CHAPTER 1

INTRODUCTION
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Water is the most valuable natural resource available on Earth without which the life, in context of both animal and plant kingdoms, could simply be not sustained. The hydrosphere, although constitutes three-fourth of the earth surface but ironically, the fresh water, available for human consumption, is only meager 0.71% of all the water available on the planet. The facts that such a vital resource is so very limited and is put to all kinds of menaces in terms of both quantity and quality due to population explosion and resultant urbanization and industrialization, has necessitated detailed appraisal of freshwater resources all over the world. India is no exception and right since 1970 there had been great thrust on researches in various spheres of the science dealing with groundwater resources.

Water has become the most commercial product of the 21st century. This may sound rather bizarre, but it is true. There are no two opinions that what water is to the 21st century; oil was to the 20th century. This situation has emerged due to tremendous stress on multiple water resources, which in turn, is a result of a multitude of factors. On the one hand, the rapidly rising population and changing lifestyles have increased the need for fresh water, and on the other, intense competitions among users, i.e. agriculture, industry and domestic sectors, is pushing the ground water table deeper and deeper (Srivastava, 2003).

In many parts of the world groundwater resource base and the socio-economic and environmental systems dependent on it are under threat due to unsound management strategies. The north-west region of India, comprising the states of Punjab, Haryana and Western Uttar Pradesh (of which the area of study is a part) is one such region (CASA, 2004).

There is no doubt that water is critical and will remain critical to all the endeavors directed towards making the world even better and the scenario in India is no different. Land and water are the most vital resources around which overall development of a country rests. The strong interaction between the two and their dependence on other
components of the socio-ecological system highlights the need for putting groundwater resources at the centre of any developmental effort.

In the water sector, Indian efforts have so far concentrated largely on developing the resource. Unfortunately, very little attention has been directed to ensuring its efficient, equitable and sustainable use. The increase in cropping intensity and improved technology are the main factors in bringing about manifold growth in Indian agriculture over last three decades, in spite of the fact that the arable land has ceased to grow, and as a matter of fact, has declined (Alagh, 2003). This remarkable achievement of the country has necessitated the availability of more and more water for irrigation purposes, and therefore, has definitely resulted in causing a lot of pressure on groundwater resources. The demand for agricultural products, naturally, would keep on rising if food security is to be assured to more than a billion people of the country.

A cause for depleting groundwater resource is that in our country groundwater is "an open access common property resource" and the country is faced with a situation in which one user tries to maximize his share, lowering the share of others. The irony is that when groundwater level gets lowered due to excessive and indiscriminate use, wells are deepened further and even more powerful pumps are installed. This raises the cost of the availability of groundwater for all. The net result is even further depletion of the resource.

The alluvial areas of the country have been one of the most productive areas from the point of view of agriculture. There has been a spectacular increase in agricultural production in these areas during the past few decades. This is largely attributed to the expansion of irrigation networks that existed in these regions. Canals in the initial stages and tube wells immediately thereafter, have played a crucial role in a quantum jump in agriculture production (Prihar et al., 1993). The development of irrigation has been a mixed blessing. As mentioned earlier, while it has helped in increasing the agriculture production, it has also caused water logging in canal command areas and resulted in overexploitation of groundwater and consequent declining of water table (Sondhi and Khepar, 2003). Such situations have affected 242 administrative blocks of the Gangetic
plain, which are suffering from various kinds of problems related to overexploitation of groundwater resources (Alagh, 2003).

1.1 GLOBAL SCENARIO OF GROUNDWATER

It is almost a common knowledge that saline water in the oceans accounts for 97.2% of the total hydrosphere. The land area holds the remaining 2.8%. Of this remaining 2.8%, ice-caps and glaciers hold 2.14% and 0.61% is accounted for by the groundwater to a depth of 4000 meters. More than 98% of the available fresh water is groundwater which far exceeds the volume of surface water (Fetter, 1990).

Globally, agriculture is the largest consumer of water (70% of the total availability), followed by the various industries (20%) and domestic uses at about 10% (Anon, 2008). These proportions, however, vary from country to country.

