CHAPTER 2

LITERATURE REVIEW

2.1-Introduction

Agriculture is a foundation in Indian Economy (Kumbhar and Singh, 2013). In India, large canal irrigation projects account for over 35 million hectares (m ha) of irrigated area. Of this, about 30mha were created after 1951, during successive Five Year plans. Groundwater was the main source of irrigation in these areas prior to the introduction of canal irrigation. It continues to be so in several areas even after the introduction of canal irrigation even though this factor was not considered explicitly in the design of canal irrigation systems.

Irrigation systems have been under pressure to produce more with lower supplies of water (Levidow et al., 2014). Various innovative practices can gain an economic advantage while also reducing environmental bur-dens such as water abstraction, energy use, pollutants, etc. (Faurèsand Svendsen, 2007). In recent years there has been considerable emphasis on integrated management of surface and groundwater resources in irrigation project areas to augment the canal supplies and to increase agricultural productivities. Integrated framework also controls ground water depletion, water logging, and soil salinity (Rosegrant and Svendsen, 1993; Water Technology Centre, 1998).

Agriculture has undergone several fundamental changes during the past century. Soil, water, labour resources, climatic scenarios and crop management practices are important components of sustainable agriculture (Ready and Rao, 1995). With the involvement of such biological, chemical and physical processes the agriculture production and processing systems have become more complex (Heinemann, 2010).

Ground water development is being done without adequate understanding of the balance between its occurrence (in space and time), replenishment (through recharge) and its impact on the environment, depletion of water levels in aquifers and decline in design yield of water wells. (Shah et al., 2000; Kendy et al., 2003; Pandey et al.,2011). Concerns for sustainable utilization of groundwater resources are growing in recent years (Douglas James et al., 1991; Duke U. Ophori et al., 1991; Shah et al., 2000; Hiscock et al., 2002; James McGhee al., 2004; Kretsinger and Narasimhan, 2005; Yueqing Xu et al.2005).

Groundwater sustainability may refer to the development and use of the resource in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences (Alley et al., 1999). The sustainability represents an optimal state; however, this is neither fixed nor constant but rather time and space dependent (De Carvalho et al., 2009).

Composite indicators representing the state of sustainable development (i.e. environment, economy and society), has been identified as a useful tool for policymaking and public communication on conveying information on groundwater situation and different sustainability index are developed by different researchers(Singh et al., 2009; Pandey et al., 2011). Groundwater infrastructures sustainability index developed by Pandey et al., 2011 considers five components viz groundwater monitoring, knowledge generation and dissemination, regulatory interventions, public participation and institutional responsibility which disaggregate into 16 indicators. The index is illustrated with Kathmandu Valley in Nepal as a case study.

2.1-Developed Models

A digital simulation model for groundwater basin of Mahi Right Bank Canal Project in Gujarat, is developed by S. K. Sondhi' et al (1989) in which the distribution of groundwater potential is determined by the use of specific empirical constants for estimating groundwater recharge from the surface water conveyance and distribution system. Only the annual assessment of ground water potential and its spatial distribution in study area after the construction of the canal has been done.

A lumped simulation model for Conjunctive Use of Surface and Ground Water Resources for Bagmati River Basin in Nepal has been developed by Pushpa Raj Onta et al.1991; to evaluate the alternative plans and policies, considering a number of mutually related synthetic sequences of stream flow and rainfall. Alternative plan are developed for indicating the system design (pumping and diversion canal) capacities and water allocation policies. Important policy and management implications are drawn from sensitivity analyses with respect to unit pumping cost, irrigation system efficiency, and recharge coefficient.

Linear programming-based optimization model has been used by many researchers to investigate a variety of water allocation problems. Linear programming is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. Latif et al. (1991) presented a linear programming-based conjunctive use model, applied for the Indus basin in Pakistan to maximize the net income of irrigators through cycles of wet and dry years over the long period. The model determines the optimal groundwater extraction for supplementing canal water to avoid adverse effects of high (water logging and salinity) or low (depletion and high pumping cost) groundwater level.

