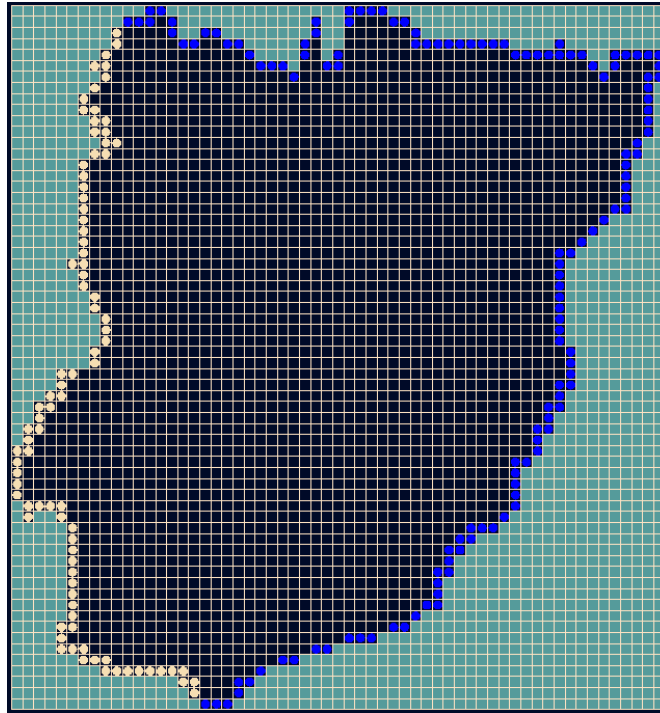


# REPORT

On

## The regional hydrological impact of agricultural water saving measures in the Gangetic plains



2019-2021

Groundwater Hydrology Division  
National Institute of Hydrology  
Roorkee – 247 667, Uttarakhand

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## Preface

Groundwater is the most important source of domestic, industrial and agricultural water supply in the world. The unplanned urbanization and industrialization has adversely affected groundwater resources both in terms of quantity and quality. Increased population and increasing demands for food in the Indo-Gangetic plains are likely to increase intensification of agriculture and more use of irrigation. The Indo Gangetic Plain has perhaps one of the most important water systems on the planet that accounts for 25 % of global groundwater abstraction. The middle Gangetic plain plays an important role in providing livelihood to millions from its dominant rice–wheat cropping system. Groundwater together with surface water is utilized in middle Gangetic plain for agricultural practices. One potential remedy for combatting the unsustainable use of groundwater is to use conservation agriculture techniques and other farm-scale water saving measures. Water-saving strategies viz. improved irrigation technology such as drip and sprinkler irrigation, reduction in conveyance system, mulching, conservation tillage, improved crop varieties have been proved to be effective to achieve substantial water-saving. The aim of this scoping study is to review the state of knowledge of agricultural water saving measures and their relation to the regional hydrology, particularly groundwater. The groundwater dynamics and interaction between surface and groundwater have been understood for the selected study area in middle Gangetic plain with hydrological data analysis and groundwater modelling.

This report has been prepared by Dr. Sumant Kumar, Scientist-D as Principal Investigator along with Mr. C.P. Kumar, Ex-Scientist-G, Dr. Archana Sarkar, Scientist-E, Dr. Surjeet Singh, Scientist-F and Dr. P.K. Mishra, Scientist-C with contributors from CSIRO, Australia, under the work program for the year 2019-2021 of the Groundwater Hydrology Division, NIH Roorkee.

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Many agricultural water saving measures have been in practice such as improved irrigation delivery technologies viz. drip irrigation; stopping seepage from water delivery canals; agronomic practices like zero tillage, minimum tillage, etc. Farm conservation practices affect the water accounting of watersheds and it is required to study what is the likely regional hydrological impact of agricultural water saving measures. To study the hydrological impact, it requires comprehensive data and its analyses.

This scoping study has been completed with the available and collected data from different Central and State department agencies. I thankfully acknowledge the data supports from Central Ground Water Board (CGWB), Ministry of Jal Shakti, Department of Agriculture, Govt. of Bihar and Minor Water Resources Department, Govt. of Bihar. The data and information obtained from different reports published by various organizations on this area are also duly acknowledged.

This study involved desktop analyses of data & interpretations, preparation of a number of maps in the ArcGIS framework and modelling GW system using Visual MODFLOW. I thankfully acknowledge the untiring services provided by Mr. C.P. Kumar, Ex-Scientist-G, Dr. Archana Sarkar, Scientist-E, Dr. Surjeet Singh, Scientist-F, Dr. P.K. Mishra, Scientist-C, Dr. Sreekanth Janardhanan, Senior Research Scientist, CSIRO Land and Water, Australia, Dr. Mohammed Mainuddin, Principal Research Scientist, CSIRO Land and Water, Australia. I also thank Mr. Nageshwar Rao, SRA, Dr. Ravi Saini and Mr. Vinod Kumar for their help and support. I duly acknowledge the guidance provided by Dr. M.K. Goel, Scientist-G & Head, GWHD for completion of the project. I also duly acknowledge CSIRO, Australia for collaborating in the project.

We are thankful to the Director, National Institute of Hydrology, Roorkee for providing all administrative and financial support for the successful completion of the project.

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## Abstract

Increased population and increasing demands for food in the Indo-Gangetic plains are likely to increase intensification of agriculture and more use of irrigation. The Indo-Gangetic plain has perhaps one of the most important water systems on the planet that accounts for 25 % of global groundwater abstraction. The middle Gangetic plain plays an important role in providing livelihood to millions from its dominant rice–wheat cropping system. Groundwater together with surface water is extensively utilized in middle Gangetic plain for agricultural practices. Conservation agriculture and other farm-scale water saving measures viz. improved irrigation technology such as drip and sprinkler irrigation, reduction in conveyance system, mulching, conservation tillage, improved crop varieties are being promoted as potential remedy for combatting the unsustainable use of groundwater. However, the impacts of these water saving measures depend on the definition of water savings, their scales, types of irrigation systems, and on the underlying geophysical conditions. The aim of this scoping study is to review the state of knowledge of agricultural water saving measures and their relation to the regional hydrology, particularly groundwater. The Bhojpur district, Bihar located in middle Gangetic plain has been selected for the study. The objectives of this study are: (i) a review of agriculture practices and agricultural water saving measures and their impact on groundwater resources; (ii) trend analysis of groundwater level data to understand recharge and discharge processes; (ii) to study surface water and groundwater interaction based on the available and monitored data.