Domestic water supplies are provided dominantly from groundwater resources in most of the countries. In addition, groundwater also plays an integral role in sustaining ecosystems and landscapes in humid and semi arid regions and on coastal margins.

As the growth in the global population continues, the demand for clean water increases the pressure on both surface and ground water resources proportionally, and consequently, in recent decades, more than two dozen countries have become water-scarce. The projected population growth for the next few decades could push yet another two dozen countries and hundreds of millions of people over the brink of water shortage. Water scarcity may be faced by the entire “watery planet” by 2050, if action is not taken in time (Campbell, 2003; Kumar, 2003). This is particularly so in semiarid and arid regions of the world where usable water supplies are relatively scarce.

The problem that is being faced globally is a consequence of a number of factors, such as:

1. The pressure on the water resources has increased by an order of magnitude during the post-II World War period, particularly due to rapid industrialization and urbanization.
2. Water resources, both on surface and underground, have been, in general, poorly managed. Strategic planning had always been lacking.
3. No thrust was given to groundwater investigations in the previous century although it had been realized that the success of changing crop patterns and intensive agricultural activities depend almost exclusively on availability of more and more water for irrigation purposes.

4. There is a directly proportional relationship between pollution and population. Increasing population has resulted in large scale pollution of groundwater resources. This is mainly related to discharges from industries and municipal wastes. These situations, in particular, have reached alarming levels in underdeveloped and developing countries.

A late realization though, it is now understood the world over that for better management of groundwater resources, the vulnerability of groundwater resources to drought, over-abstraction and quality deterioration must be assessed both now and in the context of climatic change and global warming that the planet is in the course of experiencing (Struckmeier et al., 2004).

The hydrological cycle is an integral part of the climate system and the trends of climate change, as inferred by meteorologists and climatologists are expected to have negative effects on water resources in the form of a shorter spell of precipitation season and an increase in hydrological extremes, such as, floods and droughts. Relative to surface water resources, the potential effects and consequences of climate change on groundwater have not received as much attention (IPCC, 2001). These effects may manifest in many forms, such as, variations in groundwater level fluctuation (Chen et al., 2004), changes in soil pore water pressure (Collison et al., 2000), alteration of groundwater flow regimes (Scibek and Allen, 2006) and changes in the volume and quality of groundwater resources (Brouyère et al., 2004; Bloomfield et al. 2006; Ranjan et al. 2006). Several studies have aimed to quantify the likely direct impacts of changing precipitation and temperature patterns on groundwater recharge (Eckhardt and Ulbrich, 2003), while others have extended this analytical approach to include the indirect effects on recharge characteristics (Holman, 2006).
1.2 SCENARIO OF GROUNDWATER RESOURCES IN INDIA

The climatic conditions in India are unique in the sense that the country has a distinct rainy season, under the influence of monsoon, starting from June to October. It is estimated that the annual rainfall in India is about 400 million-hectare meters. However, less than 20% of it is utilized only and the remaining reaches the sea eventually or gets evaporated. Although, overall there is plenty of water around but still many areas in the country remain drought-prone. This is more due to improper planning of water conservation and lack of water resources management policies rather than natural factors that India is ranked 122 out of 130 nations in terms of water quality and 132 out of 180 nations in terms of water availability (Tikoo, 2003).

Rainfall is the main source of recharge to groundwater storage. Most of the groundwater development takes place from the dynamic zone of water level fluctuation in the unconfined aquifers where active recharge takes place. The dynamic groundwater resources of the country have been computed as 433 BCM (billion cubic meters). Keeping 34 BCM for natural discharge, the net annual groundwater availability for the entire country is of the order of 399 BCM. The annual groundwater draft has been computed as 231 BCM, out of which 92% is for irrigation (213 BCM) and 8% is for domestic and industrial use (18 BCM). The stage of groundwater development is 58% (Romani et al., 2006; Nandakumaran, 2008).

Currently, total water use (including groundwater) is 634 BCM, of which 83 percent is utilized for irrigation purposes. This means that in addition to the availability of 433 BCM of groundwater, 201 BCM of water in use is from surface resources. The demand for water is projected to grow to 813 BCM by 2010, 1,093 BCM by 2025 and 1,447 BCM by 2050. Groundwater, in particular, will come under even greater pressure in the coming years http://news.boloji.com/2007-2/200709/11983.htm).