Conjunctive Water Use model developed to Control Water logging and Stalinization Salt distribution and transport in crop root zone are modeled by Douglas James et al., (1991), using the physical soil properties and mass balance. The main objective of this conjunctive-use study was to find the optimal ground-water extraction for stabilizing the water table at specific depths below land surface, while at the same time supplementing the surface irrigation supply. Salt distribution in the crop root zone is modeled and its effect on crop yield is also taken into account in the model. A daily crop water stress index is used to quantify crop yield reduction due to water stress over the growing season of a crop. Yield reduction due to salinity is calculated from the weighted average salinities (electrical conductivity) of applied waters.

In the conceptual model developed by P.K.Manumdar et al., 1991; for Ghataprabha sub in Krishna River basin for steady state condition and validated for both steady state and transient condition through USGS, 3D-Finite difference code, MODFLOW, various application were tried out on the calibrated model, like river-drain Influencing the aquifer, reasons for water logging and drying out of wells and well design strategies. Spatial aspect of water requirement and availability not considered.

Male et al. (1992) presented a dual-objective linear programming-based conjunctive use model, for the fixation of groundwater withdrawal permits, considering the use of groundwater without depletion of stream. Stream aquifer interaction was modelled using a linear lumped model, which uses stream depletion factor to represent basin characteristics. Peralta et al. (1995) developed a linear programming-based simulation cum optimization model to obtain the sustainable groundwater extractions over a period of five decades, under a conjunctive water use scenario. Running the model for five decades, considering potential increase in the water demand ensured sustainability of the groundwater, satisfying upper and lower bounds on the water levels in the aquifer.

In the MODSIM DSS developed by John W. Labadie et al.(1998) for a portion of the Lower South Platte River Basin, Colorado, MODRSP, a three-dimensional finite-difference ground water model is used for simulating spatially varied and time-lagged return depletion flows from stream-aquifer interactions. Results of the case study indicate significant differences between using ground water response coefficients developed from pre assigned stream depletion factor values, being used in the basin, and those generated using a finite-difference ground water model.

A groundwater balance model has been developed by Sethi et al.(2002) and applied to a portion of coastal river basin in Orissa State, considering mass balance approach. The groundwater balance of a basin was studied considering recharge from rainfall, irrigated rice fields, irrigated non-rice fields, base flow from rivers and seepage flow from drains and drafts through different groundwater structures like government deep tube wells, private shallow and medium deep tube wells. The linear programming model formulated for maximization of annual net return with optimal water and cropping pattern allocation considering the saline and non-saline soil type, rainfed and irrigated agriculture and the monsoon and winter seasons and the crops is found to be an effective tool for land and water resources allocation. All the assessments done are at basin level, spatial aspect within basin is not considered.

Barlow et al. (2003) presented a linear programming-based conjunctive management model to evaluate the tradeoffs between groundwater withdrawal and stream flow depletion for alluvial-valley stream aquifer systems representative of the north-eastern United States. Groundwater flow was simulated using the finite difference based program MODFLOW has been used (In a finite difference based program the assumption is that each directional velocity component varies linearly within a grid cell in its own coordinate direction. This assumption allows an analytical expression to be obtained describing the flow path within a grid cell. Given the initial position of a particle anywhere in a cell, the coordinates of any other point along its path line within the cell, and the time of travel between them, can be computed directly. While in the finite element method, a numerical technique is applied for finding approximate solutions of partial differential equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the partial differential equation into an approximating system of ordinary differential equations, which are then numerically integrated).Groundwater stream interactions were simulated using a stream routing package along with the MODFLOW. The objective function maximizes the sustained yield from the aquifer in a specified month for the given standard of stream depletion.

Yueqing Xu et al.(2005) developed a water balance model for the Hebei Plain in China, in conjunction with regression techniques (In regression technique a statistical procedure is used to find relationships among a set of variables. There is a dependent variable, and one or more independent variables that are related to it.) to estimate the groundwater recharge coefficient, specific yield, the groundwater withdrawn by different water use sectors and the corresponding drop in the water table. He determined the factors resulting in groundwater level decline and analyzes the impact of different land uses on groundwater table drawdown in order to develop a more practical plan to realize sustainable groundwater use in this region. Economic analysis on water economy benefit of crops is also performed and some alternatives to adjust cropping pattern to reach sustainable groundwater resources use are provided. Spatial water availability and requirement aspect not considered.

