CHAPTER-1

INTRODUCTION

1.1 General

Although there is plenty of water on the Earth's surface, freshwater is limited. Only 2.7 percent of the world's entire content (around 1.4 billion cubic kilometres) is fresh and fit for human consumption; the rest is in solid form. About 77.2% of this is permanently frozen, while 22.5 percent is found in groundwater and soil moisture, 0.35 percent in lakes and wetlands, and less than 0.01 percent in rivers and streams, as shown in figure 1.1. The amount of water available above ground, i.e., in the atmosphere, is a tiny part of the overall water resources of the globe, estimated to be 1/10000 of the total. Groundwater is a critical source of water for humanity. Groundwater serves as a source of drinking water for up to 50 percent of the world's population and accounts for 43 percent of all agricultural water. 2.5 billion People around the globe rely primarily on groundwater resources to meet their basic daily water needs. The Earth's population of nearly 8 billion in 2020 is expected to reach 11 billion by 2100 (www.un.org). During the period 2011-2036, India's population is predicted to expand by 25.7 percent, or 1.0 percent per year, from 121.1 crores to 152.2 crores, an increase of 25.7 percent in twenty-five years. As a result, the population density will rise to 463 people per square kilometre, up from 368 currently (Census of India). Humans will have to learn to produce sufficient food without destroying the soil, water, and climate. Freshwater consumption per person is around 2.7 litres per day or one cubic meter per year. These criteria, however, are not met in all parts of the world. The global hunt for new sources of freshwater, particularly groundwater, has escalated to solve the difficulties of water scarcity. It has been described as humanity's greatest challenge. It is critical to have a scientific understanding of groundwater and to manage it properly.

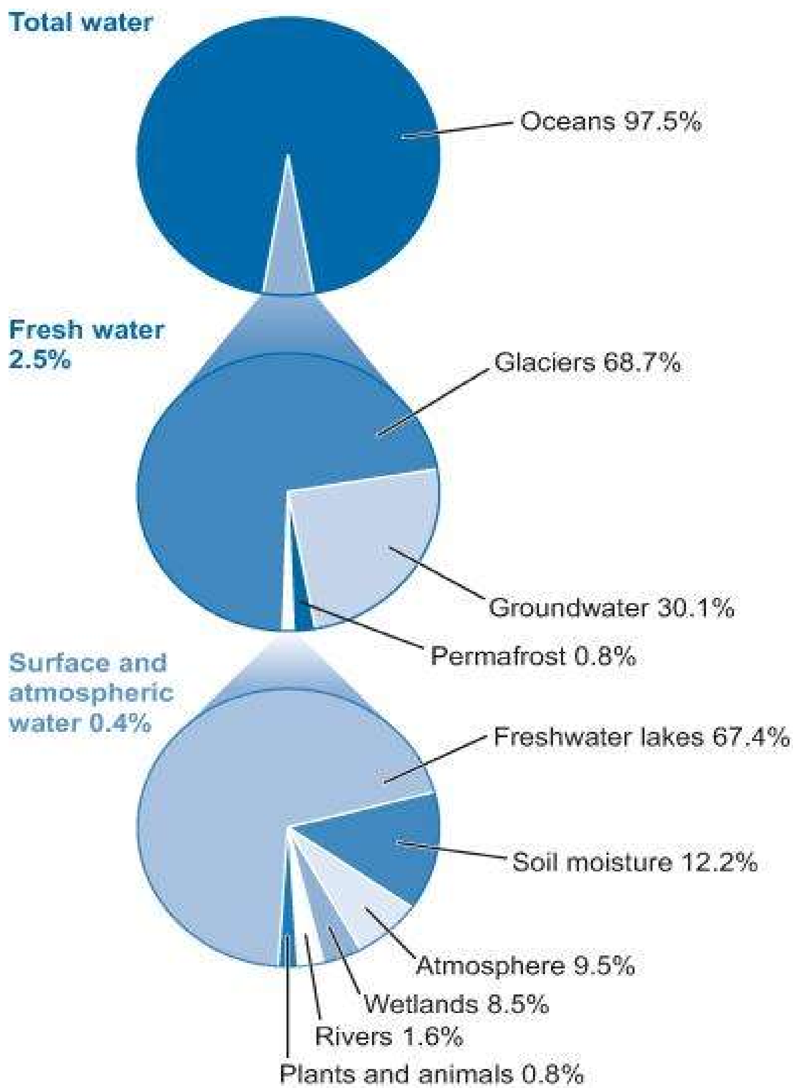

Figure 1.1 Distribution of Earth's water (USGS 2018)