The rate of extraction of groundwater is increasing and in many blocks exceeds the rate of recharge, leading to lowered water tables. “Twenty-eight percent of the blocks are now semi-critical, critical and over-exploited” stated the report of the Expert Group on Ground Water Management. The number of dark or over-exploited critical blocks has

As suggested by another study, of the 5723 assessment units (blocks/mandals/talukas/watersheds), 839 are categorized as "over-exploited" where the stage of development exceeds annual replenishment, and 226 blocks/watersheds are critical where groundwater development has reached a highly alarming level (Romani et al., 2006).

Groundwater constitutes a vital natural resource in India for sustaining agricultural economy and meeting ecological and environmental goals. It is a unique resource, widely available, providing security against droughts and yet it is closely linked to surface-water resources and the hydrological cycle. Its availability depends on geohydrological conditions and characteristics of aquifers and, in general, it is available from shallower levels in alluvium to deeper levels in the bedrock. It plays a key role in the provision of safe drinking water to both rural and urban populations. Almost 80% of domestic water use in rural areas in India is groundwater-supplied (Kumar, 2007). In urban regions this quantity is even more.

India is a vast country having diverse geological, climatological and physiographic scenarios. This cumulatively results in giving rise to divergent groundwater situations in different parts of the country. The hydrogeological set up in the country, consequently, varies widely. The prevalent rock formations, ranging in age from Archean to Recent, are widely varied in composition and structure and control both the occurrence and the movement of groundwater.

Groundwater resource availability thus depends upon a combination of favourable parameters, such as, geological environment, geomorphological conditions, topographical set-up, nature and type of the weathered zone and soil cover and climatic conditions, particularly in terms of precipitation. As mentioned above, these parameters are not uniform throughout the country. Consequently, the resource availability is also highly variable in the country, for example, one third of the country, covered by alluvial and sedimentary formations has very good potential, where as the remaining two-third, overlain by hard rocks, has limited to moderate potential only (Kittu 2003).
The lofty mountain chains in the north with high runoff, offers little scope for groundwater storage. However, they play an important role in recharging the vast Indo-Ganga-Brahmaputra plains, extending over a distance of 2000 kms from Punjab in the west, to Assam in the east. This region is characterized by multi-aquifer system, which has been explored to 600 m, and evidently holds promise for extensive and productive groundwater reservoirs. The aquifer systems are extensive, thick, hydraulically interconnected and moderate to high yielding (Sharma, 2004; Romani, 2006).

The peninsular shield in the south, on the other hand, comprises discontinuous aquifers of limited potential in weathered and fissured consolidated sedimentary rocks, basalts and crystalline rocks. Rugged topography and compact and fissured nature of the rock formations results in the formation of discontinuous aquifers with limited to moderate yield potentials. Generally, the potential water-saturated fracture systems occur down to 100 m depth and yield up to 30 liters per second (l/s).

The coastal areas around the peninsular shield have a thick cover of Pleistocene to Recent alluvium with potential aquifers but associated with the risk of sea water intrusions. In fact, instances of sea water are reported at a number of places along both eastern and western coasts.

The arid and semi-arid regions of Rajasthan and Gujarat with scanty rainfall and practically no recharge have restricted occurrence of deep aquifers tapping fossil water only (Kumar, 2003).

On volumetric basis, status of groundwater development for the country as a whole is around 37.24%. The state-wise development pattern is highly variable. For example, the western U.P., of which the present study area is a part, registers a high status of development which varies from 60 to >100%. This scenario necessitates precise evaluation of groundwater resources. With this objective, various aspect of water entering into the system can be quantitatively and qualitatively evaluated so that a rational approach may be adopted regarding development and management of groundwater resources of the area. Keeping this in view, the present study area was selected for the study.
1.3 AREA OF STUDY

The study area lies in the western part of Muzaffarnagar district, bounded on the east by the Hindon river and on the west by the Krishni river. It lies between the latitude 29°05’N and 29°30’N and the longitude 77°20’ E and 77°32’ E and covers an area of about 650 km² (Figure-1). The area falls in Survey of India Toposheets No. 53G/7, 53G/8, 53G/11 and 53G/12 on 1:50,000 scale. Almost all the villages are well connected by motorable roads.

