating water scarce situations. Mukundan2 discussed Ery systems of water harvesting in south India. It is pointed out that modern agriculture, especially with the advent of Green Revolution, cultivation has great obsession for water. Massive irrigation schemes and enormous quantities of water are said to be necessary in order to produce large yields. However, the traditional Indian approach to manage the water resources has been most actively involved in making very minute observations of water and to make optimal adjustment with nature. In areas where rainfall was relatively low, every effort was made to retain all the water that fell on the ground through appropriate water retention and conservation strategies such as Ery. Similarly, in Jhabua, which falls in semi-arid and sub-humid agro-climatic zones, cheaper version of water harvesting for trees and shrubs have been used. Most common and successful method is

planting of sapling in the centre of contours trench. While studying the morphohydrological aspects of Jojri river basin, which is a part of upper Luni basin, Singh elaborated that the additional surface water resources could be developed by constructing water harvesting structures at suitable geomorphic sites and also increasing storage capacity of existing reservoirs/tanks using proper management techniques. Kandaswamy and Kandaswamy and Ramaswami observed that floods in one season and drought in another season in many parts of India is due to poor storage capacity of the tanks and other reservoirs. Thousands of tanks big or small are being filled with periodic accumulation of silt. Due to non-removal of silt, the storage capacity of the tanks is reduced and with the slight rainfall the tanks get filled up and started flowing by breaking the bunds. They advocated that rivers and tanks are to be linked together by suitable canal formation so that the excess water of either rivers or tanks can be diverted to the other. Harvesting of Runoff at a micro-level for storage and recycling is necessary for better utilisation of rainfall, control of erosion and providing life-saving irrigations to crops during dry spells in the monsoon season and also for growing a

second crop in *rabi* season in many parts of the country. Similarly, Singh discussed various hydrological models for groundwater recharge through the percolation tanks. Athavale and Rangarajan tried to establish rainfall recharge relationship in four different geological provinces of India. Kumar, Sundaram and Anuthaman tried to estimate rooftop rain water quantity for groundwater recharge by using Geographic Information System (GIS) in Chennai Airport Terminal buildings and indicated vast possibilities of groundwater recharge from roof top rainwater.

The indiscriminate pumping of groundwater is likely to invite the serious problem of contamination and lowering of water table in many parts of the State. Tanwar mentioned that as per the erstwhile Groundwater Directorate of Haryana State Minor Irrigation and Tubewells Corporation, there were 46 dark category blocks (where the stage of groundwater development is more than 85 per cent) during 1997. Maximum number of these dark blocks falls in fresh groundwater quality zones. Lohan specified that in fresh water

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aquifers overdraft of this resource has taken place and surface supply is also deteriorating in some areas. Therefore, he suggested that supply of water from other sources is required. Tyagi and Mishra\textsuperscript{1} and Sharma and Chaudhary\textsuperscript{2} documented mismatch in supply and demand in Gohana (Western Yamuna Canal, diversion type) and Adampur (Bhakara Canal System, storage reservoir based). Mittal\textsuperscript{3} while investigating rainwater harvesting in Shiwalik foothills analysed that this region has all those components like, soil type, vegetative cover, storage capacity, etc., which are essential for rainwater harvesting. He pointed out that due to these factors; first rainwater harvesting structure was constructed in village Sukhomajari in 1978 and followed by Nada in 1980 and Bunga in 1985 and Relmajara 1992.

Similarly, The Haryana State Minor Irrigation and Tubewells Corporation (HSMITC) (which has been abolished later on in the year 2000) established a Groundwater Directorate at Karnal in 1972. This Directorate has carried out extensive groundwater explorations, assessments and monitoring. The HSMITC published two reports namely, 'Groundwater Exploitation in Haryana'\textsuperscript{4} and 'Modernisation


of Groundwater Development in Haryana. According to these studies water table has declined in the fresh water area of Ambala, Karnal and Kurukshetra districts. The declining trend has also been observed in parts of the lower Ghaggar basin and small patches of the Krishnawati, Sahibi and lower Yamuna basin. These studies confirmed that more than 80 per cent of the extraction from groundwater storage in the State is done through private shallow tubewells. Subsequently, the Haryana Irrigation Research and Training Institute (HIRT) was created at Kurukshetra. Later on, the State has decided to convert it into the Haryana Irrigation Research Management Institute (HIRM).

It will be noted from the forgoing that various scholars have shown interest in the study of rainwater harvesting in the country especially in the arid and semi-arid parts. These studies have been carried out with varying objectives under different physical and social environments. Thus, the picture of totality is lost in the sense that they are limited to the extent of the chosen problem. Though they are problem oriented, but they are deficient in offering explanation. Rainwater harvesting studies on Haryana carried out by researchers have different aims and approaches yet lacking in geographical perspective.