The scoping study was mainly based on a desktop analysis using existing hydrological, meteorological and agricultural data etc. A review of literature was done to study the existing agricultural practices including irrigation in the study area. Various thematic map such as drainage, geological, depth to water level, land use and land cover (LULC) map for the study area were prepared. Trend analysis of groundwater level was carried out using Mann- Kendall (M-K) test. Based on the available data, a coarse groundwater modelling using ‘Visual MODFLOW Flex’ was attempted to study the SW-GW interaction in the study area. The Bhojpur district is covered by two major rivers viz., Ganga and Son in the north and eastern side. The population of the district is 27.20 lakh with population density of 1136 inhabitants per square kilometre. The major Kharif crops in the district are rice, maize and gram etc and major Rabi crops are wheat, pulses, gram, mustard, potatoes etc. The geographical area is 2,33,729 ha out of which 1,88,134 ha is net cultivable area. The net irrigation area in Kharif season is 1,00,407 ha and in Rabi season it becomes 68,781 ha. The study area has warm and

humid climate. The maximum temperature of the district is 39°C during the month of May, whereas minimum temperature decreases up to 6.3°C during the month of January. The monsoon starts in the month of June and continues up to September. The normal rainfall of the district is reported to be 1,080 mm/yr and the annual rainfall varies from 1,025 mm to 1,106 mm. The monsoon period receives about 85.6% of the total annual rainfall and the rest is received in the non-monsoon period (November-May). The land use and land cover (LULC) classification showed that vegetation (46.13 %) followed by built-up area (21.64 %), fallow land (16.52 %), barren land (7.37 %), sand bank (6.08 %), water (2.26 %) are the major types of land uses/covers. The analysis of groundwater level data collected from Central Ground Water Board (CGWB) revealed that depth to water level varies from 3.0 to 9.0 m bgl (year, 2018) in the study area. The M-K test shows that there is no significant declining trend of the groundwater level in the study area. A coarser transient groundwater modelling was attempted with relevant data collected and making certain assumptions. The model was calibrated and validated for 2 years with four stress period each year. The results revealed that groundwater head is higher in southern part in comparison to northern part of the study area and groundwater is contributing to the Ganga River. The groundwater head fluctuation is 2 m from 1<sup>st</sup> stress period (monsoon season) to 4<sup>th</sup> stress period (pre-monsoon season). It was also observed that groundwater is contributing more in monsoon season to the river in comparison to non-monsoon season. The impact of reduction of pumping (GW withdrawal) on GW heads was also investigated. The 10 % reduction in groundwater withdrawal was assumed in all stress periods of a year. It was observed that the groundwater head is showing similar pattern as it shown during calibration and validation period. However, the groundwater head rises upto 2 m in the southern part of the study area and groundwater head rises upto 0.2-0.5 m in middle and northern part of the district.

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## 1.0 Introduction

India has around 17% of the world's population with just 4% of the world's freshwater resources. The distribution of these water resources throughout the huge area of the nation is extremely unequal. The increasing demand for water resources by India's escalating population, the deteriorating condition of existing water resources due to pollution, and the additional requirements of serving India's industrial and agricultural growth have resulted in a situation in which water consumption is rapidly increasing while freshwater supply remains more or less constant. India is experiencing a prolonged water deficit as a result of a weak water resources management system and due to climate change. According to Tata Institute of Social Sciences (TISS) surveys, most metropolitan centers are already water-stressed. Groundwater provides over 40% of the water demand in metropolitan India. As a result, groundwater tables in most cities' are dropping at an alarming pace.

Globally, groundwater supplies around 40% of irrigation water and in India it is expected to be more than 50% (Dhawan, 2017). It has been observed that in developing nations, groundwater is relatively difficult to monitor and manage due to its common pool character and also faced difficulty in directly inspecting it. Moreover, the unsustainable extraction levels that surpass natural recharge rates are depleting groundwater supplies (Kumar et al., 2021). Groundwater irrigation accounts for more than half of all irrigated land in India (around 42 million ha). The authorities in India are working together at the federal, state, and municipal levels for sustainable water resources management. The Central Water Commission (CWC) aims to promote integrated and sustainable development and management of water resources via the use of cutting-edge technology and expertise in coordinating all stakeholders. They are strengthening a reservoir monitoring system, real-time water quality monitoring, flood forecasting, river basin management, watershed development, and the revitalization of significant concerns, among other things.

In India, the Central Ground Water Board (CGWB) was established to develop and disseminate technologies for monitoring and implementing policies for scientific and sustainable development and management of groundwater resources, such as exploitation, assessment, conservation, augmentation, pollution prevention, and strategy based on economic and ecological efficiency and equality. The CWC and CGWB have developed "General Guidelines for Water Audit and Conservation" in the country. These guidelines have been shared with all

state governments, pertinent central ministries, and other utilities department to develop their own unique recommendations. Some state governments, such as Punjab (Northern India), provide free power for groundwater pumping. Solar pumps are heavily subsidized in states such as Gujarat and Maharashtra (both in Western India). A significant subsidy on water sprinklers/drip irrigation systems has been provided to increase water consumption efficiency. Several regions of the nation are constantly subjected to acute water stress. These include districts in South and North Interior Karnataka (Southern India), Rayalseema in Andhra Pradesh (Southeastern India), Vidarbha and Marathwada in Maharashtra (Western India), Western Rajasthan and the Bundelkhand area of Uttar Pradesh (Northern India), and Madhya Pradesh (Central India). Low and unpredictable rainfall in these regions for several years has made water-harvesting infrastructure unutilized and conservation measures nearly impossible to implement. There is a lack of drinking water due to the diminishing level of reservoirs' water storage. Punjab, Uttar Pradesh and Uttarakhand are some states having the highest dependency on groundwater for irrigation with the contribution of 79%, 80% and 67% respectively. In 1992, the Panchayati Raj system (PRC) was established as local administration in India. It is a three-tiered structure that comprises elected authorities at the village, taluk, and district levels. Different strategies have been proposed by the federal and state governments to increase irrigation and water usage efficiency. At the local level, these PRC performs a variety of duties connected to the growth of agriculture, including decisions about irrigation services.

Despite growing scarcity, India's groundwater irrigation is still inefficient from a technological standpoint. For example, according to India's third Minor Irrigation Census, barely 3% of India's 8.5 million tube-well owners employed drip or sprinkler irrigation in 2001, while 88 percent flooded their crops through open channels. According to the CGWB-2020, India's total annual replenishable groundwater resource is roughly 436 billion cubic meters (BCM), with 398 BCM of net annual groundwater availability, of which India withdraws 245 BCM (62%) yearly. Moreover, around 39% of the wells show a decrease in groundwater level. Out of the country's 6,965 assessment units, 1,114 units have been labelled as "overexploited" due to the stage of groundwater depletion and long-term reduction in groundwater levels. Aquifers in impoverished, heavily inhabited areas, like North-West India, are particularly stressed. The Indus River Basin, which India and Pakistan share, contains the world's second most stressed aquifer. In India, debates are being cantered on how to reform irrigation departments so that they may become competent to enhance the water supply process. Understanding best practices from other nations as well as India's own community-based intervention models can assist

current policymakers and planners in improving governance structures and understanding critical indicators that can aid in data-driven decision-making.