Muzaffarnagar is an important industrial district with sugar, steel and paper being the major products. More than 70% of its population is engaged in agriculture. It boasts of having one of the highest per capita incomes in the country and the highest in the state of Uttar Pradesh. The Muzaffarnagar market of Jaggery is the largest in the world (http://en.wikipedia.org/wiki/Muzaffarnagar).

1.4 AIMS AND OBJECTIVES

The investigation being presented here, was carried out in the Krishni-Hindon interstream region with the following objectives:

➢ To delineate the regional aquifer system, their geometry, and their aquifer parameters
➢ To study the movement of groundwater and long term behaviour of water level in space and time
➢ To evaluate groundwater resources of the area
➢ Development and improvement of water balance of an aquifer incorporating natural conditions of flow system
➢ To study the chemistry of groundwater system and evaluate its suitability for various uses
➢ Demarcation of aquifer zone vulnerable to contaminations
Figure- 1.1 Location map of the study area
1.5 METHODS AND LINES OF STUDY PURSUED

In order to generate quantitative data base on hydrogeology and hydrochemistry, systematic groundwater surveys were carried out supported by laboratory investigations. The methodology followed and the techniques adopted are enumerated below.

- The literature pertaining to study area was collected and background information was generated.
- Toposheets of the study area were used to generate base map for the field survey.
- Rainfall and various other hydrological and hydrogeological data pertaining to the area were collected. The rainfall data were statistically analyzed and the mean, standard deviation, coefficient of variation were calculated.
- A Landuse and Landcover map for the area was generated using Landsat Multispectral Imagery for two different time periods. A change detection analysis in Landuse and Landcover using two time period data is also attempted.
- Evenly spaced 39 observations well (handpumps) were selected to monitor water levels. Coordinates of the wells were taken using GPS.
- Repeat measurements to monitor the changes in water level, for pre and post monsoon were carried out in year 2006 and 2007 in all the monitoring wells.
- The water level data of monitoring wells were processed and various maps like depth to water map, water table contour maps and water level fluctuation maps were prepared.
- Historical water level data of hydrograph stations monitored by Central Ground Water Board and State Groundwater Department was utilized to prepare hydrographs to infer long term water level trends.
- Lithologs of deep tube wells were collected to prepare various cross-sections and fence diagram.
- Sand samples were collected from varying depths of granular zones and were utilized for permeability estimation in the Laboratory using Permeameter.
- The sand samples were also mechanically analyzed for grain size analysis and parameters like effective grain size and uniformity coefficient were determined.
- Groundwater Budget was prepared for June 2006 to June 2007 using guidelines provided by Groundwater Estimation Committee 1997 (GEC 97).
• In all, 108 groundwater samples were collected from shallow and deep aquifer for physico-chemical analysis in two successive seasons viz. post-monsoon and pre-monsoon period corresponding November 2005 and June 2006, respectively.

• Out of 108 samples, 44 samples were collected in November 2005 and 64 samples in June 2006. In addition to this 25 samples were also collected from deeper levels representing same sampling sites.

• Beside major ions, eighteen groundwater and two effluent samples were also analyzed for trace elements using Inductive Coupled Plasma-Mass Spectrophotometer (ICP-MS). Twelve samples were also analyzed for their SiO₂ content.

• Six surface water samples were also collected from Krishni and Hindon rivers during November 2005 and were analyzed for major ions.

• Groundwater of the study area was classified into different chemical groups on the basis of major ions constituents.

• Various mechanisms were identified and presented, which seem responsible for alteration in groundwater chemistry.

• Classification of aquifer vulnerability to contamination is also attempted.