A three-dimensional transient groundwater flow model is used by Jaceb Scibek et al., (2007)to simulate three climate time periods (1960–1999, 2010–2039, 2040–2069) for estimating future impacts of climate change on groundwater–surface water interactions and groundwater levels within the unconfined Grand Forks aquifer in south-central British Columbia, Canada. The high-resolution (spatialand temporal) model is intended to capture not only the transient responses to river discharge and direct groundwater recharge from precipitation under the various climate change scenarios, but also the complex geometry of theaquifer and rivers. In addition, pumping wells and irrigation return flows during the peak demand period in the summer months are also considered.

A canal simulation model Icrop for Jaunpur branch sub basin a part of ghagra gomti basin of Uttar Pradesh has been developed by M/S SMEC International pty limited Australia in 2010,at micro sub basin level. Each micro sub basin is further subdivided in to four sub irrigation units depending upon the ground water levels. The developed I crop model is calibrated from Visual MODFLOW by giving recharge from Icrop and tallying from observed ground water levels. Similarly for runoff component it has been calibrated from drainage model IQQM and generated runoff values are checked from observed runoff values. After calibration and validation various management scenarios has been developed for different land use, rainfall, canal supplies and ground water levels at micro sub basin level to solve the water distribution issues along with change in gross margin levels. Here ground water model has been used only for calibration purposes. Actual three dimensional movement of ground water has not been considered for sustainability aspect at micro sub basin level.

Groundwater recharge and evapotranspiration through the vadose zone are of great importance for sustainable groundwater use and control of salinity and water-logging in arid and semi-arid regions with shallow water tables (Lerner et al.,1990; Arnold et al., 1993).However, the recharge and evapotranspiration are observed to vary with topography, soil type, land use, and water management practices (Xu *et al., 2012);*. Some reports have centered on improving irrigation efficiency to reduce ground-water pumping and suggested that it is imperative to practice economical irrigation, utilize water resources efficiently and develop water-saving agriculture (Zhao et al., 1995; Jin et al., 1999; Zhang et al., 1999, 2003; Wang et al., 2001; Yang et al., 2001).

Geographic information systems (GIS) have emerged as powerful tools for handling spatial data and decision-making in several areas including engineering and environmental fields (Stafford 1991, Goodchild 1993).Thus for sustainable agriculture management modern frontier technologies such as geographical information system (GIS) and process simulation models needs to be integrated. Decision makers may employ an integrated and interactive framework to solve unstructured problems.

2.3. Literature gap and motivation

Synchronization of seasonal water availability with demands is a water resources management challenge in many agricultural river basins (e.g. Camnasio and Becciu 2011; Pavelic et al.2012). Excess wet season river flow causes flooding, while low flows are often inadequate for dry season water supply. This results in conflicts between upstream and downstream users in transboundary rivers (e.g. Uitto and Duda 2002; UNDP 2006). Under a changing climate, seasonal extremes (Kundzewicz et al. 2010) and supply–demand imbalance (Immerzeel et al.2010) are likely to increase. One approach to managing water resources in such basins is upstream storage of excess wet-season river flow for use during dry season. This requires conjunctive-use management strategies (Coe 1990). Effective conjunctive use of surface water and groundwater results in a total annual system yield that exceeds the sum of the yields of the separate components (Bredehoeft and Young 1983).

Conjunctive use of groundwater and surface water already occurs in many UP canal irrigation areas, but not to full potential, largely due to lack of management (Garduño and Foster 2010). In these areas, unmanaged water use and the greater cost of groundwater compared to surface water creates interlinked management issues. Surface water is used preferentially in canal head areas where it is readily available,forcing farmers in canal tail areas to pump groundwater when surface water becomes scarce (World Bank 2010). The result is a reduction in crop yield due to rising water tables and soil waterlogging in canal head areas (Singh et al. 2012), whereas in canal tail areas, groundwater use is unsustainable and water tables decline over time (Gandhi and Bhamoriya 2011) resulting in increasing pumping costs.

The strategies require re-engineering of the river and canal systems, and significant changes in irrigation practices throughout the basin.The actual efficacy of the conjunctive-use management schemes considered would vary in the basin depending on local aquifer geology, the local nature of riverbed and surficial sediments, river stage, river geometry, topography, and other hydrologic, geologic, and anthropogenic factors. Implementation would require testing in pilot projects within limited areas. Observations made in such projects can provide direct information for improving design, perhaps by narrowing the possible range of hydrogeologic parameters and conditions for each local area and by improving the modeling analysis to provide more locally descriptive predictions of system response.