The middle Gangetic plain (MGP) region is one of the most significant eco-regions which form the core portion of the Indo-Gangetic plains (IGP) (Timsina and Connor, 2001). Because of its dominating rice-wheat farming system, the MGP provides a living for millions of people there (Subash et al., 2015). However, with the growth of population, it is now imperative to increase the production of rice. In the MGP, several obstacles hinder the implementation of the critical measures that boost food productions. Some key concerns are a decrease in net cultivated area, a decrease in irrigation water availability, and an increased strain on soil fertility (Stevenson et al., 2013; Kabir et al., 2015). The challenges in agriculture are likely to increase the production while considering or protecting the natural resources (e.g., forests, croplands, water) for future generations (Hobbs et al., 2008). Moreover, agricultural development in the IGP has led to concerns over falling groundwater tables and the implied unsustainable use of groundwater, and hence exaggerate the concern about the availability of water for irrigation in the future. In the MGP, dry season irrigation and falling groundwater tables are typically not causing worry as of now. However, increased population and increasing demands for food in the region are likely to see an intensification of agriculture and more use of irrigation.

The use of conservative agriculture techniques and other farm-scale water-saving measures, are the potential remedies that are known for combatting the situation of unsustainable use of groundwater. But does this really save water at the regional scale? The studies of Ahmad et al. (2007) and Perry et al. (2017) give a piece of evidence that it may not. With the above in mind, there are significant gaps in our knowledge of the water balance in the middle Gangetic plains, and the likely consequences of changes to the regional hydrology that might result from changes such as increases in water use, implementation of farm-scale water-saving measures, and climate change. This report aims to review the state of knowledge of farm scale water-saving measures and their relation to regional hydrology, particularly groundwater in the middle Ganga river plain region of India. It is also attempted to analyse hydrological data and develop coarser groundwater model to study the surface water and groundwater interaction based on the available data.

The objectives framed under this scoping study is as follows:

- i. A review of agriculture practices and agricultural water saving measures and their impact on groundwater resources.
- ii. Trend analysis of groundwater level data to understand recharge and discharge processes.
- iii. To study surface water and groundwater interaction based on the available and monitored data.

## 2.0 Literature review

### 2.1 Water use in agriculture

In many parts of the world, including India, agriculture is expected to face great challenges in the coming decades in increasing food production for the growing population. The sustainability of agricultural productivity is threatened in many regions of the world by environmental and socio-economic factors, such as (i) depletion and/or degradation of natural resources (e.g., water, soil, forests), (ii) low input-use efficiency (e.g., water, energy, fertilizers, pesticides, labor), (iii) environmental pollution (e.g., soil, water, air), (iv) changing climate, and (v) increasing scarcity of farm labor (Hira, 2009; Humphreys et al., 2010). Water is the most important component in agricultural production, and irrigated agriculture is the world's largest user of fresh water, accounting for over 70% of total consumption. Without additional increases in water productivity or significant modifications in production patterns, the quantity of water required by crop agriculture is expected to rise by 30% by 2030 (Parry, 2012) and 70% - 90% by 2050 (Gleick and Heberger, 2014). However, the increasing rivalry for water among diverse industries would have an impact on farmers' capacity to increase the production of food. As a result, keeping the food production sustainable while preserving declining water sources will be a major issue in the future (Leemans & De Groot, 2003), particularly in heavily populated areas like the MGP.

The MGP is seen as a global priority for sustainably boosting food production. A tropical monsoon climate, with a hot, humid, and rainy summer and a dry winter dominates the Ganges basin (Sanderson and Ahmed, 1979). Due to insufficient surface water during the primary cropping season, groundwater is critical to sustaining agricultural output in many irrigated locations across the world, including MGP. Groundwater extracted from the alluvial aquifer system accounts for almost one-quarter of total global groundwater abstraction (Siebert et al., 2007) and contributes to South Asia's agricultural output (Shah, 2009). The Indo Gangetic Plain is one of the most important water basins in the world, accounting for 25% of global groundwater abstraction (Fendorf and Benner, 2016). As a result, India has overtaken the United States as the world's largest user of groundwater (Aeschbach-Hertig and Gleeson, 2012), with groundwater accounting for 60% of total agricultural water demand and more than 50% of the total irrigated area (Shah et al., 2003). Over the last 50 years, groundwater abstraction in the Indian subcontinent has increased from 10–20 km<sup>3</sup>/year to roughly 260

km<sup>3</sup>/year (Shah et al., 2003; Giordano, 2009). Irrigated rice is the most significant crop in the MGP, which is mostly farmed in permanently moist conditions. Due to the high input water requirement of this typical puddled transplanted rice, irrigated agriculture is putting pressure on the region's limited freshwater supplies (Li et al., 2011). As a result of unsustainable extraction levels that exceed natural recharge rates, groundwater supplies are depleting in many parts of the world (Wada et al., 2010, Famiglietti, 2014, Aeschbach-Hertig and Gleeson, 2012). Furthermore, increased groundwater use may cause a drop in groundwater level below which extraction may no longer be economically viable, resulting in a variety of environmental problems such as saltwater intrusion (Ahmad et al., 2002), deterioration of water quality due to arsenic contamination, and drying up of soil moisture for perennial trees. Land and water system intensification must account for a major share of the increased food output (FAO, 2003; Khan et al., 2006). Reducing the use of agricultural water might be a viable and promising approach towards groundwater depletion (Hu et al., 2016). The organic matter in the soil boosts the water-holding capacity of the soil. Conservation agriculture, as an organic matter-enhancing technique, can increase soil water-holding capacity. It can boost the possibility for quick rainwater collection by decreasing bulk density and boosting porosity and aggregation in the surface of the soil. As a result, the possibility for water runoff and evaporation is reduced, resulting in more water remains in the soil. Hence, conservation agriculture makes more availability of water for plant use and improves the efficiency of system precipitation use (Shaver et al., 2002). The increased soil-water content after zero-tillage than under conventional tillage suggests less water evaporation loss during the prior time (De Vita et al., 2007).