• Concurrence and synthesis of hydrogeological, hydrometeorological and hydrochemical data was attempted to generate the model for groundwater regime of the area

1.6 PREVIOUS WORK IN THE STUDY AREA
Detailed hydrogeological investigations in the area were carried out by Central Ground Water Board (CGWB) and Groundwater Department of U.P. state government. A part of the study area is well studied under upper Yamuna project of CGWB. The objectives of the project were to map sub-surface aquifers occurring to depths of 450 mbgl and to determine their parameters. Bhatnagar et al., (1982) analyzed, correlated the electrical and lithological logs of exploratory boreholes, and identified four distinct groups of permeable granular zones separated by three poorly permeable to impermeable horizons. These groups of aquifer extend all over the basin except close to Delhi where the bedrock is encountered at shallow depth.
Gupta et al., (1979) carried out Electric Analog model study in Krishni-Hindon interstream region. The model study shows that the aquifer can sustain the withdrawal rate of 200 million cubic metre (Mcum)/year with out much damage to the groundwater regime. However, only an increase of 5% to the said draft shows detrimental and deleterious effects on the aquifer. Further decreased rainfall/droughts would deteriorate the situation.

In another aquifer modeling study Gupta et al., (1985), have assessed the stream aquifer interaction and impact of conjunctive use of surface water and groundwater on groundwater regime of the area.

Goel, (1975) conducted recharge estimation studies using environmental tritium method and recommended 22% of rainfall as recharge to aquifers in Western Uttar Pradesh.

Khan (1992) carried out systematic hydrogeological survey in parts of Muzaffarnagar district. This study encompasses groundwater chemistry and water balance study of the area. Kumar (1994) carried out reappraisal survey in parts of Muzaffarnagar and identified Baghra, Kairana, Un, Budhana, and Shahpur blocks as overexploited, where the groundwater development has reached up to 142.15%. The study recommended that the exploitation of groundwater be stopped in these blocks.

Kumar and Seethapathi (2002) suggested an empirical relationship for estimation of the groundwater recharge from rainfall with reasonable accuracy in Upper Ganga Canal command area which is adjacent to the present study area. The formula states

\[ R = 0.63(P - 15.28)^{0.76} \]

Where, \( R \) is groundwater recharge from rainfall in monsoon season (inch) and \( P \) is mean rainfall in monsoon season (inch).

Jain et al., (2004) have studied zinc metal in bed sediments of river Hindon and concluded that the pollution from industrial and agricultural sources to a great extent is responsible for high concentration of zinc in river water. In another study, Jain et al., (2005) have studied metal pollution in water and sediments of River Hindon in western Uttar Pradesh. The metals which were reported are Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn. The study reveals that the River Hindon is subjected to varying degree of pollution caused by numerous untreated and/or partially treated waste inputs of municipal and industrial effluents. Further, the higher concentrations of metals in
river water in the upper stretch are largely attributed due to the mixing of effluents from Paper Mill and Distillery.

Umar et al., (2006) carried out detailed hydrogeochemical survey in parts of Kali-Hindon interstream region and classified different types of groundwater with high TDS. Strikingly high sulphate concentration and its possible sources were also reported. In another study, Umar and Ahmed (2007) carried out detailed hydrogeochemical survey in Yamuna-Krishni interfluve region and observed similar trends. The groundwater was high in TDS with high sodium, bicarbonate and sulphate. They presented various mechanisms involved in chemical alteration of groundwaters of the study area.

Bhosle et al., (2007) carried out remote sensing, GIS and GPR studies in Western Gangetic Plains and located a new active transverse E-W running fault passing through the city of Muzaffarnagar.

Ahmed and Umar (2008) presented a detailed assessment of groundwater budget in Krishni-Yamuna interfluve incorporating all possible inflow and outflow component. The results show a deficit groundwater balance. The study shows that the Kairana and Shamli blocks are overexploited.

Umar et al., (2008) carried out detailed hydrogeological survey and an attempt has been made to calculate a water balance for Kali-Hindon inter-stream region of Muzaffarnagar district. Various inflows and outflows to and from the aquifer have been calculated. The results show that total recharge into the system is 148.72 million cubic meters, whereas total discharge is 161.06 MCM, leaving a deficit balance of -12.34 MCM. This study shows that the area is overexploited.