1.3 RESEARCH PROBLEM

Haryana has an agriculture-based economy with perpetual deficit of water. Canal irrigation is more prominent in dry areas of the State. Haryana’s water resources include: (1) rainwater; (2) surface water; (3) soil water; and (4) groundwater. The man-managed water resource supplies include mainly the surface water and groundwater. The surface water supply is available as a share of the Yamuna, Sutlej, Ravi and Beas rivers as per Inter-State Agreements. The groundwater supply is available from shallow and deep tubewells. During the last five decades, there has been a phenomenal rise in the growth of groundwater development through formulation and clearance of a number of techno-economically viable groundwater based Minor Irrigation Schemes. These schemes have been backed by liberal funding from Institutional Finance Agencies, energisation programmes and subsidies on electricity tariff. The total supply is about 570 cumec which is far below the normal annual demands. The total demand is about 1305 cumec. The water deficit is enormously high at 735 cumec. The projected annual demand of agriculture sector at canal head with 62 per cent intensity of irrigation for the State is estimated as 200 cumec. In addition, the requirement for drinking, industrial and power sector at present is about 570 cumec. Due to heavy pressure of pumpage on groundwater, depletion has started in many parts especially in Ambala, Yamunanagar, Kurukshetra, Kaithal Karnal Panipat, parts of Sonipat Gurgaon Faridabad, Rewari and
Mahendragarh districts. As compared to the groundwater conditions prevailing during 1974 there has been over all decline of more than 2.0 meters during June 2001 in these districts. As per the monitoring reports of the Groundwater Directorate, maximum fall of 11.74 meters has been noticed in Mahendragarh district during 1974-2001. It is extremely difficult or rather impossible to meet the complete demand from existing sources. Problem of low rainfall leads to less recharge which further accentuate on account of the drought situation and the absence of vegetative cover in the State. The increase of the groundwater draft is for obvious reasons but the decrease in recharge which is noticeable, due to man's interference with nature. Therefore, the problem of groundwater depletion in the State seems to be the both shortage and managerial. For this, two options are available. The first is to reduce the withdrawal of groundwater. This will be anti development action and can not be adopted. Second is to find out new sources to meet the requirements. Hence, the available water resources need to be managed scientifically. Not only the efficient management is required but also it is high time to capture the available excess rainfall during monsoon months. But due to almost flat topography, the State is devoid of natural water storage reservoirs except a few small storages in Shivalik hills and Aravali hills. The Bibipur, Bhambeva, Jhajgarh, Kotla lakes and Narnaul Dam near Narnaul are developed as plain area depressions. Thus, fast depleting groundwater level, and limited surface water has necessitated a critical appraisal of the scope for rainwater harvesting.
especially in those areas, which have registered appreciable declining trends in groundwater levels.

Thus, the present research is concerned with the study to examine the scope of rainwater harvesting. This study is mainly focuses on available volume of rainfall in its spatial and temporal variations. Such a study may lead to identification and determination of potential areas where rainwater is surplus and flows in the form of runoff. This research establishes a relationship between rainfall, runoff and groundwater recharging possibilities. Therefore, the main objective is to find out the scope of rainwater harvesting in those areas where groundwater depletion has taken place. Consequently, the conclusions obtained may be helpful to planners, administrators, geohydrologists and geographers.

1.4 CONCEPTUAL FRAMEWORK

1.4.1 Concept of Rainwater Harvesting

According to Myers the term water harvesting was first defined by Geddes as the "collection and storage of any form of water, either creek flow for irrigation use," Myers himself defined it in 1967 in almost exactly the same way by stating that water harvesting is "the collection and storage of any form of water for irrigation uses". Water harvesting is usually employed as an umbrella term describing a whole range of methods of collecting and

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concentrating various forms of runoff (rooftop runoff, overland flow, stream flow, etc.) from various sources (precipitation, dew etc.) and for various purposes (agriculture, livestock, domestic and other purposes). These as well as other definitions demonstrate that surface runoff is the key factor in water harvesting. Other important elements in the definition of water harvesting are the source of runoff, the form of runoff, the use of runoff and the harvesting techniques itself.

Finkel, Unger and Critchley defined that as far as the source of runoff is concerned most definitions do not give any specification on this matter and they just mention "runoff". Some definitions restrict the topic to 'natural precipitation' while others like UNEP, Matlock and Dutt and Myers speak only of 'rainfall' or

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snowmelt' as source of runoff. Bruins, Evenari and Nessler\textsuperscript{1} remarked that the term water harvesting has a purely hydrological meaning, and it does neither specify what kind of runoff is harvested, nor for what purpose it will be used.

Some terms bring out more precisely the source of runoff. National Academy of Sciences\textsuperscript{2}, Boers and Ben-Asher\textsuperscript{3}, Das\textsuperscript{4}, Armitage\textsuperscript{5}, Pacey and Cullis\textsuperscript{6}, consider more apt term, 'rainwater harvesting' whereas Parcey and Cullis stressed the phrase, 'rain harvesting', similarly, Matlock and Dutt\textsuperscript{7}, used the word 'rainfall collection'. Like 'water harvesting these are also hydrological terms\textsuperscript{8}.

Another important factor is the form of runoff harvested. Different terms are used when referring to water running off an area. The term 'runoff' is a collective term and refers to water flowing over (surface runoff) or under (subsurface runoff) the ground surface to reach the sea\textsuperscript{9}. Surface runoff is subdivided into overland flow and stream/channel flow. Subsurface flow is subdivided into

\textsuperscript{9} Strahler, A.N., (1976) Physical Geography, Johan Wiley and Sons Inc. USA.
throughflow, still contributing to runoff peaks in river hydrographs and groundwater flow, contributing only to base flow in rivers\(^1\).