Across the crop growing season, some researchers discovered a 20% increase in soil-water content with zero-tillage over traditional tillage. Based on limited scientific data and farmer experience, zero-tillage planting can save a significant amount of irrigation water and fertilizers. According to Kahlow et al. (2006), the implementation of resource-saving methods such as zero-tillage, laser leveling, and bed and furrow planting can reduce irrigation water usage by 23 to 45 percent while boosting crop production. In this line, the study of Farooq et al. (2007) revealed that farmers who implemented zero-tillage methods in Pakistan's Punjab have saved irrigation water by 5–15 percent while achieving comparable yields to traditional agricultural techniques. In the literature, there are also contradictory outcomes described. According to a study of multiple research (e.g., Gupta and Seth, 2007; Jat et al., 2009; Humphreys et al., 2010; ADMIT, 2012), laser land leveling in India can cut irrigation water

application by 25% and boost wheat output by 30% when compared to conventional approaches. Direct-seeded rice has several advantages to transplanted puddled rice, including labor savings (40–45%) and irrigation water savings (30–40%) (Mohammad et al., 2018). However, while direct dry seeding of rice on flat and raised beds saves a significant amount of water, it has a detrimental influence on yield (Choudhury et al., 2007; Humphreys et al., 2010). Farmers' habitual practice of puddled transplanted rice, alternating wetting and drying water management for rice, rice straw removal, and tillage for wheat resulted in 390 mm greater irrigation input than conservation agriculture in the Indo-Gangetic Plain (Jat et al., 2019). As a result, crop-water production rose from 11.3 to 11.7 kg/ha/mm. These researchers also discovered that rice-maize systems with the use of a permanent bed and zero-tillage have reduced 10.6 percent to 21.8 percent total water (irrigation+ effective rainfall) than traditional tillage. According to their findings, conservation agriculture based on a permanent bed and zero-tillage boosted system-water production by 27.1- 57.4 percent and 39.4 -68.3 percent, respectively, when compared to conventional tillage. As a result, conservation agriculture-based management (zero-tillage and permanent bed with partial residue retention) in the rice-maize production system offers a feasible alternative for producing more crops with less water. This can assist in fulfilling the demand for food in the future while also raising agricultural revenue on a long-term basis to benefit poor farmers in the Indo-Gangetic Plain (Dutta et al., 2020). However, Humphreys and Gaydon (2015b) observed that switching from conventional to conservation agriculture can only cut evapotranspiration by 4% (55 mm) annually in the highest yielding system and much less in other existing practices. Growing short-duration rice varieties in both farmers' ordinary practice and conservation agriculture systems is a practical approach to accomplish a significant reduction in evapotranspiration. However, with the existing short-duration cultivars, this may be accomplished at the expense of both rice and system yields (Humphreys and Gaydon, 2015b).

## **2.2 Water losses in agriculture**

The requirement of water for growing rice crops comprises of water required for land preparation, natural losses from the field (e.g., surface evaporation, percolation), and consumptive use by the plant (Zawawi et al., 2010). Rice agriculture in the Gangetic plain is traditionally done by puddling, followed by (manual) transplantation of rice seedlings and subsequent flooding of the fields with irrigation treatments. In the MGP and Southeast Asia, this approach is very common. Only around 100–250 mm of water is necessary for puddling,

depending on soil texture (Yadav et al., 2011a, b). Puddling has various advantages in rice cultivation, including weed control, ease of transplanting, and reduced water loss through percolation in the field. Water requirement of rice varies based on climate, soil, crop, and adopted water management practices. Because of the tradition of keeping rice fields ponded for extended periods, as well as the mainly porous character of the soils, significant volumes of deep percolation, irrigation application to rice in South-East Asia far exceeds that required to fulfil evapotranspiration requirements (Ahmad et al., 2014).

In times of over-irrigation and excessive rainfall, water is lost from farmers' fields by transpiration via plants, evaporation from the soil, or water resting on the soil surface, percolation beyond the crop root zone, seepage, and surface runoff. Thus, the water used in irrigation goes to one or more of the three classes (Perry et al., 2017): (i) consumptive use that comprises beneficial consumption (e.g., crop transpiration, evaporation from croplands) and non-beneficial consumption (e.g., evaporation from free water surfaces and non-crop lands, transpiration by weeds), (ii) non-consumptive use that comprises recoverable flows (e.g., returning to a river or aquifer for potential reuse) and non-recoverable flows (e.g., flowing to saline/polluted aquifer or sea or other economically unviable sinks), and (iii) change in storage.

### **2.3 Water resource-conserving technologies**

Water, energy and food securities are very closely interlinked; an integrated approach is required for their management (Gain et al., 2015). However, until recently, these issues were only considered in isolation (Bazilian et al., 2011). However, it is increasingly critical to create technology that may minimize energy, labor, and water usage, as well as pollution, while simultaneously improving soil physical, chemical, and biological qualities and preserving or increasing yields (Carrijo et al., 2017). Conversion of conventional agriculture to conservation agriculture is of particular interest in this regard (Giller et al., 2009; Hobbs et al., 2008; Jat et al., 2012). As a result, in South Asia (Masih and Giordano, 2014) and elsewhere, boosting crop yield with limited water resources is bringing increased attention to Resource-Conservation Technologies including zero/minimum tillage, laser field leveling, and furrow bed planting. The most promising solutions for water-saving for rice cultivation include delayed rice transplanting, switching to shorter-duration rice varieties, and switching from continuous flooding to alternate wetting and drying (AWD) water management (Humphreys et al., 2010). So, water-saving technologies that can reduce water loss from diversion canals and irrigation

fields with the potential to increase water use efficiency (Zhang et al., 2012) are now spreading rapidly to sustain agricultural production.

### **2.3.1 Conserving agriculture practices**

Conservation agriculture (CA) was created in response to worldwide concerns about the sustainability of agriculture (FAO, 2012). It is based on the principles of soil restoration, crop input optimization, food sustainability or improvement, and profit maximization (Islam et al., 2019). CA entails the use of three interconnected principles: i) no or minimal mechanical soil disturbance through conservation tillage (e.g., reduced, minimum, or zero-tillage), (ii) biomass mulch soil cover, and (iii) crop diversification, as well as a few complementary good agricultural practices of integrated crop and production management (Kassam et al., 2019). Under the no-tillage system, a crop is planted straight onto a seedbed that has not been tilled since its first preparation in the preceding crop season. To prevent soil erosion caused by water, conservation tillage leaves at least 30% of the soil surface covered with crop residue after planting (CTIC, 2004). The application of resource-conserving technologies can reduce field-scale irrigation and fertilizer application; increase crop diversification; improve resource use efficiency; reduce labor shortages, energy use (fossil fuels and electricity), greenhouse gas emissions, soil erosion, and degradation of natural resource base; and increase yields and farm incomes (Jat et al., 2009; Nangia et al., 2010; Pandey et al., 2012; Saharawat et al., 2012; Bhan and Behera, 2014). The zero-tillage farming strategy produces larger yields at a reduced cost while also being an ecologically beneficial approach that conserves water and soil (Gupta et al., 2002; Hobbs et al., 1997; Hobbs and Gupta, 2003). However, the primary motivation for farmers to embrace this approach is monetary gain and labor savings (Erenstein et al., 2008). Nevertheless, achieving water-saving by conserving water is being increasingly felt. The currently practiced irrigated rice-wheat system in some parts of the Ganges basin has become unsustainable due to over-exploitation of groundwater. The zero-tillage farming strategy produces larger yields at a reduced cost while also being an ecologically beneficial approach that conserves water and soil (Gupta et al., 2002; Hobbs and Gupta, 2003). However, the primary motivation for farmers to embrace this approach is monetary gain and labor savings (Erenstein et al., 2008). Other water-saving methods, such as laser leveling, have lately been used by certain farmers in North-West India (Jat et al., 2009). Experimental data from the North-Eastern section of India reveals that conservation agriculture-based management provides some immediate benefits as well as some long-term benefits (Bhushan et al., 2007;

Parihar et al., 2017). Rice-maize systems using CA-based management approaches to increase system production (Gathala et al., 2015), maintain soil health and environmental quality (Singh et al., 2016), and reduce irrigation water and labor costs (Parihar et al., 2017). Conservation agriculture and crop diversification or intensification are increasingly seen as critical components of new agricultural systems in South Asia for maintaining food security (Jat et al., 2014; Islam et al., 2019).

