CHAPTER 2

LITERATURE REVIEW

2.1 General

It is generally assumed that the process of groundwater flow is controlled by the relationship expressed in Darcy's law along with the conservation of mass. In 1856, Henry Darcy derived a well-known flow law, based on the results of the experiments, which can replicate the flow of water or groundwater movement in a porous medium. Darcy's law was formulated for the saturated flow and is valid for laminar flow only. Darcy's law has been used by most of the groundwater flow studies as a base and it helps in the identification of the true results either experimentally or numerically. Study of the groundwater has become essential because it is an important source of fresh water. That's why, many researchers, scientists, and water resource engineers have dealt with the groundwater flow and its interaction with the surface water. This surface water and groundwater exchanges are connected to each other and affects each other geologically, hydro-geologically, and environmentally.

In the groundwater studies, the aquifer characteristic and its behavior are investigated. A groundwater model is a good method for these studies. Groundwater model is a technique to represent the natural groundwater flow and predict the effects of hydrological changes on the aquifer behavior. Groundwater modeling corresponds to a management technique that helps in taking decisions about the behavior of the groundwater aquifer system and the future response of that system due to the many hydrological effects applied to the groundwater aquifers. Any groundwater modeling process has three basic objectives (Anderson et al. 1992):

1. To get the replica of the actual system that satisfies the already agreed criteria.

2. Predicting the behavior of the actual system by varying input model parameters.
3. To know the sensitive parameters of the system, this can be useful while collecting/gathering the model data.

The problems commonly encountered in the groundwater systems can be divided into three categories. First one is depletion in the groundwater table (head) due to excess withdrawals of water from the aquifers.

Overdraft or overuse is a practice of withdrawal of groundwater beyond the equilibrium or safe yield of the aquifer. Over drafting or overexploitation may cause serious consequences such as drying up the groundwater aquifers (Shah et al. 2000).

The second is submerged areas with water that lead to increase in salinization (soil salinity). Salinization is a process in which water-soluble salts accumulated in the soil. It may occur naturally or due to the presence of insufficient drainage system in the area and the lack of proper water management practices. The increase in the irrigation process for agriculture has doubled the risk of water-logging and soil salinity (Gebrehiwot, 2018).

Contamination (pollution) in the groundwater due to the wastes from industries, agricultural activities and other anthropogenic activities is the third category of the groundwater problems. In coastal areas, the problem of groundwater becomes even more complicated. Groundwater quality is threatened by degradation either by seawater intrusion or by the anthropogenic pollution resulting from a variety of contaminants present in industrial or urban, or even agricultural areas. Due to which the need for groundwater management increases further (Groundwater Governance, 2015).

2.2 Groundwater Models

Groundwater models play a significant role in the evaluation of quantity of the groundwater as well as the quality. These models can be used for issues ranging from calculations of overall water balance to problems of small-scale pollution. The status of the different groundwater modeling systems that are being used has been presented in Table 2.1.

Table 2.1 Status of Hydrological modeling systems (Refsgaard, 1996)

<table>
<tr><th rowspan="3">S No</th><th rowspan="3">Status of Application of Groundwater modeling systems</th><th colspan="3">Field of Problem</th></tr>
<tr><th rowspan="2">Assessment of Groundwater Resources</th><th colspan="2">Type of Groundwater Pollution</th></tr>
<tr><th>Point Sources</th><th>Non-Point Sources</th></tr>
<tr><td>1.</td><td>Is the scientific basis sufficient?</td><td>Good</td><td>Good</td><td>Fair</td></tr>
<tr><td>2.</td><td>Scientifically tested?</td><td>Good</td><td>Good</td><td>Fair</td></tr>
<tr><td>3.</td><td>Validation?</td><td>Adequate</td><td>Partially</td><td>Very Limited</td></tr>
<tr><td>4.</td><td>Realistic Applications</td><td>Standard professional tools in some regions</td><td>Standard professional tools in some regions</td><td>Few well proven cases of operational realistic application</td></tr>
</table>

The utility and use of any model depends on the purpose for which model is being developed. In the model development, it's a challenge to depict the real world situation in a simplified manner without negotiation the accuracy of the model or making any rough hypothesis. Groundwater model is a powerful tool to manage, protect and remediate the natural water resources (Anderson et al. 1992). The development of the groundwater model can be done with two purposes (Poeter and Hill, 1997). First one is to solve the head distribution over a domain (area) and calculate the hydrological transformation for the area. The second purpose is to identify the contamination in the groundwater by developing the solute-transport model. This model simulates the fate and transport of dissolved constituents in groundwater, which include salts and contaminants. A solute transport model which can be communicated with

MODFLOW through data files MT3DMS, was used to solve the problem of contaminants transport and the change of their concentrations with time (Ghoraba et al. 2013).