In most definitions of water harvesting only surface runoff from slopes and runoff from ephemeral streams are included. Runoff from perennial streams is excluded; as such streams are normally classified as irrigation. Critchley\(^2\), for example, speaks of 'runoff before it reaches seasonal or permanent streams', Boers and Ben-Asher\(^3\) described 'local surface runoff' and MoALD\(^4\) advocated about 'sheet runoff' or ephemeral stream flows. Pacey and Cullis\(^5\) excluded the harvesting of any valley floodwater or stream flow and restrict rainwater harvesting to water running off surfaces on which rain has directly fallen.

The term water spreading is used by many authors, but in different ways. In most definitions water spreading is seen as a form of water harvesting whereby water from streams is spread by means of a system of dikes, dams and ditches as a thin layer over relatively flat land. Some authors speak of ephemeral streams and spreading of the water on the floodplain of the stream itself\(^6\). The term water spreading, water diversion and water ponding are purely

\(^2\) Critchley, W.R.S., (1986b) "Introduction and Overview of Runoff Harvesting", op.cit., P.9
hydrological terms. ‘Water ponding is mentioned by Bruins, Evenari and Nesseler\(^1\) as a term used by Newman\(^2\) and Cunningham\(^3\) to describe the control of runoff water from storms.

Although most authors on water harvesting make their own definitions of water harvesting and related subjects, which leads to considerable confusion as will be noted from the foregoing paragraphs, there is a general consensus from the literature that the following factors are characteristic of water harvesting\(^4\).

1. Water harvesting is applied in arid and semi-arid regions where runoff often has an intermittent character. Because of the ephemerality of flow, storage is an integral part of water harvesting systems\(^5\).

2. Water harvesting is based on the utilisation of surface runoff, and requires a runoff producing and a runoff receiving area\(^6\).

3. Most water harvesting systems use water only near where it falls\(^7\). They, therefore, do not include the storing of river water in large reservoirs or mining of groundwater\(^8\).

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4. Water harvesting systems are relatively small-scale operations in terms of catchment's area, volume of storage, and capital investment.

Various methods of collecting and concentrating surface runoff are classified in a different way by a number of authors. The classification of Pacey and Cullis is primarily based on the source of water and the form of runoff. Three main sources of water are distinguished; (a) river and other surface water, (b) wells and groundwater, and (c) rainwater. Rainwater may lead to:

I. large erosive flows of runoff from long catchments; technique of water harvesting to be used in these cases is 'floodwater harvesting';

II. sheet runoff from short (less than 50-150m) catchments; the technique of water harvesting is called 'rainwater harvesting', which may be divided into:

i. runoff farming, using external catchments;

ii. microcatchment water harvesting, using within-field systems; and

iii. rooftop rainwater harvesting.

Present study is concerned mainly with rainwater harvesting. This study includes both runoff farming from external catchments in the northern and southwest hilly areas especially in Ambala, Punchkula, Gurgaon and Mahendragarh districts and microcatchment

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water harvesting in the remaining parts of the State due to the flat topography. Basically, the emphasis of this research is to find out the potentiality and scope of rainwater harvesting in groundwater depleted zones.

1.5 CONCEPTUAL ISSUES

It hardly needs stressing that the groundwater is the largest available source of fresh water in Haryana. Due to unreliable availability of surface water, particularly during drought years, there has been increasing realisation of the importance of rainwater as a source to meet the needs of our ever-increasing population for drinking, irrigation as well as industry. In many parts of the State, in the absence of other source of water, groundwater has contributed significantly to the improvement of social and economic conditions of the farmers. But extraction of groundwater in the State is not matching with the sustainable concept of resource development. Harvesting rainwater has become inevitable to mitigate many irreversible social, economic and physical consequences arising out of water shortage especially in fresh quality zones.

1.5.1 Demand and Supply

The projected annual demand of agriculture sector at canal head with 62 per cent intensity of irrigation for the State is estimated as 626 cumec. In addition, the requirement for drinking, industrial and power sector at present is about 679 cumec. The total demand is about
1305 cumec. The water deficit is enormously high at 735 cumec. Such variations seriously affect the water availability in commands which are diversion type and to a slightly lesser extent, the storage reservoir based system. Irregularity in water delivery in Gohana (Western Yamuna Canal diversion type) and Adampur (Bhakara Canal System, storage reservoir based). The mismatch between supply and demand arising from inadequacy as well as irregularity was as high as 68 per cent in Gohana and 40.7 per cent in Adampur. Similarly, in case of domestic supply, there is a large gap in urban and rural inhabitants of the State. People residing in urban centers require more water for their daily use in comparison to their counterparts living in rural areas. In rural areas, cattle farming mostly depend on rainwater for drinking and other purposes. Most of the village storage structures like, ponds (Johar), tanks and cattle ghats depend upon rainwater for daily supply.

1.5.2 Groundwater Depletion

Inadequate supply of surface water and low amount and erratic nature of rainfall have compelled the farmers of the State to depend on groundwater. Consequently, groundwater extraction for variety of purposes has made a major contribution in the agricultural developments along with the social and economic life of the people of

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the State. However, the development and use of groundwater resource have mostly been unsystematic, uncontrolled and unplanned resulting into imprudent exploitation of resource and in many undesirable and often irreversible environmental consequences. As groundwater is pumped from a well, the level of water in the well drops and surrounding table is lowered in the shape of conical surface, termed the cone of depression. Where many wells are in operation, there interference cone produce more lowering of water table leading to depletion.