Conservation agriculture has been practiced for the last three decades and the principles of conservation agriculture are now increasingly being recognized as essential for sustainable agriculture. Various resource-conservation technologies are being developed continually and are gaining favor in many regions of the world as an alternative to both conventional agriculture and organic agriculture, particularly in rice-growing (PARC-RWC, 2003; Mujeeb-ur-Rehman et al., 2011). The expansion of zero-tillage wheat in the rice-wheat system is occurring throughout the IGP where rice-wheat farming systems predominate (Bhan and Behera, 2014). The impacts of conservation agriculture on soil qualities vary depending on the method used, the kind of soil, the meteorological circumstances, cropping history, and other factors (Mahboubi et al., 1993; Halvorson et al., 2002). As a result, the published research on soil characteristics and crop performance under zero-tillage systems is uneven and often conflicting. Zero-tillage systems retain high surface soil covering with biomass mulch and result in soil property change; the change is noticeable in the topmost few centimeters (Anikwe and Ubochi, 2007). Soils subjected to zero-tillage with residue retention become more stable and less prone to structural degradation, whereas soils subjected to conventional tillage are more prone to erosion (Verhulst et al., 2010). As a result, soil physical qualities are often better with zero-tillage systems than with traditional tillage systems (Lal, 1997). When compared to conventional tillage, the levels of organic matter, residue retention, and fertilizing matter are higher in soil under zero-tillage/minimum tillage (Dalal et al., 2011; Somasundaram et al., 2017). Soil organic carbon accumulates over time when no-tillage is used instead of traditional tillage, and when crop residues are retained rather than burned (Roper et al., 2013). Sinha et al. (2019) found that zero-tillage yielded more organic carbon at 0–15 and 15–30 cm profiles in Inceptisols and Entisols in the Eastern Gangetic Alluvial Plains than conventional tillage. The study of Singh et al. (2014) found that zero-tillage increased soil organic carbon to depths of 0.10, 0.15, and 0.25 m in sandy loam, loam, and clay loam soils, respectively, when compared to conventional tillage. This vertical distribution of organic carbon in different-textured soils suggests that it accumulates to greater depths as soil texture fineness increases. In general, zero-

tillage decreases soil pH as compared to traditional tillage methods (Somasundaram et al., 2017). Conservation agriculture uses a variety of organic resources, as well as crop rotation, to promote soil organic matter and maintain the continuity of soil pores. Soil organic matter enhances soil physical qualities such as aggregation, which affects other soil characteristics; well-aggregated soils with continuous pores increase leaching and accelerate soil acidification. (Sinha et al., 2019). Conservation agriculture cropping strategies produce more crop residue than conventional agriculture and lower the bulk density of field soils. However, in the short term, there is no obvious influence of crop management practices on bulk density. Verhulst et al. (2010) investigated the impacts of different tillage practices on soil bulk density over 10 years. The bulk density increases when crop residues accumulate on the soil surface; this impact is more pronounced in the 0–3 cm soil layer than in the 3–10 cm soil layer (Blanco-Canqui and Lal, 2007). Although zero-tillage minimizes plough pan formation, Singh et al. (2014) found a substantial increase in bulk density in the 0–5 cm soil profile in sandy loam and the 0–10 cm soil profile in both loam and clay loam soils. Zero-tillage soils have more stable aggregates on the upper surface of the soil and more crop residue than tilled soils. Under zero-tillage, this results in lower soil bulk density and high total and effective porosities within the top 5 cm soil profile (Shaver et al., 2002; Busari et al., 2015). The rise in overall porosity is coupled with considerable changes in pore-size distribution in the macropore class. In general, micro and mesoporosity are found to be greater in zero-tillage compared to conventional tillage. When compared to traditional ploughing, minimal tillage increased the soil pore system by increasing the number of storage holes (0.5–50 mm) and lengthened transmission holes (50–500 mm) (Pagliai et al., 2004). This can be linked to the long-term preservation of root and earthworm pathways under zero-tillage, whereas these are destroyed annually under conventional tillage. When bulk density increases, zero-tillage might result in a reduction of total pore space inside the plough layer. Many soil parameters, such as bulk density, porosity, sorptivity, and aggregation, influence soil infiltration. In addition to these, many additional elements impact infiltration in rice fields, including soil texture and structure, top and subsoil thickness, flooded water depth, water and soil temperature and salinity, groundwater table depth, and other topographical conditions (Wickham and Singh, 1978). The interaction of site latitude (associated with evaporation potential), landscape slope, and cropping system intensity affects the physical qualities of surface soil, which are also very crucial for water capture and infiltration (Shaver et al., 2002). Infiltration is greater with zero-tillage and crop residue retention and lower with crop residue burning and cropping (Roper et al., 2013). Water infiltration is greater with long-term conservation tillage (e.g., 8–10 years) than with

conventional tillage (Bissett and O'Leary, 1996). Because of the continuity of pores (Benjamin, 1993) or the movement of water via very few big pores, zero-tillage considerably enhances saturated and unsaturated hydraulic conductivity of soils (Allmaras et al., 1977). When compared to conventional tillage, the increased number of bio pores in conservation tillage leads to higher macropore conductivity and, as a result, higher hydraulic conductivity under zero-tillage with residue retention (Verhulst et al., 2010). Singh et al. (2014) also revealed that zero-tillage enhanced saturated hydraulic conductivity only to a depth of 10 cm when compared to conventional tillage. However, the results of much research on hydraulic conductivity are inconsistent.

### **2.3.2 Agricultural water-saving**

Any attempt to improve irrigation efficiency is regarded to be beneficial to conserve a significant volume of excellent quality water (Babajimopoulos et al., 2007). However, the word "water-saving" means different things to various individuals at different temporal and geographic dimensions (Dong et al., 2001). At the agricultural level, water-saving most commonly refers to a reduction in irrigation water applied to crops (Tuong and Bhuiyan, 1999). For a farmer, water-saving implies using less irrigation water to grow a crop, with the same or greater output. Many scholars have investigated how water consumption efficiency and water yield adapt to agricultural water-saving at the field size (Gowing et al., 2009; Mojid and Mainuddin, 2021; Rao et al., 2016; Zhou, 2009).