Approach for developing the Groundwater flow models can be classified as:-

1. Analogue model,
2. Mathematical model

Analogue modeling is a laboratory experimental method using uncomplicated physical models, while mathematical model is a description of a system that uses mathematical concepts. Physical models are built in the laboratory to identify the groundwater heads and flows directly, by using the porous material (usually sand) (Schellart, and Strak, 2016). Mathematical groundwater flow models are usually depended upon the groundwater flow equation. Groundwater flow equation is partial differential equations (PDE) and derived using the continuity principle (i.e., equation of mass balance) and Darcy's law. Mathematical models of the groundwater flow models have been used by many researchers since the late 18^{th} century. The basic concept of these mathematical models to deal with the behavior of the aquifer systems is represented by a set of mathematical equations, which may be linear algebraic equations or partial differential equations. These mathematically equations can often be solved by analytically or numerically approaches.

To simplify the complicated geometry of groundwater aquifer systems, analytical models normally use the mathematical equations. That's why, Analytical models didn't need large amounts of data, but their application is limited to the simple problems. Numerical or mathematical models are usually based on the real physics (geological condition, hydro-geological status, and boundary condition) of the groundwater flow through deriving the appropriate mathematical flow equations. Numerical models can handle more complex problems than analytical solutions. As advancement in the field of computing system, numerical modeling has become more popular. These mathematical equations can be answered by different numerical solution techniques or methods such as the finite difference method (FDM), the finite element method (FEM), and many more such as integrated finite difference method (IFDM), finite volume method (FVM) and boundary element method (BEM) (Abbott and Basco, 1989; Anderson et al. 1992). The most important and widely accepted method, by researchers, in the groundwater flow problems is the FDM and FEM. Both methods have their own advantages and limitations. FDM may provide different results to FEM, if the problem of concern is complicated.

2.3 Groundwater codes/programs

There are different codes (algorithms) available in the literature which can be used in the management of groundwater resource. These codes are structured to formulate the numerical algorithms to be able to deal with the problems of groundwater flow. The applicability of these codes depends on the types of problem, desired accuracy, data availability, and performance of the model (Loudyi, 2005). In the case of analyzing the problems of surface water and groundwater, more than 500 programs are available (Van der Heijde, 1996) and several new codes are in the developing stage, depending on the research purposes. But still, there is scope for the new developments. For instance, there are still no regular accepted methodologies for the assessment of groundwater model applications. In the case of decision-making based on model applications in many flow problems and water quality issues, researchers need guidance to make an objective assessment. The selection of the appropriate code or program to solve the groundwater flow problems is very essential and the accurate code could be very useful and helpful for solving the groundwater issues.

For specific objectives, researchers have proposed a number of codes or programs for groundwater protection, pumping test, and well head protection program (Ouazar et al. 1996; Wang, 1997). Groundwater handbooks and manuals have also been published by many government agencies that help and guide the researchers in selecting the appropriate code or program for the application in the field of either groundwater flow or solute transport (USEPA, 1994; NGWCL, 2001). However, the selection of the suitable code or program for a particular field problem depends upon the objectives of the modeling and the criterion that describe the corresponding code for a specific region.

2.4 Numerical models

Here, a review of the various methods or approaches, which used MODFLOW code, available for the groundwater flow studies and groundwater flow modeling is presented.

To estimate the availability of groundwater for the Trinity aquifer (upper and middle), in Hill country area, USA, Mace et al. (2000) conceptualized a 3-dimenional flow model. They calibrated the model in steady state as well as in the transient state using MODFLOW algorithm for the year 1975. Results of the study will help in the estimating the groundwater levels, which helps in the sustainable management of the water and appropriate use of water for the purpose of pumping in the future.