More than 5.5 lakh tubewells are extracting groundwater for irrigation in fresh ground water quality zones. Moreover, the number of tubewells is increasing every year which creates extra burden on groundwater. Consequently, overexploitation of groundwater leading to permanent lowering of water table has been created by shallow tubewells in Kurukshetra, Karnal, Kaithal, Panipat, Gurgaon, Faridabad, Rewari and Mahendragarh districts. Evidently, lowering in water table has taken place which ensues to permanent depletion in the groundwater reservoir in all the above mentioned districts.

1.5.3 Inadequate Surface Water Supply and Regional Imbalances in Canal Water Delivery System

Even though a fairly extensive network of canal system (more than 10,000 Kms length) has been laid to cover 80 per cent area of the State, adequate surface supplies are available only during the rainy season through the Bhakara and Yamuna canal systems. Due to steep fall in the surface water supply during the lean period of about nine
months in the year, the designated capacity of irrigation channels
remains unutilised and the channels are forced to run in rotation\textsuperscript{1}. The
Bhakara canal system mostly flows for 21 days in a month and five
group system of the Western Yamuna Canal get an eight day supply
by rotation in a 40 days circle, i.e. each group is subjected to 32 days
closer. This system shows that the State is facing acute shortage of
surface water supply in almost every part. Even many districts especially in fresh quality zones and south western parts are not
going their share from the State's pool. Almost entire share of these
parts goes to Hissar, Sirsa and Bhiwani districts. Therefore, these
districts are the victims of discrimination in terms of surface water
distribution. As a result of that farmers are extracting groundwater
indiscriminately to meet their irrigational requirements. Almost
entire dependence on groundwater has registered sinking trend of
water table in Kurukshetra, Kaithal, Karnal, Panipat, parts of Sonipat,
Mahendragarh and Rewari districts.

\textbf{1.5.4 Increasing Cost of Additional Surface Irrigation and Groundwater Structures}

Developing additional surface irrigation potential may be
increasingly expensive and excessive groundwater pumpage highly
unsustainable. Owing to close spacing of tubewells, pump sets after
some times starts giving low yield of water. To cope with the
situation, cavity of the tubewell has to be deepened and sometimes
farmers are forced to choose another site for tubewell installation. All
these make extra financial burden on the farmers. A shift in focus is

\textsuperscript{1} Modernisation of Groundwater Development in Haryana,(1981), op.cit.P.6
required from the development of additional irrigation resources to traditional and newly created rainwater harvesting structures. Adoption of these structures offers a strategy to reduce dependency on canal irrigation and on the other hand it provides extra water during rainy season for groundwater recharging in depleting areas. Though the study area is deficient in annual rainfall yet during the three months of monsoon season it receives ample amount of rainfall that can be harvested by developing proper infrastructure.

1.5.6 Low Storage Capacity

Ponds are the most common and simple type of storage structure in the State. The capacity of these ponds depends upon the size of a catchment and dimensions of the pond itself. These ponds/cattle ghats play a crucial role in the State. They provide drinking water to the cattle and more prominently work as recharge zones (donor) to the nearby areas. Invariably, each village has one or two such ponds to cater their demands. But these ponds do not have sufficient capacity to meet completely the purpose for which they are created. This is mainly due to silting and encroachment of the ponds area for other purposes. Presently, abrupt increase in the population most of these village ponds have been filled up for constructing houses. Therefore, existing ponds require intermittent deepening to maintain their capacity along with more number of new ponds.

1.6 PURPOSE OF STUDY

The primary purpose of this study is:
i. to examine the rate and magnitude of groundwater depletion;

ii. to explain the rainfall characteristics and pattern;

iii. to determine the rainfall-runoff relationship;

iv. to explore the possibility and scope of rainwater harvesting; (with the help of the following determinants like, rainwater harvesting structures e.g., ponds, tanks, earthen bunds baories their size shape etc., hydrological investigations like, runoff volumes, long term rainfall data, rainfall volume, and important physiographic characteristics which includes, slope, relief., soil, land-use, natural vegetation etc., potential zones of groundwater recharge by rainwater harvesting; and

v. to suggest ecological, institutional and technological strategies for the development of rainwater harvesting.

1.7 THE STUDY AREA

Haryana State comprises 19 districts having geographical area of 44212 sq. km and lies between the latitudes 27°39' N to 30° 55' N and longitudes 74° 28' E to 77° 36' E. There are 12 districts comprising 45 administrative blocks which fall under dark category having groundwater development more than 85 per cent as per the groundwater budgeting of Groundwater Directorate of erstwhile Haryana State Minor Irrigation and Tubewells Corporation (HSMITC) during 2001 (Annexure-I). Therefore, in the present investigation
those parts of the State where depletion has taken place, are included in the study area. Therefore, study area includes those administrative blocks where groundwater depletion has taken place. (Figure 1.1).

Though the groundwater development has taken place all over the country, the maximum development has taken place in the Indo-Gangetic plain. In general, Punjab, Haryana, Gujarat and Uttar Pradesh, use both the surface and groundwater for irrigation and other uses. In those areas where only surface water is used and the underlying groundwater is saline, groundwater recharge has taken place in the past 20 to 25 years and waterlogging conditions have arisen with the subsequent loss of agriculture. However, in areas where surface water is only available for protective and the larger part of irrigation is being sustained by the groundwater from the tubewells, water has registered continuous lowering resulting in over-development\(^1\). Such situations are well known in these parts of the State in the fresh quality zones especially along the perennial and seasonal rivers. The lowering of the groundwater table has created an alarming problem among the farmers because of increasing cost of tubewell installation and change in cropping pattern. The number of tubewells clearly indicates the wholesale exploitation of groundwater in the State. Thus, falling water table as a result of overdevelopment and overexploitation has been recognised as a major environmental

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problem in this area. As a result, this area is chosen to analyse and assess the rainwater harvesting to recoup the sinking ware table. Secondly, this researcher has deep familiarity with this segment of the country. Thirdly, this researcher has been observing various socio-economic and environmental consequences of groundwater depletion for the past many years in the State.