Saving irrigation water does not always imply a reduction in overall water usage (rainwater, soil water, and irrigation) at the field size (Humphreys et al., 2005). An individual farmer regards the combined outflow of water from the rice field due to evapotranspiration, seepage, and percolation as water consumption, and these components of the outflow constitute actual water losses for him/her. However, water conservation by one user may result in a loss for another. This occurs on a broader geographic scale when seepage and percolation from one field penetrate groundwater, streams, and drains, where it is reused by other farmers to irrigate other areas. Significant water savings are only possible when non-recoverable water losses are minimized or eliminated. If the underlying aquifer is salty or the water is discharged straight into the sea, the water savings are real. On the other hand, only a complete set of water accounts can show whether true water savings have been realized, allowing water to be distributed to other customers without causing harm. Water conservation in agricultural systems entails

limiting non-beneficial water losses that cannot be economically recovered elsewhere in the hydrological system. Evaporation from the soil and applied irrigation water, as well as deep percolation into water sources that are too contaminated for reuse (e.g., saline groundwater, seawater) or into locations where recapture is too difficult or expensive (e.g., aquifers with low transmissivity), are examples of non-beneficial losses (Humphreys et al., 2005). Reduced percolation beyond the root zone is expected to be the source of irrigation water savings, with no influence on evapotranspiration. However, decreases in irrigation application at the field size may not necessarily translate into significant water savings or decreases in water usage at the farm, cropping system, or watershed stages, particularly in places where root zone percolation may be reused as groundwater irrigation (Mainuddin et al., 2020; Masih and Giordano, 2014). In North-West India, groundwater is used to irrigate more than 90% of the key rice-wheat regions. Excess irrigation water seeps into the groundwater reserve, where it is extracted for reuse by the same or other farmers (Keller et al., 1996; Ahmad et al., 2002; Tuong et al., 2005; Rushton et al., 2020). The advent of large-scale surface irrigation has produced a substantial new source of recharge to groundwater in huge portions of the Indo-Gangetic plains, northern China, and elsewhere (Giordano, 2009; Rushton et al., 2020). The seepage from one area is usually regarded as a gain for the neighbouring fields, resulting in no net loss for the system (Huang et al., 2003). As a result, percolation and seepage from the soil-groundwater system may no longer be deemed lost or wasted water for water resource management (Ahmad et al., 2014). Reducing percolation will not save water nor reduce the rate of groundwater decline (Perry et al., 2017). Reducing non-beneficial evaporation losses is a true water-saving. Apart from this, optimal planting time of rice to avoid the period of highest evaporative demand and changing to non-ponded rice culture can save significant amounts of water (Humphreys et al., 2005). Delay in rice transplanting and the adoption of short-duration rice cultivars are the most promising strategies for minimizing evapotranspiration. Reduced percolation delivers substantial water savings in locations where groundwater is not appropriate for irrigation owing to excessive salt, as well as additional benefits like reduced waterlogging and secondary salinization. Water conservation is aided by factors such as water recycling and the interplay between non-agricultural and agricultural water users (Bouman et al., 2002). It is sometimes stated that only water saved by minimizing evaporation and flows to sinks constitutes a genuine saving at the basin size. On the other hand, Water-saving methods at the field size to lower supply to fields, may not always result in transferrable savings at the basin size. Some studies (e.g., Shah, 2014) believe that micro-irrigation reduces percolation by delivering the same total volume of water in more frequent but smaller amounts. This reduces the amount of return water

that may be used farther downstream. Despite the complications, the ultimate goals of water conservation are clear: to stop unsustainable overexploitation of surface and groundwater resources and to enhance the quantity of water available for non-agricultural uses (e.g., urban, industrial, fisheries, environmental, recreational).

Various water-saving irrigation systems have been developed in different rice-growing locations to maintain acceptable rice yields (Bouman et al., 2007a; Geerts and Raes, 2009). For example, a combination of a shallow water depth with wetting and drying (Liang et al., 2015; Mao, 2001), alternate wetting and drying (Ye et al., 2013), semi-drying (Prathapar and Qureshi, 1999), aerobic rice cultivation (Bouman et al., 2007a; Kato and Okami, 2011), partial root-zone drying (El-Sadek, 2014), moistening, non-flooded mulching (Zhang et al., 2008) cultivations, conveyance loss reduction through canal lining and piping, matching water-saving investments with higher value cropping systems, removing salinity constraints from farm to regional levels through efficient leaching of soils and promoting sustainable multiple uses of water (Khan, 2007) are popular techniques that have been adopted around the world. Saturated soil culture and alternating wetting and drying (AWD) can minimize in-field water losses significantly (Zaman and Gangarani Th., 2014). AWD entails leaving the soil to dry out for a few days after ponded water has evaporated before re-irrigating the crop (Feng et al., 2007). Numerous-shallow irrigation is a form of AWD irrigation in which rice fields are irrigated multiple times at shallow depths (e.g., 1–3 cm) according to soil conditions and weather forecasts. High-yielding rice is cultivated on non-puddled aerobic soil with supplemental irrigation, similar to highland crops, in aerobic rice farming. Rice is cultivated in this technique on well-drained, non-puddled, non-saturated soils that are free of ponded water (Bouman et al., 2007a).

Many farmers in the North-West Indo-Gangetic Plain are already using AWD, and it has been claimed that AWD saves 15–40% of the applied water in puddled transplanted rice compared to continuous flooding, with little or small yield loss. (Choudhury et al., 2007 Sudhir-Yadav et al., 2011; Maniruzzaman et al., 2019). Rice fields can transition from being continually anaerobic to being partially or even totally aerobic by using water-saving irrigation systems. Other water-saving methods, such as piped water transfer and pressured micro-irrigation rather than flood irrigation, might also help promote sustainable groundwater usage (Shah, 2014). However, because the majority of the water savings come from lower percolation rates, such a strategy will diminish groundwater recharge (Li et al., 2017). Real water savings, which result

in more water accessible for other users and/or restoring depleted aquifer storage, may only be accomplished by combining any of the following: (i) reducing non-beneficial evaporation through the reduced application of irrigation water, (ii) eliminating sources of non-beneficial evapotranspiration, and (iii) switching to the cultivation of less water-consuming crops (Foster et al., 2000; 2002).