Our country is thought to be one of the wettest in the world. It receives 1170 mm of rain on an annual basis. India gets 400 million hectares meter (Mha-m) of rainfall per year, which is distributed as follows: 70 Mha-m evaporates, 115 Mha-m runs off into surface water bodies, and 215 Mha-m percolates into the soil, where 165 Mha-m moistens it, and the remaining 50 Mha-m enters the groundwater table.

On the other hand, the estimated groundwater resources (up to a depth of 300m) are 3700 Mha-m, equal to about ten times the annual rainfall -the primary source of groundwater recharges. It is replenished annually to the extent of 42.3 Mha-m, of which nearly 24% is used. Indeed, the groundwater is not being gainfully utilized in the country. The recent investigations show that the “hard rock" formation of peninsular India-nearly 70% of the countries landmass holds more groundwater than was assumed earlier. Many observers regard the widespread use of groundwater irrigation in the Indo-Gangetic plain as the key to the "Green Revolution" spread. The 'Green Revolution,' which began in the 1960s and has nearly quadrupled production of food grains, has revolutionised the face of Indian agriculture, making the economy of country self-sufficient and one of the world's major exporters of food grain. As detailed in a piece published on December 20, 2017, water has been the unquestioned motor of India's Green Revolution. The Green Revolution has had a significant impact on both the quality and quantity country's water resources. (https://www.downtoearth.org.in/)

Its use offers several advantages when compared to surface water. Groundwater reserves do not suffer seepage loss like a surface reservoir, and evapotranspiration losses are minimal. Groundwater could be developed quickly and near the place of use. The tube well is one of the most popular ways of using groundwater in the country. The growth of tube well for irrigation purposes in alluvial tracts is related to the ease of tapping the water. The sandy aquifers of the Indo-Gangetic plain make the construction of shallow tube wells, also called filter points, within reach of individual farmers. In arid and semi-arid areas, hand pump tube wells have been immensely useful in meeting domestic water requirements. Besides, groundwater is an essential water source for irrigation in the country at present. Groundwater caters for about 40% of the gross irrigated area in the country. The role of groundwater is all the more critical in the Ganga basin, which has a vast reservoir of groundwater replenished every year at a very high rate. Water has been a fundamental resource for agricultural development besides land. Any agricultural development requires improvement in land along with water supply. In our country, the experiment in the mid-sixties gave positive results through the success of the green revolution strategy based on the trial of water fertilizers and HYU seeds.

The production of food grains recorded tremendous growth. The water played a crucial determining role in the intensification of cropping and giving a fillip to the yield of cereals, particularly rice and wheat. Expansion of irrigation has no doubt ensured self-sufficiency in food grain production. Water has played a crucial role in the production of rice and wheat in India in general and particularly in the states like Punjab, Haryana, and Uttar Pradesh.

In recent years, the total water withdrawal for irrigation, industry, and urban supply has been significant in several basin areas. For proper water management and the prevention of possible groundwater pollution by seepage of industrial and municipal waste, it is essential to access the available groundwater resources in the Ganga basin in a more scientific manner.