Tyagi et al., (2008) carried out hydrochemical appraisal of groundwater and its suitability in the intensive agricultural area of Muzaffarnagar district, Uttar Pradesh. In this study, groundwater is neutral to moderately alkaline in nature. Chemistry of groundwater suggests that alkaline earths (Ca + Mg) significantly exceed the alkalis (Na + K) and weak acids exceed the strong acids (Cl + SO4), suggesting the dominance of carbonate weathering followed by silicate weathering. Majority of the groundwater samples posses various types of hydrochemical species. A positive high correlation \( r^2 = 0.928 \) between Na and Cl suggests that the salinity of groundwater is due to intermixing of two or more groundwater bodies with different hydrochemical compositions.
1.7 NEED TO CARRY OUT THIS STUDY
The study area is dependent on agricultural activities as it is the mainstay of life. Groundwater development has already reached to a critical stage in some part of the study area. The high rate of groundwater abstraction, application of fertilizers and increasing industrialization and other factors which are indeed prerequisite for the prosperity of the study area are posing several threats to the groundwater regime both qualitatively and quantitatively. The declining groundwater trend would eventually lead towards dewatering of shallow saturated zones and thus future groundwater scarcity is inevitable with the present rate.

The deficit groundwater balance vis-à-vis quality deterioration of groundwater raises serious concern, as groundwater is the major source of irrigation and agriculture is the mainstay of life in this region. The present study is significant because of the water balance studies have been carried out afresh at microwatershed level incorporating all inflow and outflow components. This study will eventually facilitate various groundwater management schemes at micro level as well as the quality of groundwater as related to different purposes.

The geomorphology, geology, hydrogeology, hydrochemistry, and groundwater budget have been described under the present study to provide a quantitative data base at micro level.

1.8 BRIEF OUTLINE OF THE CHAPTERS
Present study was started during November, 2005, as a part of the requirements for the Doctor of Philosophy programme, with a view to carry out detailed hydrogeological, hydrogeochemical and groundwater resource evaluation of Krishni-Hindon Inter-stream region, western Uttar Pradesh.

Chapter 1 provides the basic background needed to address the importance of groundwater, its availability throughout the globe, in general, and in India, in particular. It also lists out the objectives and methodology employed for the present study. Previous studies and the need for carrying out the present study have also been discussed.

Chapter 2 summarizes techniques of data acquisition and methodologies adopted pertaining to detailed hydrological, meteorological, hydrogeochemical and aquifer vulnerability studies.
Chapter 3 deals with the introduction to the study area. It includes its geographic location, physiography, climate, occurrence and variability of rainfall, soil types and surface and subsurface geology. It also encompasses prevailing water use, land use and land cover in the study area.

Chapters 4, 5 and 6 present regional hydrogeological set up of the area and a rather detailed account on various aspects of the hydrogeology of the area. These chapters include aquifer geometry, its extension and types. Depth to water table, slope and movement of groundwater, long term water level trends are also described. Aquifer parameters determined by various techniques and from previous studies have also been discussed in these chapters.

Chapter 7 examines the groundwater budget within the study area. The quantification of dynamic resource is a challenging task, full of uncertainty and errors in its estimation. The resource estimation in alluvial aquifer often carries errors pertaining to accurate estimation of various inflows contributing to the aquifer system. In order to implement groundwater management plan, groundwater budget study of the area is a prerequisite. Efforts were made to carry out groundwater budget, including all possible components of groundwater recharges and discharges. The Groundwater Resource Estimation (GEC 97) norms were applied for the present study.

Chapter 8 demarcation of aquifer zone vulnerable to contaminations and feasibility study of its mitigation have also been attempted.

Chapter 9 encompasses the detailed chemical classification of groundwater into different groups with the help of Piper's trilinear diagram and LL diagram. It also deals with physical and chemical properties of groundwater. The suitability of groundwater for drinking and irrigation purpose has also been discussed.

Chapters 10 discuss chemical characterization of groundwater with the help of X-Y plots. Trace element analysis, chemical characteristics of soil and dissolved silica analysis have also been presented in this chapter.