## **2.4 Impact on Hydrology**

Tillage in wet fields (puddling) degrades soil aggregates, resulting in smaller soil particles that fill pore space and close fractures and macropores when they settle (Moormann and van Breeman, 1978; Sharma and De Datta, 1986). They also produce plough pans, which are usually 20 to 25 centimeters deep (Dittmar et al., 2007). The plough pan works as a water-flow barrier. Even while the field surface remains wet, the differential in hydraulic conductivity between the plough pan and the subsoil leads to the creation of an unsaturated zone under the pan (Takagi, 1960; Zaslavsky, 1964; Wopereis et al., 1994; Chen and Liu, 2002). With increasing puddling intensity, the hydraulic conductivity of the puddled layer drops; for example, Kukal and Aggarwal (2002) observed hydraulic conductivity of 0.064 cm/h for medium puddling and 0.009 cm/h for high-puddling. Chen and Liu (2002) in Taiwan found that puddled soil had an order of magnitude poorer hydraulic conductivity than non-puddled soil in their respective fields (0.15 against 2.3 cm/d and 0.05 against 1.5 cm/d, respectively), even though the bulk density (Tuong et al., 1994; Chen and Liu, 2002) and porosity (Chen and Liu, 2002) of the two soils varied by less than a factor of 2. Soils in rice fields frequently fracture as a result of drying and wetting cycles, forming preferred flow routes (Janssen and Lennartz, 2007, 2008, 2009). Earthworm castings are a typical characteristic in Eastern Gangetic rice soils, and they are known to produce preferred water flow paths. The fact that field-observed hydraulic conductivity is larger than intrinsic matrix permeability shows that field-scale infiltration rates are controlled by cracks and macropores in the planted field rather than intrinsic matrix permeability (Neumann et al., 2009).

Irrigation water is a poorly known component of the hydrological cycle in an area with intense agricultural irrigation owing to a lack of sufficient monitoring infrastructure (Hu et al., 2016). Separate management of surface and groundwater produces conflict in the allocation of water resources among diverse sectors such as irrigation, households, industry, and fisheries in places with highly integrated hydrologic systems. Separate management may potentially put

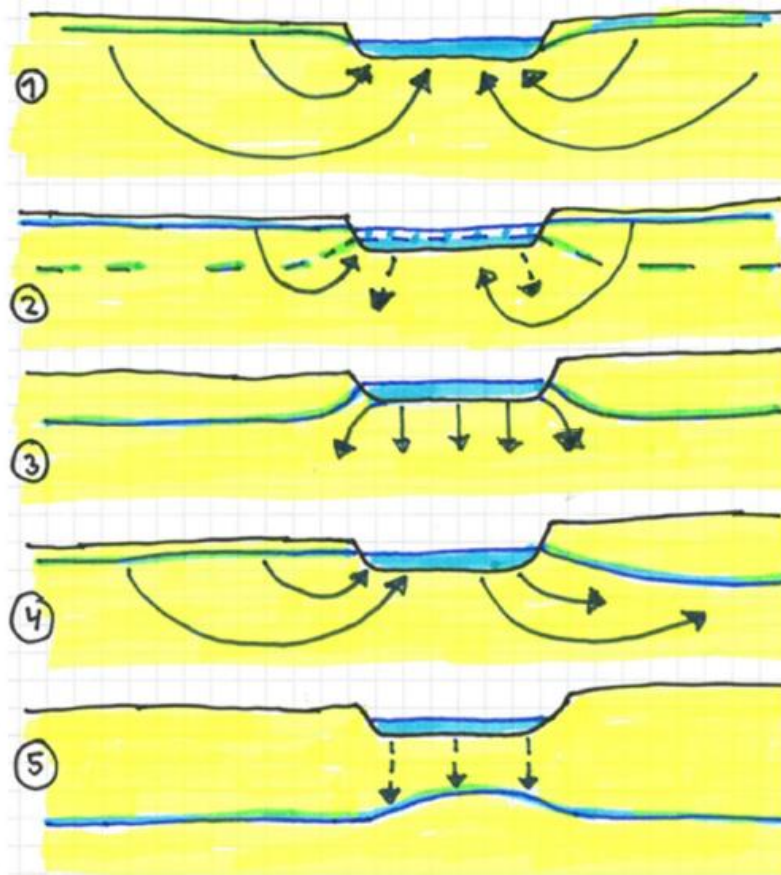
groundwater-dependent ecosystems under stress (Winter et al., 1998; Fullagar et al., 2006). As a result, water managers have long been plagued by an incorrect delineation of the natural interconnection between surface and groundwater resources (Giordano, 2009).

Groundwater in the MGP is a renewable resource due to its connection to the recharging processes of the yearly hydrologic cycle. The recharging of the aquifers in the Indo-Gangetic Basin happens via many different mechanisms, including rain-fed recharge and leakage from rivers and canals. Other factors, such as irrigation return flow and recharge caused by groundwater withdrawal, can also be relevant in particular places (Bonsor et al., 2017). Water distribution via irrigation canals and field application include potentially high rates of seepage and percolation, respectively. Irrigation return flows are a significant component of recharge in groundwater resource balances (Rushton et al., 2020). As a result, rainfall and irrigated agriculture fields are acknowledged as the two primary sources for recharging groundwater aquifers. Rice fields are the most important source of groundwater recharge among all irrigated crop fields, owing to significant percolation from irrigated rice fields (Li et al., 2014). As a result, groundwater recharge is seen as a by-product of irrigated rice production (Iwasaki et al., 2013).

Figure 2.1 illustrated the most likely river–subsurface interactions. These settings can vary in both spatial and temporal:

- 1) A situation in which groundwater is continuously drained;
- 2) A situation of seasonal groundwater drainage;
- 3) A situation in which there is a constant loss of water, such as the coarse sediment Himalaya foothill region receiving mountain drainage water;
- 4) Flow through a situation, i.e., the water body gets water on one side of the river, canal, or pond while losing water on the other;
- 5) In severe instances, surface water can also be fully isolated from groundwater such as extreme pumping or deep natural groundwater levels. In this case, there is an unsaturated zone under the river.

Understanding these river-subsurface interactions can help with long-term groundwater management.



**Figure 2.1:** Different possible river – subsurface flow interactions (Source: <http://cwc.gov.in/sites/default/files/ganga-river-basin-assessment-report.pdf>)

The interaction of groundwater and surface water in the main rivers can only be understood at a regional scale and through modeling. During the monsoon season, practically the whole river system loses water to the groundwater system. Model studies demonstrate comparable problems even during the dry season when low river water levels imply that base flow conditions are poor. High surface water levels can create water logging in regions outside the levees. Geophysical research can aid in understanding the likelihood and/or distribution of perched groundwater conditions. Baseflow appears to be the most sensitive water balance term, more so than groundwater consumption or groundwater depletion. Advanced measures, such as hydro-chemical analysis, can help to better define the base flow. To better understand the surface water-groundwater interaction, groundwater monitoring networks should be combined with surface water monitoring. According to Rahman and Roehrig's (2006) model, most rivers in Bangladesh are in direct hydraulic contact with aquifer systems, contributing to aquifer recharge from March to November and receiving water from the aquifers from December to February. As a result, rivers have a significant beneficial impact on groundwater recharge

during the wet season. This hypothesis is supported by regional groundwater flow modeling in the Bengal Basin (Michael and Voss, 2009). These characteristics of the river–aquifer systems have prompted some scholars to study the potential of purposely reducing groundwater levels during the dry season to improve recharge during the monsoon. The intended consequence of such action is to help minimize floods during the monsoon season and to improve water reserves available for agriculture during the dry season. These concepts were initially proposed in the 1970s as part of a concept known as the Ganges Water Machine (Revelle and Lakshminarayana, 1975), and have lately been explored by certain researchers (e.g., Khan et al., 2014). MacDonald et al. (2016) compiled and evaluated a massive dataset containing thousands of in-situ measurements collected from around the region. They analyzed groundwater levels, how much of that groundwater was inside the top 200 meters of the aquifer, and groundwater pollution using available information. Despite considerable abstraction, the researchers discovered that groundwater levels in 70 percent of the region remain steady or growing.