1.2 Description of Groundwater

The water beneath the surface trapped in sediment and rock is called groundwater. Most of the freshwater available for human use is groundwater. The rainfall that soaks into the ground and moves downwards into spaces and cracks in the rocks below the ground surface becomes groundwater, as shown in Figure 1.1 (Siebert et al. 2010). The saturated zone, also called the groundwater zone, is where all the soil pores of soil mass are filled with water. The soil pores in this zone are only partially saturated with water. The extent of this zone varies from the ground surface to the groundwater table. Aeration zone can be categorized into three sub-zones i.e., Capillary, Intermediate, and Soil-Water Zone. Another term for groundwater is "aquifer,"

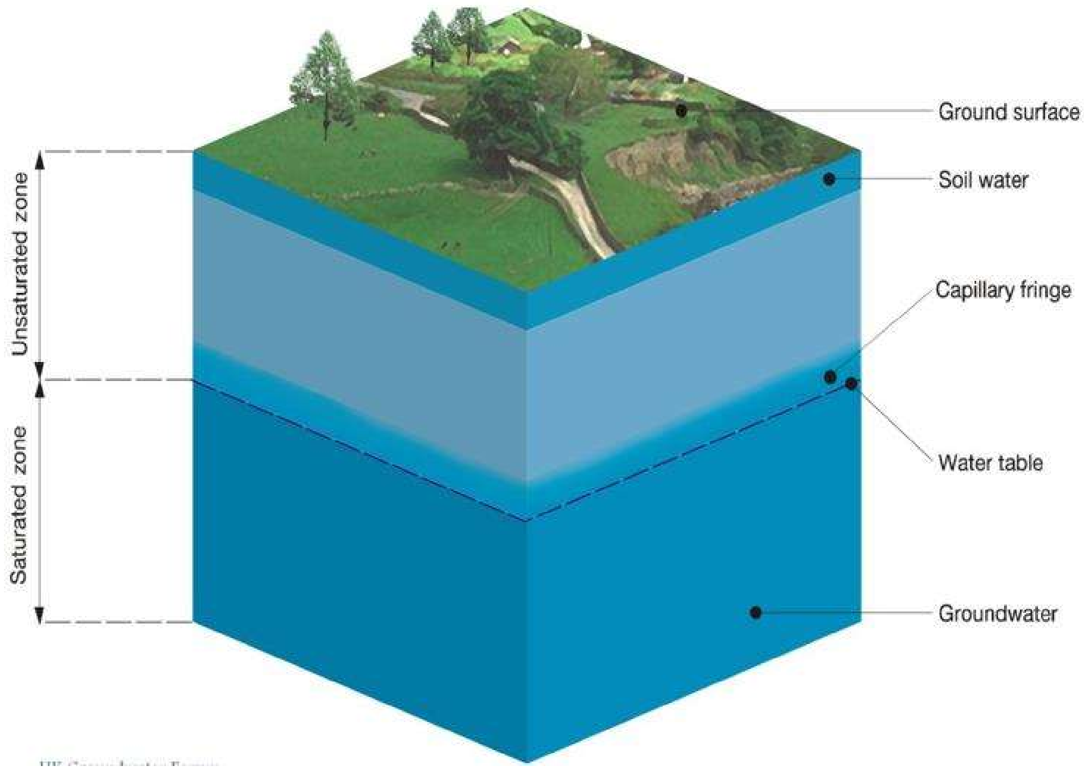

Figure 1.2 Location of Groundwater (Siebert et al. 2010)

1.3 Aquifers and its types

Aquifer usually refers to rock or soil formations that can produce an abundant amount of water to meet people's needs (Lohman et al. 1972), as shown in Figure 1.3. Aquifers are a massive reservoir of fresh water on earth (Schmoll, O et al. 2006). An aquifer is a water-bearing layer in which the vertical flow component is so less that it may be ignored compared to the horizontal flow component. Generally, it is assumed groundwater flows horizontally in an aquifer.