The following are the characteristic features of the study area.

1.7.1 Precipitation

Annual precipitation varies between 1000 mm on the Shiwaliks, sub-Shiwaliks and the Piedmont Plain in the northeast to 300 mm along the southwest border of Haryana. Generally, between 70 to 80 per cent of rainfall is concentrated during the three months of monsoon season, i.e., from July to September. Precipitation and number of rainy days are quite insufficient to meet the requirements of successful crop production. The region also receives rainfall during winter season by western depression and thermally-induced convective thunder storms of local origin which together account for the remainder of precipitation. Hydrologically, the winter frontal precipitation is relatively unimportant but highly significant in replenishing soil moisture.

1.7.2 Physiography and Drainage

The plain imperceptibly slopes from northeast to southwest. The average height ranges from 150 m to 300 m above sea level. The plain is significantly flat in the districts of Ambala (excluding
Shiwaliks, sub-Shiwaliks and Piedmont Plain areas), Kurukshetra, Kaithal, Karnal Panipat, Sonipat, Faridabad, and north eastern parts of Hisar and Sirsa. And within it are the narrow low lying flood plains known as Bet or Khadar. Additionally, the saucer of the Sonipat and the northern parts of Rohtak districts form a part of this plain topography. This tract is made up of new as well as old alluvium. Except these alluviums some hilly segments are also seen in the Ambala, Gurgaon and Mahendragarh districts, namely, Shiwaliks and Aravallis.

Most part of the study area falls in alluvial plain of the Indus River System and the Yamuna River Basin of Ganga River System. It constitutes a topographical depression between Shiwalik hills (altitude 1200 m) in the north and the Aravali hills (altitude 1300 m) in the south sloping gently downwards from both sides. The axis of the depression is at an altitude of about 200-210 m and runs through Delhi-Sirsa trough (Figure 1.2). Of the total area of the State about 68.21 per cent, lying under 300 m, is a level plain and may well be designated as Ghaggar-Yamuna Plain comprising Bhangar, Khadar, Naili and Bet; 25.55 per cent also below 300 m and lying in the district of Bhiwani, Mahendragarh and northwestern extremes of Gurgaon is undulating or rolling in nature because it is covered by sand-dunes and stumps of hills; about 1.67 per cent lies between 300 m and 400 m in the northeast at the foot of the Shiwaliks in Ambala and Panchkula districts and can be designated as Piedmont Plain; 0.92 per cent and 0.56 per cent lies between 400 m and 600 m and over 600 m forming
respectively the Sub-Shiwaliks and Shiwaliks. The remaining 3.09 per cent lies above 300 m in the south in Mahendragarh, Bhiwani and Gurgaon districts in the form of rocky surfaces. 4.57 per cent of the total land area in Haryana is moderately steep sloped hilly land in the northeast and steep sloped rocky hills in the south.

1.8 DATA SOURCE

Collection of necessary data and information through available reports or other sources, surveys and field investigation is a pre-requisite to determine the present status and future scope of rainwater harvesting system. Discussion with the local inhabitants can provide many clues about the hydrological conditions during the post and pre-rainy season. Consequently, in this investigation it is tried to extract maximum information through reports available from different sources, personal surveys and field investigations.

1.8.1 Secondary Data

The study is based on both primary and secondary data. The secondary data on rainfall were collected from Regional Meteorological Centre (RMC), Delhi of India Meteorological Department (IMD), and from the revenue records of Revenue Department of Haryana State and groundwater Directorate of erstwhile HSMITC. Presently, in Haryana a number of Central Government and State Government agencies have their own rain

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gauge stations at selected places as per their requirements. IMD observatories, Aerodromes, Research and Agricultural Institutes and Universities have automatic rain gauging equipments in addition to ordinary rain gauges. For the purpose of present study blockwise rainfall averages are required to be work out. There are more than seventy raingauge stations in the State at present, but their distribution is not satisfactory for obtaining blockwise average rainfall. Likewise, temperature data also collected from RMC of India Meteorological Department. Groundwater Cell of Agriculture Department provided data on blockwise minor irrigation structures, blockwise usable groundwater potential (1974-2001), fluctuations in groundwater table (1974-2001) and recharge (surface inflow, groundwater inflow etc.) and discharge (surface outflow, groundwater outflow, consumptive use etc.). State and Central Groundwater Board have various hydrograph stations (open wells) in the study area. They provide data for the study of water table behaviour incorporated in the form of monitoring reports. Each hydrograph station, plotted on Survey of India toposheet, is given an identification number for numbering the wells. The Agriculture Department of Haryana State has fixed large number of hydrograph stations (more than 1600), mostly open wells all over the State.