Cedare (2002) built a numerical flow model to simulate the groundwater system for Egypt Nubian states for the last 8,000 years. Results of the models are found to be in the good state and it suggested that two input parameters were affected the water levels due to climate change in the studied area.

A groundwater numerical model was built for the Antelope Valley groundwater basin, by using geo-hydrology data, in California, USA by Leighton and Phillips (2003). They did this study in multi layered form as developed model consist of grids of 43 rows and 60 columns in horizontal and three aquifers layers in vertical. Study revealed that in the span of 80 years, from 1915 to 1995, the groundwater storage was declined for an about $10.5*10^9$ m^3 and groundwater level was reduced to approx 4.50 m in the south-central part of the studied area. Result of this groundwater declination cause subsidence in the study area.

Scanlon et al. (2003) did a study to replicate the regional groundwater system in Karst aquifer. They used two different equivalent porous media approaches, lumped and distributed parameter, for the study. Along with flow simulation, they also assess the adequacy of these two approaches. The output of the study suggested that the Karst aquifer is very sensitive for the recharge rate as compare to discharge rate. Result of this study is very important to improve the spring flow in the Karst areas.

Jacek and Maciek (2004) developed a groundwater flow model for a multi layered aquifer system in Swidnica area, Poland. Conceptualization of the model was done in steady state condition using MODFLOW code in GMS software. They investigated the several hundred boreholes and analyses the impact of wells abstractions 53,000 m^3/day on the groundwater head. Results of the study showed that the groundwater decline was very slight and the impact of well abstractions was also very small in the studied area. The reason behind this phenomenon may be the existence of the boundary fault zone, and some lakes infiltrations in the area.

Blegen (2005) built a groundwater flow model for the aquifers in Trandum delta, Eastern Norway. Blegen developed the flow model using analytical and numerical approaches in steady state and after the model development, outputs of the model was compared with each-other. In analytical model development, Blegen used Poisson’s equation to get the solution.

Karamouz et al. (2005) used advance machine learning techniques in the groundwater studies. They developed a new approach to assess the interrelationship between the surface water and groundwater with emphasis on the water quality by using the Artificial Neural Networks (ANN) and Genetic Algorithms (GA) for the southern area of Tehran, Iran. Main emphasis of this study was to control the fluctuations of the groundwater level, reduce the cost of pumping.

Abdulla and Al-Assad (2006) did a groundwater flow studies for the arid region, Jordan. In Jordan, Mujib aquifer is the major source of water for fulfilling the various needs. They developed a flow model to simulate the Mujib aquifer under various hydrological stresses. Model outputs showed that the model was very responsive to the anisotropy, horizontal hydraulic conductivity, and specific yield even when the recharge rates were very low. In 2007, Wa'il and Randa developed the groundwater flow and solute transport model using MODLFOW and MT3D program for Azraq basin, Jordan. This model was simulated for five different case-studies to control the impact of the pumping rate on the groundwater systems.

In 2007, Sefelnasr built a three dimensional numerical flow model in transient condition using 'Finite Element Flow' (FEFLOW) program for Nubian Sandstone Aquifer System. In this study, Sefelnasr standardize the boundary conditions for the area of study and simulate the flow model for management of the groundwater. Apart from the model simulation, this study was also used in the prediction of the economic lifting depth through the simulation until 2100. Five different water extraction scenarios were anticipated to identify the practical option of the groundwater management. Out of these five scenarios, third scenario was the most favorable one that meets the best possible groundwater management option and the economic lifting depth.

Bandilla et al. (2007) developed a new iterative Analytic Element Method (AEM) to solve a two-dimensional groundwater flow model under steady-state conditions. They demonstrated the developed model on Northern Highlands Lakes Region of Wisconsin, which incudes thousands of head specified elements such as rivers, lakes, representing the hydrogeological features.

Humphrey (2008) built a groundwater flow numerical model for southern part of the Honey Lake Valley, California County, Nevada. The objective of developing this model was to simulate the drawdown in the studied area as this area experiences the declination in the groundwater level.

Fouépé et al. (2009) did a study for particle migration in an unconfined aquifer using groundwater flow for a small part of Yaounde City, Cameroon. A numerical flow model was conceptualized for shallow aquifer in steady state condition and calibration was done using eighteen observation wells located in the area. The results of the model provided quite realistic results as calibration gave good match between the computed and observed head except one observation well. An error was found in measuring the head value of this well.