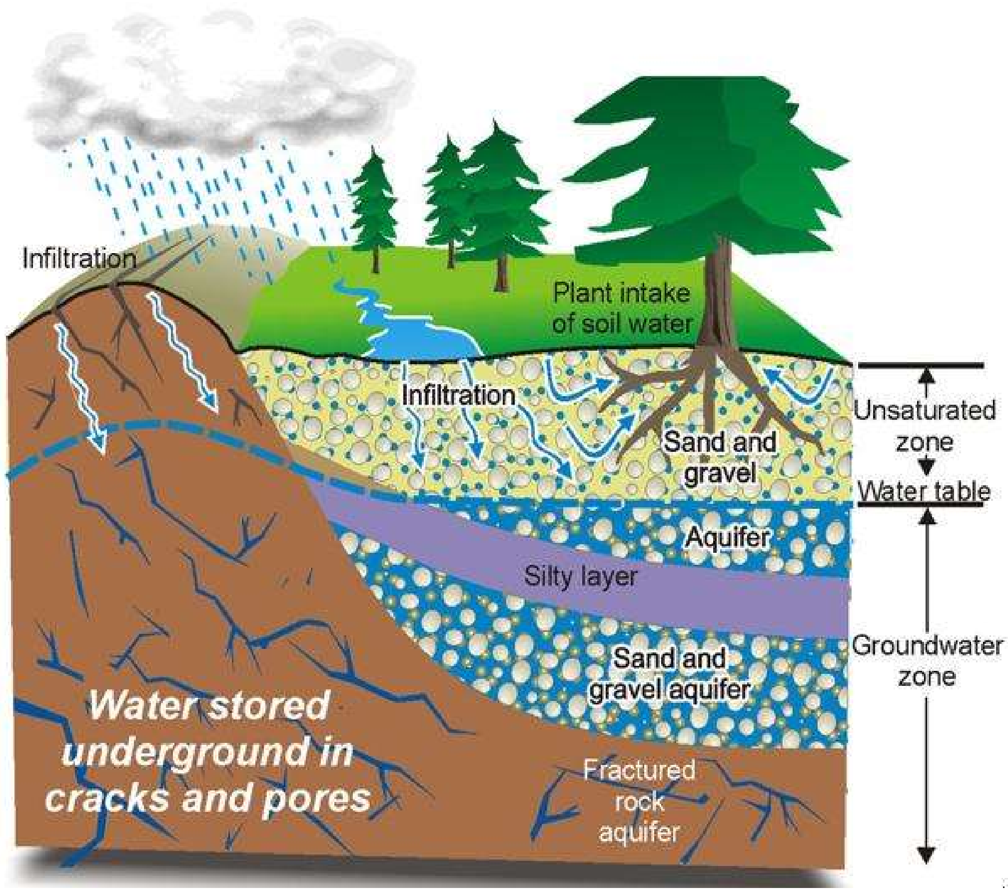

Figure 1.3: Location of Aquifer

The four types of the aquifer, i.e., confined, unconfined, and leaky, are as shown in Figure 1.4.

1.3.1 Confined Aquifers

Water bodies in permeable rock are surrounded by two impermeable rock layers or rock bodies under a confined aquifer. Confined Aquifers are aquifers that are found to be overlain by a restricting rock layer or rock bodies, commonly comprised of clay that may provide some level of protection from contamination from the surface. The non-permeable geological barriers between the aquifer cause the water to be under higher pressure than the atmospheric pressure.

1.3.2 Unconfined Aquifer

Unconfined aquifers are not overlain by any confining layer but have a confining layer at their bottom. It is generally open to the atmosphere and has a water-saturated upper portion. The water table is the upper surface of saturation that is under atmospheric pressure; hence this aquifer is also known as a phreatic aquifer. (https://www.usgs.gov.in)

1.3.3 Leaky aquifer

This is also known as a semi-confined aquifer, a completely saturated aquifer bounded below an aquiclude and above by an aquitard. If the overlying aquitard extends to the land surface, it may be partially saturated. Still, if it is overlain by an unconfined aquifer bounded above the water table, it will be fully saturated.

1.3.3.1 Aquitard

It's a geological formation of semi impervious nature transmitting water at lower rate than an aquifer.

1.3.3.2 Aquiclude

It has a water-tight geological formation. It has a lot of water, but it would not let water pass through it and do not let water out. Its high porosity accounts for this. Clay is an example of an aquiclude.