Similarly, data on existing water bodies viz., drainage pattern, slope, rivers, streams, reservoir etc. are obtained from toposheets available from survey of India. This department possess one inch toposheet for the whole of State. Data on existing depressions, ponds,
cattle ghats, and area under Panchayat etc. collected from District Revenue Department of all the concerned districts. Data relating to irrigation from Irrigation Department and data on rice, wheat etc. cultivation and area under different crops are collected from Agriculture Statistics.

1.8.2 Primary Data

In this investigation primary data is collected from the personal surveys of sampled villages falling in the overexploited blocks (where groundwater development is more than 100 per cent). Presently, in the study area there are 61 overexploited blocks comprising 2560 villages with a geographical area of more than 10,000 sq. km. This survey is conducted to identify the existing water bodies and storage capacity of the villages in terms of rivers, reservoirs, ponds, depressions etc. and suitable geomorphic sites for further water harvesting in the sampled villages. With the help of this survey, common land under Panchayat and buildings under government schools and dispensaries are also identified for future rainwater harvesting. Biophysical factors such as landuse, slope drainage patterns nature of the sediments rock types and their texture and structure which control the surface runoff and percolation of surface water and occurrence and development of groundwater were evaluated and mapped. The recharge (donor) and recharged (receptor) zones were recognized, delineated and mapped for the development of groundwater resources.
Water harvesting measure under the present study has been conducted for the existing village ponds. These ponds provide storage structures for rainwater. This stored water can further be used for irrigation and in groundwater recharging. Apart from the village ponds, drainage pattern, the flow of water with rivulets/nalas, drains etc. have also been considered in the villages falling along Shiwalik and Aravali ranges. It is observed that there is enough surface runoff during rainy season, which flows unutilised. It is tried to evolve certain steps to harvest that runoff in suitable sites and structures.

In order to identify the suitable sites for rainwater harvesting an intensive study of the sample villages is conducted. In the present research, study area has distinct characteristics in terms of geology, geohydrology, physiographic aspects, rainfall, water requirements for different purposes, agricultural practices etc. Punchkula, Ambala and parts of Yamunanagar encompass Shiwalik hills and their foothills, which generate many rivulets and small seasonal streams making the topography dissected. Parts of Yamunanagar, Kurukshetra, Kaithal, Karnal, Panipat, Sonipat, Faridabad situated in the central and southern fringe exhibiting the plain topography with different type of agricultural practices and water requirements. Similarly, Gurgaon and Mahendragarh districts are situated in the utter southern fringe with hilly terrain due to the presence of Aravali hills. Sand dunes also mark their presence in the scattered patches in different directions. Systematic random sampling method is used for the selection of the villages. This sampling has certain practical
advantages: (i) In particular, it is usually easier and quicker to obtain samples. In many geographical situations this may be a major consideration. (ii) This technique produces an even and therefore, fair coverage of the population. Samples are selected evenly avoiding the bunching. In systematic sample, no individual is selected more than once. For a large area it is impossible to measure the value of concerned variables at every point. The aim of sampling in this situation is to provide as economically and as accurately as possible a description of spatial distribution of that variable considering all above given points. Therefore, it is decided to choose systematic sampling for this study. In this way from each district, sample villages are selected

A grid of suitable size has been formed by drawing westward lines from the Yamuna river and north south over the study area. The intersection points define and produce a sample point. Village falling on intersecting point or in near vicinity is selected as representative sample. Thus, altogether, 55 villages are considered for this investigation. A sample of this size covers about .6 per cent in terms of total number of villages in each district. In the selection of rainwater harvesting structure from the selected villages, consideration is given to sampling frame. Sampling is a setting in which sampled population is found. Ideally, sampling should be from the target population about which the information is required1. In the

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present study village water storage infrastructure like, ponds, tanks and depressions alongwith biophysical factors are considered as target population. During the stay period in the village all the storage structures morphological features and biophysical factors as mentioned above are identified and mapped. Personal survey is conducted to extract information from the villagers regarding sediment deposition in the ponds, in how much time period villagers remove the silt from these ponds by digging these structures. Moreover, some hydrological investigations are also made from the local inhabitants. Soil characteristics which are important for proper design of water harvesting structure are also collected during the visits of these villages. In addition to foregoing factors, socio-economic aspects also surveyed. These aspects includes availability of labour, social acceptability, people's participation etc.

From the selected villages, a villagewise list of storage structures, physiographic factors, morphological features and socio-economic aspects was prepared. Thus, all storage structures from each village amounting 330 in number was selected. Therefore, each structure was considered unit for the present study.

Limited time and the large extent of the study area restricted the selection of the number of villages. Nevertheless, this researcher got the financial assistance from the UGC, but stipulated time period forced to concentrate only on certain important issues living behind equally significant factors. Furthermore, there is a little awareness
about the rainwater harvesting among the villagers due to perennial supply of groundwater. Consequently, village communities are not interested in management of available water resources. Thus, these are the main constraints in this study.

1.9 METHODOLOGY

A voluminous raw statistical data were fed to computer for the extraction of ratios and inferences. The ratio is the highest level of measurement, which has all the properties of lower measurement scales. These ratios are analysed graphically, cartographically and statistically to arrive at sound and meaningful conclusions.

Map analysis has been done to present the cartographic representation. Preference has been given to quantitative maps, especially those employing isopleth and choropleth techniques, showing data relating to distribution of rainfall, probability of rainfall, magnitude of runoff, groundwater quality, types of soils, fluctuations in water table depth of different locations, potential groundwater recharge zones, etc.