Montenegro and Odenwald (2009) did a study to assess the design parameters for an excavation pit in Minden, Germany. The main objective of this study was to find out the reason behind the groundwater table difference about 13 m beside this excavation pit. In the study, difference between three dimensional flow model and conventional vertical plane approach was found out. The results of three-dimensional model confirmed the availability of a seepage face slightly above the pit bottom.

Tesfaye (2009) built a groundwater flow and solute transport model for 100 m thick aquifer for Akaki well field, Ethiopia in steady state condition. This study was done using PMWIN (Chiang and Kinzelbach, 1998) software with the help of MODFLOW code. In advance stage, they also find out the path lines and travel time of the contaminant using PMPATH code. In the model calibration, trial and error technique was applied, which resultant a good agreement between observed and computed head values.

Singhal and Goyal (2011) conceptualized a three-dimensional flow model using MODFLOW. In this model, random distributed recharge values were used as an average of recharge that is in general find by method of water budgeting.

Nasrin et al. (2013) simulated a groundwater flow model to assess the effects of future development on the current Narmab aquifer system for Golestan region, Iran. Calibration of the model was done using fifteen observation wells from October 2003 to October 2004 in Visual MODLFOW version 3.1. Output of the model illustrated that the groundwater head remains under control with the present pumping schedule even in the worse climate change also. Whereas, in the case of groundwater table prediction for the next few years, the groundwater level showed a declining trend, especially when the pumping rate increased.

Kumar and Kumar, (2014) conceptualized a mathematical flow model to quantify the groundwater for Choutuppal Mandal, Nalgonda, India. Model was built in MODFLOW program for steady state condition using Finite Difference Method (FDM). Nineteen observation wells were used in the calibration process and output of the model shows a fine agreement with the observed head excluding seven wells as it did not match with the calculated heads. Results confirm that the water level is declining in the aquifers which cause the low groundwater storage and there is need of immediate recharge into the groundwater to save the aquifer for future usage.

A groundwater fluctuation study was done by Zare and Koch, (2014) from 2007 to 2009. They simulated a groundwater model using MODFLOW and results revealed that after 10 years of pumping and irrigation action in the study area groundwater table keep on rising, and it will lead to water logging in the 50% of the plain area.

A dynamic steady-state groundwater model was developed by Graffi et al. (2015), in which specific yield was estimated considering one unconfined layer. Capillary rise of water table was ignored in this study which can affect the soil moisture and evapotranspiration.

To assess the groundwater resources for an urban area Jilin in China, a groundwater flow model was built by Shuwei et al. (2015). They collected the borehole data from 190 wells situated in the area. In GMS software, they calibrated the river stages using trial and error approach and they achieved root mean square error (RMSE) is 0.66 m. for the value of hydraulic conductivity and aquifer specific yield they did almost 290 pumping tests in the area. From the results, they found that recharge was the most important sensitive factor as compare to conductivity of the aquifer. A declination trend in the groundwater level has been found from the model and this area needs a scientific research based approach for the sustainable use of the groundwater to compensate the future usage of this resources.

From all of the above literature reviews, it has been very clear that for any groundwater flow model, calibration process is very important step of the groundwater model development. In the calibration process, a comparison has been done between the computed (modeled) heads with the observed field head values, during the adjustment of parameters of the groundwater aquifer. Generally, any groundwater flow model can be calibrated in three conditions. One is for the steady-state conditions only, second is for the transient-state conditions only, and third is for a steady-state followed by a transient-state calibration (Anderson et al. 1992). Steady state condition are said when there are no pumping conditions applied over the studied area, while in transient state condition pumping conditions are applied on the study area. When calibration was done for steady state conditions called *static calibration* and for transient state conditions calibration is called *dynamic calibration*.

The name static or dynamic comes from the behavior of the groundwater tables throughout the study area that is influenced by the parameters of groundwater. For a better understanding of the static and dynamic heads, one can take the help of Figure 2.1. From the Figure, it is clear that cone of depression is absent in the case of static head, while for dynamic heads cone of depression of varying size is formed. In short, static head occurs when the pumping wells is out of work or not in operation, while dynamic head occurs when the pumping well in operation (Philip, 1980).