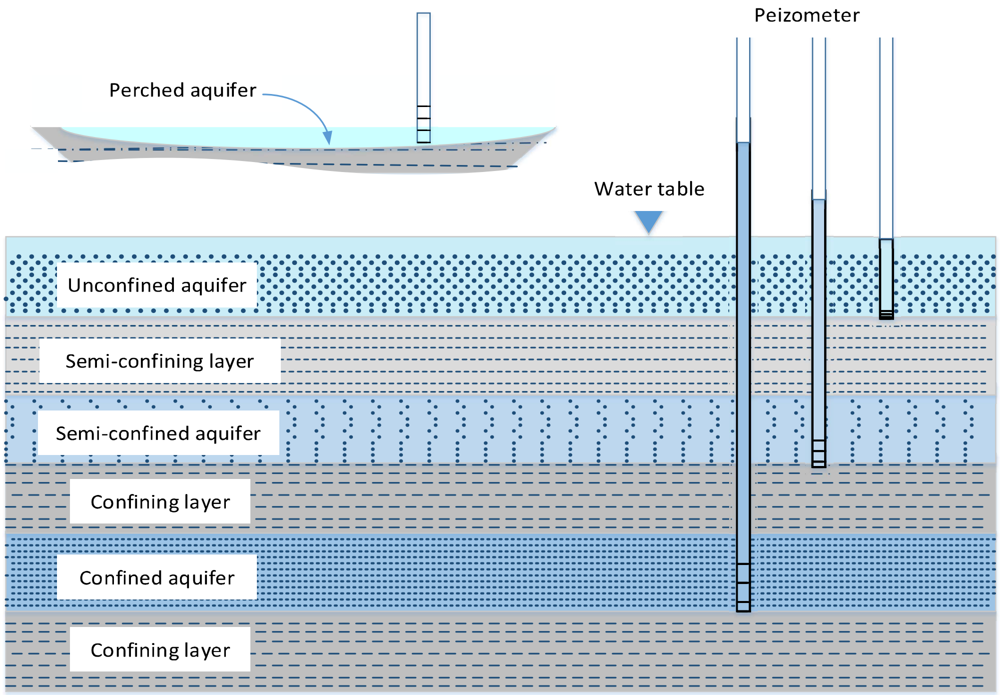

Figure 1.4: Different Types of Aquifer

1.3.4 Perched aquifer

An aquifer that lies above the local (regional) water table and occurs due to an impermeable layer of sediments (Aquiclude) or relatively low impermeable layer (Aquitard) above the main water table but is below the surface of the land.

Aquifers are powerfully described by their capacity to hold water, which is measured by different properties like,

- Permeability- the property of the soil to transmit water and air
- Hydraulic conductivity –fluid's capacity to move through pores and cracked rocks.
- Transmissivity- under a unit hydraulic gradient, the rate at which water moves through a unit width of aquifer.
- Porosity- ratio of the volume of pores to the volume of bulk rock in percentage.

- Storativity- volume of water released from storage per unit aquifer surface area per unit hydraulic head decline.

1.4 Source and replenishment of groundwater

The ultimate source of water which sustains groundwater bodies in fine to coarse-grained sands of the 'older alluvium' is rainfall. A part of the rain that falls returns to the atmosphere by evaporation; a part runs off on the surface as streams, whereas a considerable part seeps down to the water table to replenish the groundwater body. Other source of replenishment are infiltration from the river while in space, return seepage from irrigation, and inflow from the neighbouring areas of the above-mentioned source of recharge ,direct penetration of rainfall is probably the most important. The rate and amount of infiltration general depends on several variable factors Viz.

1. Duration intensity and amount of rainfall
2. Nature of the plant cover on the soil
3. Permeability of the soil
4. Condition of soil moisture and
5. The atmospheric temperature the annual increments of recharge to the ground water body vary with total annual rainfall.