Finally, Chapter 11 sums up the entire work which has been carried out stating its importance and significance for better understanding the groundwater regime of the study area. It also puts forward certain recommendations which may be used for long term water management and planning. Various management options available
1.9 SCOPE OF THE PRESENT WORK

The area under study is a highly fertile land and is a leading producer of a number of crops. It is densely populated and its economy is mainly dependent on agriculture and its allied activities. In order to keep pace with the increasing demand of food grains due to explosive population growth, it is essential to boost the agrarian economy. For obtaining the maximum benefit from agricultural sector, assured irrigation is one of the prime requisite. Therefore, it becomes essential to manage the available water resources of the area judiciously and scientifically for fruitful results without creating any environmental hazards. A precise qualitative and quantitative evaluation of groundwater will provide a useful guideline to planners and decision makers for implementing an effective groundwater development and management strategy in the area, and in nutshell that had precisely been an objective of this work.

The present work can be extended as the sub-basin needs to be monitored for groundwater conditions for some years. The dynamic resource of the sub-basin is being exploited at an alarming rate. The groundwater is being harnessed continuously to cope up with the rising demands. Moreover, the recharge to the system is decreasing day by day as groundwater discharge exceeds the recharge, due to deficit rainfall. The applicability of recommendations and their socio-economical impacts need to be analyzed in the times to come.

Due to the escalation of demand-supply ratio because of population growth it becomes essential to monitor the groundwater management minutely with a lot of precision. For this groundwater budgeting is to be done at a micro level, which should include all the possible influential factors and components available. The precise groundwater budgeting serves as the backbone of groundwater management programme which can be achieved after a detailed hydrogeological examination. Therefore this study emphasizes upon the importance of ground water budget.

Groundwater resource development and management personnel are concerned with sustain yields of wells and aquifers, the interference between wells and well
fields, the interrelation between surface water and ground water, and the quality of groundwater.

Groundwater management has been the key issue for most of the problems related to water resources in the semi-arid areas with over exploited aquifers. In spite of several types of artificial recharge structures, the water level decline continues and it has become imperative to consider analyzing the demand of groundwater. This needs to evaluate each and every component of the groundwater and prepare a meaningful groundwater balance. The groundwater balance and budgeting using new and specific techniques of estimation will help in planning and decision making for the policy makers on one hand and to the farmers on the other hand to adopt suitable agriculture practices and prepare groundwater demand scenario providing feasible and sustainable management of groundwater.

Multidisciplinary scientific studies for the evaluation of natural phenomenon are prone to errors at some stages of assessment and improvements are always inevitable. The study is almost entirely dependent on a single parameter and that is the location of the observation points. The observation points (hand pumps) may not always be located at places where they should ideally be from the point of view of a better or more controlled sampling. This has been taken care of to the best possible way through a judicious and as far as possible nearly equally spaced observation points. Shortfalls are inevitable even then.

Improvements are always possible in groundwater budget, at the statistical level, like number of groundwater draft structures and irrigation water applied may also carry certain errors. The vertical leakage from one aquifer to the other may be one cause for errors. In spite of all precautions taken the groundwater budgetary estimates given here may not be considered final.

Fertility of the land, suitability of the region for industrial development and good rail and road connectivity to the National Capital Region are all significant factors controlling the present demography of the area. The population increase and consequent emphasis on both agriculture and industries sectors result in not only a proportionate per-capita decrease in the availability of the groundwater resource, but also affects its quality and suitability from the points of view of various modes of consumption.
With this background, in addition to discussing the conventional hydrogeological attributes of the area, emphasis has in particular been laid on hydrogeochemical aspects, such as, chemical types of groundwater, temporal and spatial variation in chemical characteristics, chemical alteration trends of groundwater, factors affecting the chemical quality and a relationship between hydrogeology and hydrogeochemistry. Again, the idea is to provide some clues to planners and administrators to mitigate the problem of groundwater pollution.

It is expected that this study will be useful in developing a better understanding of hydrological and hydrogeochemical conditions of the area, which in turn, would be useful for the development of agriculture and thus would help raise the living standard of the people inhabiting the area.