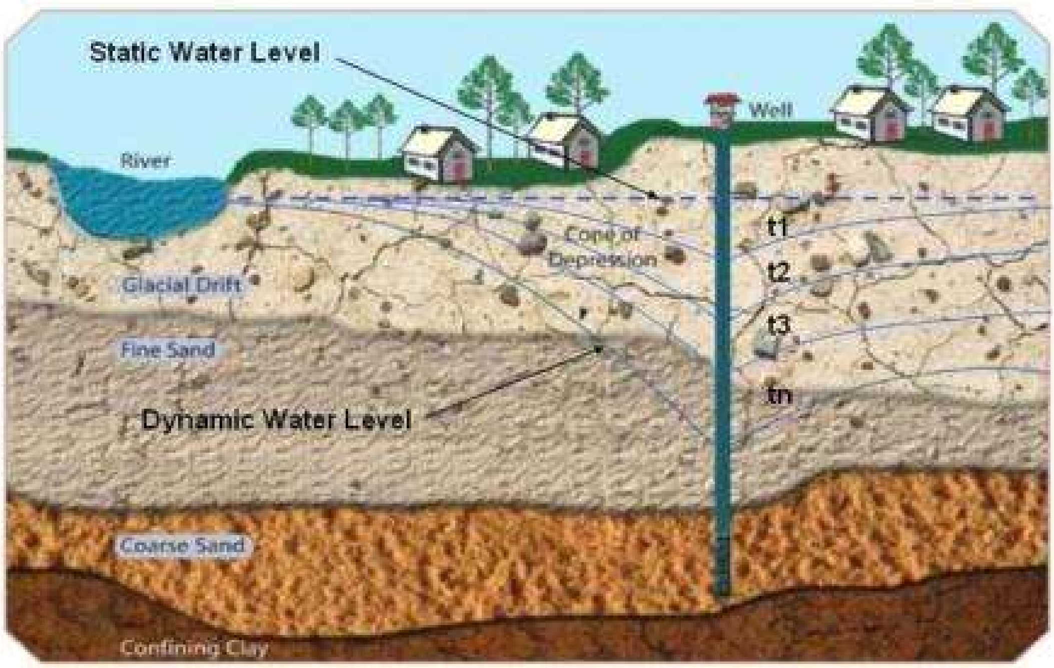

Figure 2.1 Effect of pumping schedule on the groundwater level (Adopted from Philip et al. 2010)

2.5 Groundwater and surface water Interaction

When water resources engineers talked about water management, they usually focused on the groundwater or surface water as a single entity. However, due to the advancement in the computing capacity and development of land and water resources, evidence has been found that surface water and groundwater are interconnected and they affect the water quantity and quality of each other. The interaction between the groundwater and surface water exchanges water as well as solutes between them. Therefore, there is a need for a study to understand this phenomenon for the sustainable and effective water management for any area (Winter et al. 1998). Various processes and issues associated with the groundwater and surface water interactions has been reviewed and presented here.

The procedures stirring groundwater–surface water (GW-SW) flux change are difficult and comprise of, groundwater interactions by wetlands hyporheic exchanges, flood inundation, evapotranspiration from various water bodies, parafluvial flow, and bank storage. This groundwater and surface water exchange phenomenon can be categorized into three important processes, and this is known as three stages of complexity.

Stage 1: Established on experimentally based relations, which derived from conclusions of various field experiments/observations.

Stage 2: Compared with the first-order model, working on finer Spatio-temporal scales has high logical resolution and process complexity.

Stage 3: Case-based, stochastic processes and based on that deterministic models.

After analyses of three stages of complexity, the development of the following model is proposed:

A stage 1 complexity, stream scale, 'Groundwater–Surface water connection' model, which works as a groundwater relation to the streams of low elevation. The predicted result of this approach is responsible for groundwater–surface water exchange at the stream level.

A stage 2 complexity, sub-stream scale, 'Floodplain course,' was done, and this model leads to the gradually model the flood plain inundation, bank storage, and rate of evapotranspiration for the water bodies. The results of this complex model lead to GW-SW exchanges with the capability to relate to environmental response models.