1.5 Concept of water infiltration

Water-saturated rocks contain all the water types, from the chemically bound water present in the structure of minerals to the free gravitational water, which fills all pores and fissures present in the rocks. Free gravitational water may pass through pore space and fissure. It is driven by gravity and flows due to the hydrostatic head difference. The passage of gravitational water through a porous medium, which is the principal way of underground water irrigation, is called infiltration. In an actual porous medium, water migrants through the system of open and communicating pores and fissures varying in their size, form, and relative spatial distribution. Because of the complicated variability in both the paths and velocities of the water migration through a porous medium, the process of water infiltration through individual pore channels and fissures cannot be accurately studied. So, the water migration through a porous medium is taken for the total cross-sectional area of a filtrating medium as a whole. In this case, the primary characteristic of the water migration through a porous medium is an infiltration rate. The volume flux of water moving into the profile per unit of soil surface area is defined as the infiltration rate (IR) under any set of circumstances. When water is applied to soil, the IR is frequently reduced from its initial high rate due to the creation of a thin layer (less than 2 mm) at the soil surface known as a seal.

1.6 Need of Study

Excess use of GW results in temporary or permanent decline in quantity of groundwater. Estimating groundwater recharge rate is a fundamental requirement for the professional management of groundwater resources. It is vital in the arid and semi-arid sites where those assets are frequently the way to financial growth. Excessive removal of groundwater to cater the need of the ever-growing population in the region has resulted in the land subsidence in fast causing a decline of water head. Management of water resources is a critical issue for our country, its management calls for proper and systematic monitoring of levels, which fluctuates with time and space. Understanding aquifer recharge mechanisms and their linkages with land-use is essential for integrated water resources management. Groundwater location is a big issue in complex hydro-geological setting, but after satisfying all the steps, Groundwater level and recharge can be predicted for curent and future purpose. A permanent decline in the water table has been observed due to excessive groundwater withdrawal in Varanasi. The lowering of groundwater has been 7 feet (213 cm) approximately in the preceding years. Hence, it's a very critical issue for researchers to give a proper sustainability and increase the groundwater level for future purpose.

1.7 Brief discussion of research work

The study deals with a Soil and Water Assessment Tool (SWAT), a widely used application to find the hydrological behaviour of a study area. The physically-based circulating display SWAT is the most well-known model for analysing the effects of land management activities on water, sediment, and complex watersheds. SWAT is a popular technique for predicting sediment yields (Jeong et al., 2012). SWAT is a watershed management tool that helps to meet water quality criteria (Mittelstet et al., 2016). When SWAT is connected with GIS using Arc SWAT (Kinnel 2018), it is easier to estimate sediment yield. Agricultural Non-Point Source Pollution (AGNPS), System Hydrologic European (MIKE SHE), and Soil and Water Assessment Tool (SWAT) are just a few of the hydrological models that have been developed and used to simulate hydrological processes in recent years. (Young et al., 1987, Tripathi et al., 2003). The SCS-CN approach is the most extensively used method (Shivhare et al., 2018). After evaluating all of these models, the Soil and Water Assessment Tool (SWAT) is one such process-based hydrological model, made by the United States Department of Agriculture (USDA), Agricultural Research Service (ARS), which can be used conveniently for hydrological modeling (Kumar et al., 2015). Basic inputs used in this methodology is daily rainfall, DEM, LULC, temperature etc. and output was hydraulic response units like water yield, evaporation, groundwater which is shown in Figure 1.5. taken from Indian Meteorological department ,Pune