A wide variety of graphs are used in the illustration of different aspects of data. Line graphs are used to show seasonal and regional trends in various variables like temperature, rainfall. Alongwith graphs, columnar diagrams are also used to show the rhythm of seasonal changes and regional variations by superimposition upon locational base maps. Apart from these
cartographic and graphic techniques, some statistical methods and formulae are also used in the calculation of different variables.

1.9.1 Change in Groundwater Storage

Water table fluctuation map for the period June, 1974 to June 2001 is used to estimate the change in groundwater storage. This change is used to work out groundwater depletion, magnitude and rate of depletion. The following relationship is used to estimate the change in storage:

\[ \Delta \text{GWS} = A_{aq} \times \Delta \text{GWT} \times \text{Sy} \]

where,

- \( \Delta \text{GWS} \) = change in groundwater storage;
- \( A_{aq} \) = involved area of aquifer;
- \( \Delta \text{GWT} \) = fluctuation in groundwater table;
- \( \text{Sy} \) = specific yield (unconfined aquifer).

In simple terms, change in groundwater storage means net difference between recharge and draft values or water discharged from an aquifer or recharged into it represent the change in its storage volume.

1.9.2 Rainfall Characteristics

For an area like Haryana, which is essentially an agricultural tract, rainfall is the most important weather element. Even though the area generally receives low rainfall, yet its spatial and seasonal distribution is quite uneven. Further, year to year variation in the total amount of rainfall is very significant. In some years rainfall is

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precariously low while during other years it is appreciably above normal. Therefore, proper and economical recoup of groundwater storage through rainwater harvesting is essential. Accordingly, an accurate and realistic assessment of the rainfall responsible for building up groundwater storage is required. The primary natural factor responsible for change in the groundwater reservoir is the precipitation. Therefore, all the studies concerned with the development of water resources in an area require a detailed knowledge of rainfall character and its behaviour. The following analysis was performed for the identification of trend, persistence, randomness and the spatial variability of rainfall:

(a) Probability of Rainfall: Although it is not possible to be certain of exceeding a given amount of rainfall in any one year, it is possible to obtain a precise statement of the uncertainty involved. That is one can be certain of exceeding a given amount at a precisely known level of probability. Consequently, in the present work, rainfall probability is worked out using the mean and standard deviation of annual rainfall totals for various stations. A worked example for Ambala will serve to clarify the mechanics of the calculations to make probability statements. Given a mean annual rainfall of 996.6 mm and a standard deviation of 121 mm a probability of less than 500 mm of rainfall is being computed. The stages involved in the calculations are set out as follows:
(i) The rainfall value of 500 mm is \((996.6 - 500) = 496.6\) mm below the mean.

(ii) 496.6 mm is equivalent to \(\frac{496.6}{121} = 4.10\) standard deviation below the mean.

(iii) The required \(z\) in Table of the \(z\) statistics (the normal distribution function) is therefore, 4.10.

(iv) The corresponding probability value in Table is 0.99997 (or 99.97 per cent) because the standard deviation value is more than 4.0; therefore, value of 4.0 standard deviation is considered.

(v) The required probability is \((1.0 - 0.9997) = 0.0003\) (or 0.03 Per cent).

Similarly, probability maps of the corresponding values are prepared. The usefulness of the statistics to geography is nowhere more obvious than in the probability map, in which concept of probability is combined with the geographer's most important tool. The probability of receiving greater or less than given amount of rainfall at one station was calculated. Similar calculations applied to the large number of stations yielded a set of probability values. So the probability values are being plotted and a generalised map was produced.

(b) Intensity of Rainfall: The rate at which rain falls is obviously related to problems of runoff, soil percolation, flood control, etc. Information about the intensity of rainfall gives a clear

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understanding of rainfall regime. In this investigation, intensity of rainfall is calculated as described by Monkhouse and Wilkinson:

\[ I = \frac{A}{n} \]

where: \( A \) = total rainfall over a given period; \( n \) = number of rainy days; and \( I \) = intensity of rainfall.

(c) Pattern: In order to study the dependence of total rainfall on the monsoon rainfall of each monsoon months and the relationship of the rainfall of each of the monsoon month with each other, the cross-correlation has been worked out. The cross-correlation \( r(\tau) \) was computed with the equation explained by Richard and Snyder.

(d) Randomness: To test the randomness or otherwise of the annual average rainfall series (1971-2001), a non-parametric second order serial correlation test is applied. The computational objective of serial correlation is to analyse time series and determine the degree of correlation in adjacent values. Actually, the analysis usually examines the change in correlation as the separation distance increases.

(e) Rainfall Trend: To identify the trend in the rainfall series, the following tests have been applied:

(i) Comparison of Decadal Mean with the Mean of Whole Period:
Decadal analysis of rainfall conditions is quite significant and useful.

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to correlate rainwater harvesting possibilities with the reliability of rainfall of the entire period under consideration which oversimplifies the climatic factors concerned\(^1\).

\[
\frac{X_k - X}{T_k} = \frac{s}{\text{where, } T_k = \text{trend of the rainfall (Composition of decadal mean of an observation with the mean of whole period)}};
\]

\[
X_k = \text{mean of any } k \text{ observation};
\]

\[
X = \text{mean of whole};
\]

\[
s = \text{standard deviation of whole period}.
\]

(ii) **Polynomial Regression Analysis**: In the present investigation, second order polynomial regression is employed to extract any trend in the total annual and total monsoon rainfall. At the same time it is also tried to find out the relationship and dependency of total rainfall on the monsoon rainfall. In this analysis also 22 stations depending on the availability of data took into consideration.