Here the process is defined as being groundwater driven, surface water-driven, and groundwater–surface water driven. This categorization of the different processes is based on the interaction of groundwater and surface water. Figure 2.2 shows the interaction of surface water (river) and groundwater (aquifer) and a gaining river stream.

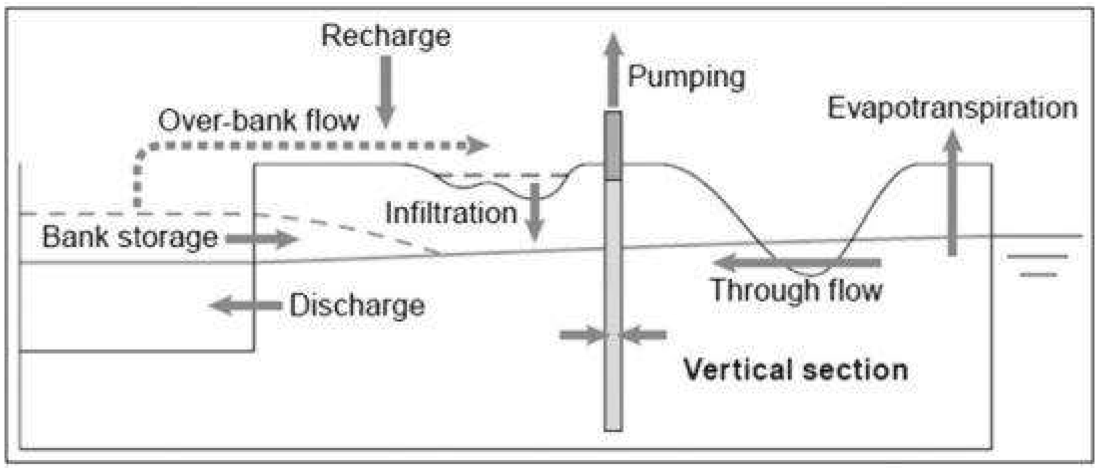

Figure 2.2 Schematic sketch showing the groundwater and surface water interaction

2.5.1 Process Driven by Groundwater

River stream reduction caused due to pumping is explained as the decrement of water flow due to the induced incursion of river channel water into the groundwater or the capture of groundwater expulsion to the river channel (Theis, 1941; Sophocleous, 1997). The situation of river-aquifer interface is connected to proper-use water management of reservoirs and hydrology of the riparian zone (Hantush, 2005). This notion is applicable only to river water channels linked to the underground surface through a fully saturated substance. Groundwater pumping close to rising streams impacts water availability, quality, and quantity of water, and water supply management. The environmental effects of stream reduction are quite significant in low lying river channels (Hunt, 2003). While pumping out, groundwater starts to decline, and the cone of depression is succeeding towards a close river channel. The start of stream depletion is marked by the infiltration of surface water (stream/river or runoff) into the aquifer because when the depression cone touches the stream, the amount of groundwater discharge to the river channel decreases. Due to long periods of continuous pumping, the cone of depression attains its ultimate figure. The quantity of pumping balanced by river channel reduction in the steady-state situation will rely on a number of aspects, such as the nearness of the borehole to the river channel as compared to the length between the bore and other points and diffused groundwater recharge sources. Stream reduction in the case of leaking aquifers partly supports groundwater removal from a pumping well (Zlotnik, 2004). Some of the more important impacts that may affect flow reduction include the flow stoppage through the aquatic aquifer hydraulic conductivity contrast, flow partial osmosis, and aquifer heterogeneity quantification. The time taken to the reach steady state is essentially noted. Glover and Balmer, (1954) provided an analytical solution which is utilized in order to point out the time frame for aquifer (groundwater) and river (surface water) decrease when pumping is carried out.