Further, results from this model have been merged to a widely used Groundwater modeling tool GMS-MODFLOW which deals with flow movement and volumetric water budgeting of the Study area. The creation of a database for modelling is the first stage in the groundwater modelling process. The data is gathered from a variety of sources, processed into the appropriate format, and then utilized as input for a groundwater model. The information gathered is analysed in a GIS context. As a result, the database contains data on different well characteristics e.g. geology, geomorphology, specific storage, hydraulic conductivity, well yield, well lithological layer details, soil type, hydraulic heads, and daily rainfall, among others. Survey of India topo sheets, Public Works Department, Geological Survey of India (GSI) maps, Annual report of Central Groundwater Board (CGWB), and other sources were used to compile the data. Each parameter's units and scales are adjusted to meet the model's requirements. Eryigit (2021) proposed ground water flow model. In addition, the model requires less observation numbers for parameter estimation than other studies. The hydraulic conductivity, transmissivity, storage coefficient, and leakage of groundwater flow were all estimated simultaneously using an optimization model based on model calibration. MODFLOW was used in conjunction with the MATLAB model to simulate the groundwater flow. The MODFLOW input files were collected using the GMS groundwater simulator. To assess the model's performance, it was applied to two separate hypothetical groundwater systems (two and three-dimensional) under transient situations. The results demonstrated that the model could be used to estimate groundwater flow and that it could correctly determine groundwater flow parameters with less observations and more grid cell numbers than previous studies. Groundwater models can be used to mimic the system's real-world conditions, which can aid in the comprehension of its behaviour and performance. The water balance changes because of pumping and other modes are estimated using a groundwater model. With accessible data, geographic information technology offers a lot of promise for visualizing and interpolating the geographical extents of groundwater resources. Using GMS-MODFLOW and GIS tools for the research region, an effort was made to build a three-dimensional groundwater flow model to describe groundwater flow system and quantitative groundwater budget as shown in the figure 1.5.

Further, a different hybrid approach has been introduced (GHAT) to predict the groundwater level in wells during Pre-monsoon and Post-Monsoon seasons. Nowadays, due to lack of data, various learning methods are being adopted for the future forecasting of rainfall, groundwater level, temperature, and general Hydrological Parameter. This method proposed the GIC (Generalised intelligence control) with HAC-ABO (Hybrid Ant colony- African Buffalo Optimization) method for forecasting the groundwater level in wells. The existing approaches face many limitations like lower prediction accuracy, utilizing more time, and using a small quantity of data to predict the groundwater level. Rainfall, pre-monsoon and post-monsoon are used as input parameters as shown in figure 1.5. The predicted results are validated with existing works such as Multiple linear regression (MLR) with ANN (Sahoo et al. 2013), Radial basis function-whale algorithm (RBF-WA) (Demirci et al. 2017; Demirci et al. 2019; Banadkooki et al. 2020), Multilayer perceptron whale algorithm model (MLP-WA) (Banadkooki et al. 2020) to prove the efficiency of the proposed approach. Further GIC model is utilized for training the data sets to the MATLAB. The parameters of a

HAC-ABO are combined with the GIC classification layer for forecasting the groundwater level and enhancing the performance. All the proposed approaches predict the groundwater level for next 30 years (2030, 2040, and 2050). Also, it encompass high prediction accuracy and a lower rate than the other models.