(f) **Excess and Deficient Rainfall**: Keeping this in view the incidence of excess and deficient rainfall, over the study area, has been examined during the last 31 years period (1971-2001). Six stations namely, Ambala, Karnal, Gurgaon, Narnaul, Rohtak and Hisar were considered for this analysis. Std. value is considered the central value.

The rainfall above it is an excess rainfall and below it is the deficient rainfall. Following steps are followed:

(i) Per cent Departure = \( \frac{\text{annual rainfall of the year} - \text{av. rainfall of the series}}{\text{av. rainfall of the series}} \times 100 \);

(ii) Std. Value = \( \frac{\text{annual rainfall of the year} - \text{av. rainfall of the series}}{\text{std. value of the series}} \)

1.9.3 Estimation of Runoff

In the present study, A.N. Khosla's formula\(^2\) to compute runoff is applied. This formula is based on the rational approach, which determines loss (rainfall minus runoff) as a function of only one factor, namely, mean temperature wherein the mean temperature has been taken, on the basis of available data to present all factors, such as wind velocity, humidity, pressure, solar radiation etc., which are responsible for the evapotranspiration. Formula is as under:

\[
R_m = P_m - L_m \quad \text{(1)}
\]

\[
L_m = 0.481 T_m \quad \text{(2)}
\]

where,

- \( R_m \) = monthly runoff (cm),
- \( P_m \) = monthly rainfall (cm),
- \( L_m \) = monthly evaporation losses (cm),
- \( T_m \) = mean monthly temperature (° C).

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2 Khosla, A. N., (1940) "Water Studies for Bhakara Storage Dam Project in Punjab", *Central Board of Irrigation of India*. 
1.9.4 Rainfall – Runoff Relationship

For developing and designing water harvesting and storage system, available estimation of runoff is essential for a given soil and land use conditions. Where, there is a causal relationship between two sets of variables and the change in one set depends upon the change in other set, we may determine the rate of change so caused. The relationship may be studied graphically on the scatter diagram and statistically with the help of linear regression analysis. Both these techniques have been used in the present study to find out the relationship between rainfall and runoff. Thus, the available volume of rainwater, studied and analysed in spatial framework will be purely geographical in nature. With this spatial analysis our basic hypothesis of rainwater harvesting, which depends upon rainfall, storage depression etc. is tested. Such analysis, therefore, reveals underlying trends and regularities in rain water harvesting.

1.9.5 Geographic Information System (GIS)

The most important characteristic of Geographic Information System is the fact that it enables the analysis of the spatial data and their attributes contained in a data base. The main function of GIS in rainwater harvesting studies is to assist in the management of land and water resources. It is used for answering questions about real world. As the database of a GIS is a simplified model of reality, it is used to represent certain aspects of this reality.
GIS is a multi-disciplinary technology. For example a geographer with knowledge of computer operation can use GIS tool. Any GIS is void without data, and all these techniques (maps, field survey, satellite imageries etc.) provide for the much need spatial data required to populate the GIS database. This technique has emerged as an important technology mainly because it is a valuable and easy to use tool in the hand of decision making bodies. As a result, GIS has exceeded all these discipline, surveyor, computer scientist, remote sensing specialist, planner and environmental scientist and many others.

In the present study, MapInfo (Professional) 7.8 version of GIS software is used for the storage of data and analysis of different parameters. The main objective is to assess GIS as tool for managing rainwater in those parts of the State where groundwater depletion has taken place and surface water in terms of canals and rivers is deficient. Collecting the large number of geographical data requires for water resource modeling is very laborious if done by hand. For both the pre- processing as well as for the post - processing stage, the use of GIS saves much time and it becomes possible to improve model results1.

The significance of differences from region to region has been ascertained statistically and, finally inferences have been drawn. The findings have brought together for the use of agricultural scientist,

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hydrologists, irrigation engineers and policy makers for future groundwater developments. It is hoped that such planning will be realistic than theoretical.

1.10 STUDY ORGANISATION

The study is organized into seven chapters. The first chapter is introductory and acquaints the reader with the nature of research problem, study area, objectives of study, data base and constraints and research methodology. Hydrology, geohydrology, geomorphology and some other socio-economic aspects of relevance are concern of the second chapter.

The subsequent four chapters contain the real content of the research problem. The third chapter deals with rate and magnitude of groundwater depletion. Various components of groundwater budget are discussed in detail. Rainfall characteristics and pattern are introduced in fourth chapter. The description of rainfall characteristics depend upon its distribution, pattern and trends. Therefore, quantitative analysis of data becomes essential to determine its optimality. Hence, assessment of spatial, temporal and seasonal behaviour of this hydrological component is conducted with the help of different statistical techniques like polynomial regression, cross correlation etc.

The fifth chapter addresses the time and space characteristics of runoff. This chapter presents an estimated amount of runoff with the help of a rational formula which gives most satisfying results in
Indian conditions. Similarly, rainfall-runoff relationship is also being established. The sixth chapter highlights the scope of rainwater harvesting by involving a powerful tool of GIS. Likewise, in seventh chapter some management strategies are discussed to harvest more rainwater depending upon the physical characteristics, which are area specific.

The final chapter presents conclusions, summaries of the study and suggests direction for further research work.