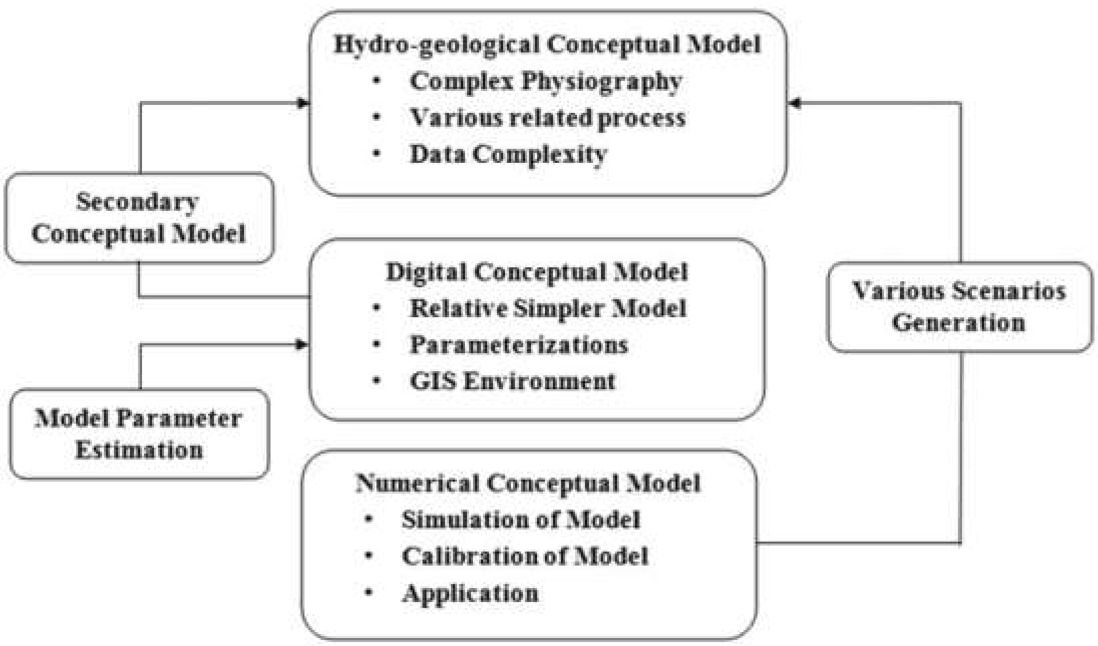

Figure 2.3 Process of the groundwater and surface water interactions

Sophocleous et al. (1995) used mathematical model (MODFLOW) (McDonald and Harbaugh, 1988) to determine the precision of the surface and sub-surface interactions solutions; the three most significant aspects analyzed, which refer to the multidimensional behavior of the flow conditions of the aquifer are:

(1) Congestion of stream-bed as specified by river-aquifer hydraulic conductivity contrast;

(2) Degree of partial channel penetration; and

(3) Aquifer is diverse in character or content.

It was finally agreed that some serious effort should be done to enumerate with appropriate precision the surface and sub-surface hydraulic conductivity contrast. Figure 2.3 shows the process of groundwater and surface water interactions in the flow chart manner. It considers the whole process into three conceptual models. The first one is the hydro-geological conceptual model, second is a digital, conceptual model, and the last one is a numerical conceptual model. Under each conceptual model, there are various processes which affect the groundwater and surface water interactions. Parameter estimation and creation of various scenarios is also an essential part of the modeling. In various scenarios, results come out differently, and the model behaves differently when changing in the parameters.

2.5.2 Processes Driven by Surface water

2.5.2.1 Overland Flow and Through-Flow

The flow pathways of the basin that consist of straight rainfall, through-flow or shallow sub-surface flow, overland flow, and groundwater flow greatly influence the channel flow response to rainfall. The water that moves above the surface either in the form of quasi-laminar flow or as flow connecting the streams in the surface, while inter-flow can be related to the sub-surface flows that move tangentially to the (small) streams via sub-surface, is described as Overland flow (Ward and Robinson, 1967). ‘Quickflow’ is known as the accumulation of channel precipitation, rapid through flow and overland flow. Spatial deviation in vegetation, surface topology, geology, and characteristics of soil, influence the overland flow (Jenkins et al. 1994). When the infiltration capacity of the soil is lower than the rainfall intensity, overland flow is said to occur (Horton, 1933), or it occurs when soil becomes saturated and low lying storages are filled, leading to descending hill flow (Hewlitt, 1961). Wardlow et al. (1994) done an integrated-basin management model study on the River Allen and separated the overland flow, surface flow, groundwater flow, and interflow (through flow).