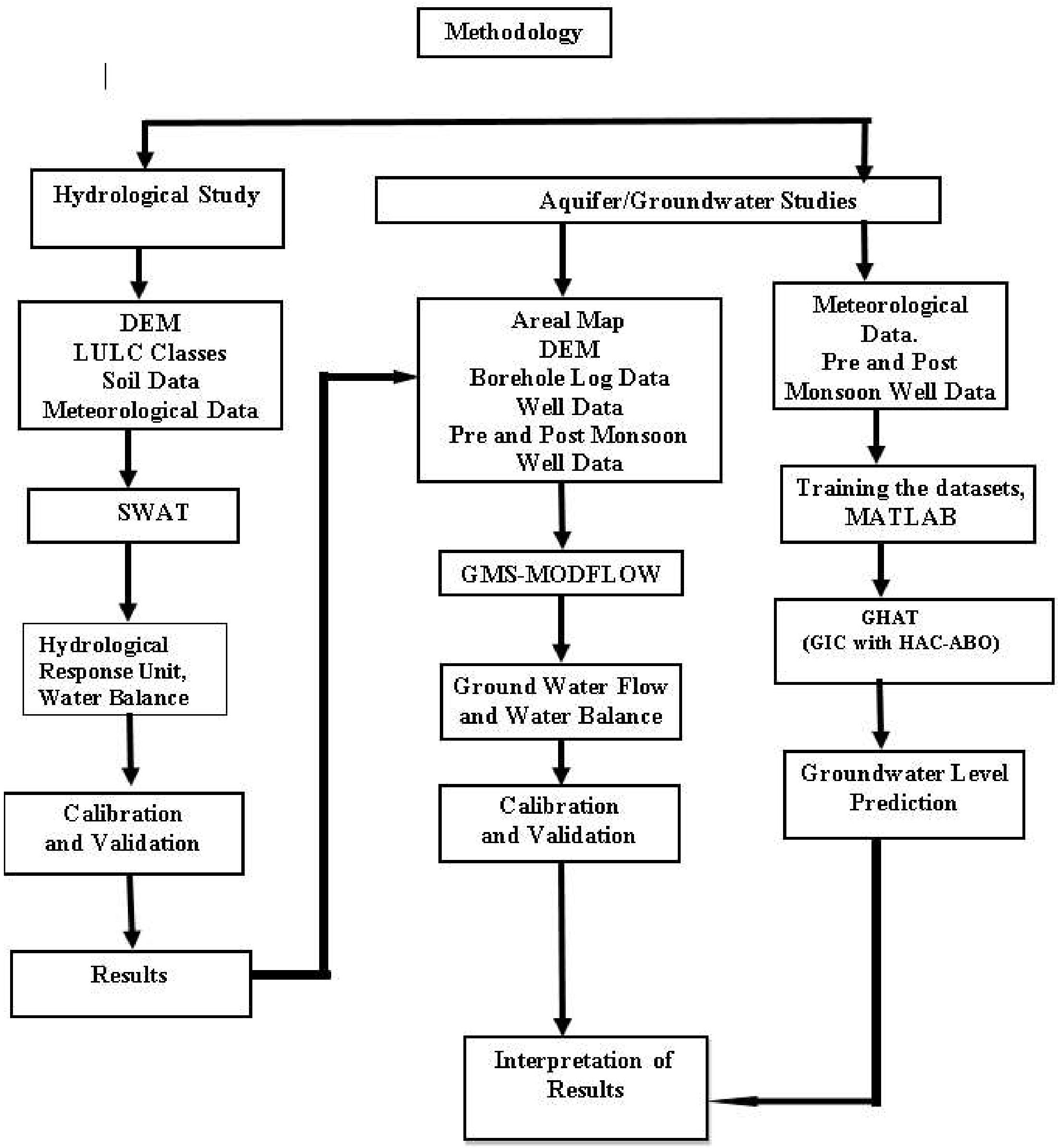

Figure 1.5 Work-Plan of methods used in study area

1.8 Objective of the Study

a. To study and comprehend the hydrological setting of study area.
b. To study the groundwater flow patterns in aquifer around Varanasi region and present the volumetric water budget of the study area.
c. To develop a novel and innovative method for the groundwater level prediction using optimization techniques GHAT- GIC (Generalised intelligence control) with HAC-ABO (Hybrid Ant colony- African Buffalo Optimization)

1.9 Presentation of the Study

The whole study has been delineated in following 9 chapters which are as follows:

Chapter 1 contains introduction about the groundwater, its necessity, objective and methods used for this study.

Chapter 2 contains a literature review of prior works on the hydrological cycle, groundwater modelling, and research optimization methodologies.

Chapter 3 discusses about the study area, groundwater age, quality, data collection, and photographs.

Chapter 4 embrass the Soil and Water Assessment Tool (SWAT) to show the hydrological behaviour of the study area from 2015 to 2020.Outputs obtained like groundwater recharge and evapotranspiration has been utilised in the next chapter.

Chapter 5 explains how to use the MODFLOW application to conceptualise a groundwater model for the research area. The chapter discusses the applicability of the boundary conditions, as well as the calibration and validation of the model, with an output like volumetric water budget and changes in the water head.

Chapter 6 highlights a new and innovative method GHAT- GIC (Generalised intelligence control) with HAC-ABO (Hybrid Ant colony- African Buffalo Optimization) method for forecasting the groundwater level in wells during Pre and Post monsoon seasons.

Chapter 7 offers Inventory of ponds and water bodies, important sources of water recharge, which will augment the groundwater level in the area.

Chapter 8 presents the summary and significant conclusions drawn from the study and contains the suggestion for augmenting the water table in the area.