Groundwater serves as the main source of irrigation and is preferred over surface water irrigation for a number of reasons: groundwater is easily assessable and pumped due to shallow depth; pumping and operational costs are low; the Government has provided sympathetic treatment to farmers in the form of free tubewell installations in early 60'sand, later, a subsidized electricity policy. All these benefits have fuelled and stimulated groundwater irrigation.

Based on reports of CGWB and that of SGWD, Groundwater is a major source of water for agricultural and domestic requirements in western Uttar Pradesh. Due to increasing agricultural requirements the abstraction of groundwater has increased manifold in the last two-to-three decades. Although the area hosts potential aquifers these have been adversely affected by poor management. For effective groundwater management of a basin it is essential that a careful water balance study should be carried out.

Keeping this in mind groundwater flow modelling was attempted to simulate the behaviour of the flow system and evaluate the water balance. The alluvial areas of Uttar Pradesh have provided the most productive soils and aquifers in this district.The expansion of the irrigation network has brought about a spectacular increase in agriculture production in these areas over the last few decades.

In the western part of Uttar Pradesh, this has led to declining groundwater levels with detrimental impacts to groundwater resources and agricultural, domestic and industrial users. Long term groundwater level trends show an average decline of 0.88m/year (Umar 2008).

Previous hydrogeological investigations in the area were mainly carried out by Central Ground Water Board (CGWB) and Groundwater Department of Uttar Pradesh (U.P.) government. Khan (1992) and Kumar (1994) carried out systematic hydrogeological investigations in Muzaffarnagar district and studied the first group of aquifer.They identified a number of blocks that were under- and over-exploited. A water balance study using water table fluctuation and tritium method was carried out in parts of Yamuna–Krishni interstream area by Ahmed and Umar (2008). The result of this water balance study showed a negative balance and place the area in an ‘overexploited ‘category.

Aquifer modelling studies have been carried out in Krishni–Hindon interstream region (Guptaet al 1979) and Daha region (Gupta et al 1985). They have assessed the stream aquifer interaction as well as conjunctive use of surface water and groundwater in Daha region. Ala Eldin et al (2000) quantified the river–aquifer interaction in Ganga–Mahaba sub-basin. The study also supported a new canal system to be introduced to check declining groundwater level. No modelling studies were carried out in the study area.

In alluvium plains of Uttar Pradesh average annual rainfall is 900-1000mm and the excepted average ground water recharge is about 25%,that comes out to be only 225-250mm.After base flow from ground water reservoir, left water can hardy meet out two furrow irrigation requirements for prevailing agricultural practices in Uttar Pradesh. The rates of recharge and evapotranspiration are the most difficult and uncertain components to estimate in groundwater budget, and they often vary spatially and temporally. Alone annually replenishible ground water from rainfall can never meet out irrigation requirements for all the three seasons and other drinking and industrial requirements. It will always reach in overexploited category and ground water will start depleting and energy cost in lifting ground water will go on increasing and this will create extra overburden on small land holding farmers, thereby decreasing their gross margin for livelihood. Spatial sustainability of annually replenishible ground water resources is manageable only at field level by considering the actual land cover and using canal water in conjunction with ground water reservoir.

An integrated approach considering surface water and ground water is imperative at field level incorporating modeling output. Application of conjunctive use of surface and groundwater employed through Water Users Associations (WUAs) and Kulaba Samities by adopting Osrabandi and Dual Roaster can increase canal water use efficiency and arrest excessive depletion of ground water levels in tail canal commands.

2.4. Objective

The prime objective is development of integrated water resources management framework for canal command in a part of Indo-gangatic plains of Uttar Pradesh.

Specific objective of the Thesis are:

1. To investigate hydrogeology of Indo-gangatic plains of Uttar Pradesh in vis a vis study area.
2. Water availability and utilization in gomti basin.
3. Spatio-Temporal mapping of ground water for the study area using Arc GIS
4. Development of ground water simulation model for the canal command area.
5. Development of Integrated Model at distributaury level using soil moisture, rainfall runoff, system loss and ground water modules on GIS plateform

6. Development of Integrated Model at Kulawa command upto field level using soil moisture, rainfall runoff, system loss and ground water modules on GIS plateform