Interflow and surface runoff was combined by Kunkel and Wendland (2002), in the study of river Elbe of the water balance in the long term. Studies by Muller et al. (2003), define that hydrological processes such as rainfall interception, depression storage, evapotranspiration, infiltration, etc., using hydrograph separation techniques, come together all sub-surface processes into a single 'base flow' module. Studies where quantification of interflow is important, models such as TOPMODEL (Moore and Thompson, 1996; Walter et al. 2002) are utilized in order to forecast shallow interflow of perched groundwater.

2.5.2.2 River Flow Attenuation

Redistribution of river flow hydrographs at some interval points along a stream proves that the storage effects of water in the rivers control the passage of flow events. Declining in maximum flows and an increment in a time lag results in the hydrograph attenuation. According to Pilgrim (1987), it is dependent on the total volume of the flow event as compared to the storage volume, and also on some variable factors of the system such as hydraulic resistance, stream flow, and slope. Another important term related to this phenomenon is 'Flow routing.' It can be defined as the determination of the timing and flow magnitude at various points along the river channel from known upstream hydrographs.

2.5.2.3 In-Stream Storages

When explained in terms of channel flow events, enhancing the in-channel storage increases the stream flow attenuation, i.e., it results in increased time-lags and decreases peak flow. Pilgrim (1987) described various other methods along with the Level Pool method. These methods are used to estimate the model of the effects of in-stream storages on hydrographs. The process of determining the effect of inflow storages on the river aquifer exchanges, rather than the flood hydrology, of a stream, is complicated (Smakhtin, 2001). Levitt et al. (2005) recently explored the effect of inflow expansion on the mixing or exchange of river (surface water) and aquifer (groundwater) in the Los Alamos Canyon. In order to enhance recharge to the surrounding aquifers, in stream storages are constructed; the fluxes so obtained are known as ‘artificial recharge’ (Abu-Taleb, 2003). Shaw (1988) and Eichert et al. (1982) gave a general overview of reservoir operation. In several cases, mixing between groundwater and reservoir is incorporated in the analyses of reservoir operation, and the recharge of groundwater as a result of leakage through reservoir can greatly impact the subsurface hydrology and further impact interactions between river and aquifer (Joeckel and Diffendal, 2004; Dassi et al. 2005; Karamouz et al. 2003; Dawoud and Allam, 2004).

2.5.2.4 Off-Stream Storages

Almost all reservoir and embankments undergo seepage, either through the base of the reservoir and abutments or through the bank itself in the case of rock-filled or earth reservoirs (US Army Corps of Engineers, 1993). Certain studies analyzed the effect of seepage from off-flow storages water on both groundwater–surface water mixing and groundwater hydrology, although Ruiz and Rodriguez (2002) had already described dynamic modeling of reservoir-groundwater interactions. Surface water embankments are used to boost up groundwater storage with the help of artificial recharge which is a result of reservoir leakage.

Water, in a different type of wetlands, is within either static or moving, fresh or algae water, brackish or saline. Bullock and Acreman (2003) find out about 6% of the world’s land area is covered by Wetlands, and their impact on the water cycle can’t be negligible. Winter et al. (1998) explained that the main propeller of wetland hydrology is: rainfall, evapotranspiration from various sources, and exchange of surface water and groundwater. Mainly the inflow of water into the wetlands is from rainfall, continuously seepage into the river, overbank floods, and inflow of groundwater; whereas the outflows comprises of evapotranspiration, effluent seepage from the river, groundwater outflow and surface runoff (Andersen, 2004). Todd et al. (2006) stated that inside the groundwater flow system, Wetland hydrology is greatly influenced by their position and order. The interchange of water between wetlands with groundwater and surface water are also impacted by the geologic features of their soil beds, and the behavior of the weather (Winter, 1999).

However, despite these ongoing advances in the field of numerical models, modeling practices are still needed more research to integrate and incorporate the complexity of the interaction of groundwater and surface water. In the interaction of groundwater and surface water, river bed performs the major role, and it is greatly simplified and simulated as static and homogenous (Sophocleous, 2002; Partington et al. 2017; Irvine et al. 2012).

2.6 Summary

All of the above studies suggested that for the sustainable management of the groundwater resources, study of river-aquifer (R-A) interactions is needed. As of now, for the Varanasi and adjoining area this type of study has not been done yet, even there are evidences of the river (Ganga) and aquifer exchanges for the area. Therefore, this study is very important for developing a sustainable plan for better utilization of the available groundwater and surface water resources in the area.