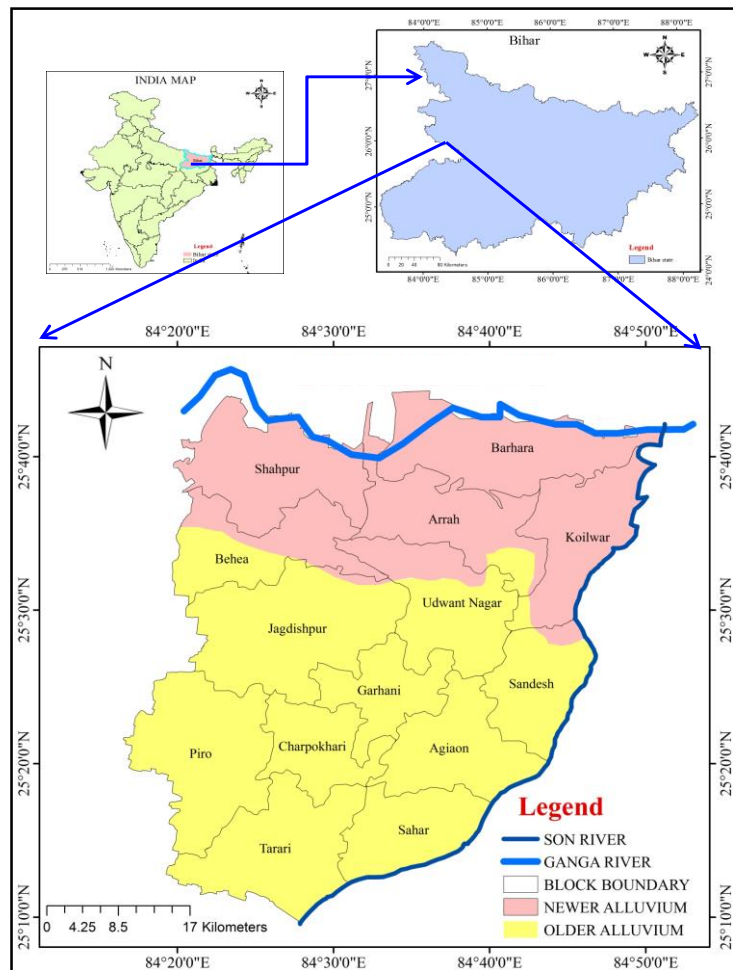
The adoption of water-saving technology on farms has the potential to alter the water cycle, agricultural water usage, and hydrology on a regional scale (Liu et al., 2016; Yang et al., 2005). Changes in irrigation management strategies can have a substantial impact on irrigation field recharge (Foster et al., 2000; 2002). Most of the water savings under resource-conserving technologies are obtained by reduced percolation rates, which are presumed to reduce groundwater recharge with eventually decreased opportunities for groundwater irrigation. Lining canals, eliminating bunds, limiting water diversion, and levelling farms all diminish groundwater recharge and consequently decrease groundwater tables (Pereira et al., 2007). Recently, mulched-drip irrigation systems have been widely used in China's Tarim River basin, altering the water exchange flow and hence the regional groundwater dynamics (Zhang et al., 2014). During the drip irrigation phase, the exchange flow at the groundwater table is primarily downward. However, with the use of water-saving irrigation systems, the downward exchange flow during irrigation times is considerably decreased (Zhang et al., 2014). As previously noted, water saved at the farm level does not always imply water savings when considering the entire irrigation system. Water lost from individual fields through seepage and percolation reaches the surface flow system via streams, drains, and groundwater, particularly shallow groundwater, and the subsurface system via groundwater. Where the surface and subsurface water systems have the potential to be used downstream, field-level water savings upstream do not result in system-level water savings. As a result, water-saving methods with high irrigation

efficiency at large scales can cause a considerable drop in groundwater levels (Tabbal et al., 2002) and have a severe influence on hydrology and ecology. The main negative effects include loss of soil quality and deforestation caused by deterioration of flora, which is especially noticeable in dry places where groundwater levels are dropping (Chen et al., 2016).

Groundwater depletion has been identified as a global issue that concerns the sustainability of water supplies (Mays, 2013), unless when depleted aquifers are restored during the wet season of each hydrologic cycle. Over the last decade, the groundwater table has dropped significantly in several regions of the Eastern Gangetic Plain, jeopardizing the long-term usage of water for agricultural and drinking water sources (Kirby et al., 2015; Mojid et al., 2019; Pena-Arancibia et al., 2020; Shamsudduha et al., 2012; Shahid, 2008; Shahid and Behrawan, 2008). Water scarcity has had an economic, social, and environmental impact in this region (Sajjan et al., 2002; Dey et al., 2011). Although MacDonald and colleagues observed that less than one-third of the Indo-Gangetic Basin has seen dropping groundwater levels over the last decade, the regions of decrease are strategically located around high-population centers, where the consequences might be disastrous. With decades of wide-scale removal and little recharge, major metropolitan areas (e.g., Dhaka city) already have deep water tables that continue to decline over time (Fendorf and Benner, 2016), suggesting groundwater overdraft. Overdraft of groundwater occurs when the rate of groundwater extraction plus natural discharge from aquifers exceeds the total recharge to the aquifers over a protracted time. However, according to MacDonald and colleagues, the most pervasive concern over the whole Indo-Gangetic Basin is reduced water quality caused by elevated arsenic and salt levels, rather than decreased groundwater quantity.

### 3.0 Study Area

The Bhojpur district, with a total geographical area of 2,395 km<sup>2</sup>, is situated in Bihar state has been selected as study area. The study area is located in central Ganga basin and lies within 25° 10' to 25° 40' N and 84°10' to 84° 50' E. The district is covered by two major rivers viz., Ganga and Son in the north and eastern side (Fig. 3.1). The study area has warm and humid climate. The monsoon season starts in the month of June and continues up to September. The geological characteristics of the district are alluvium in nature consisting of younger and older Gangetic alluvium which forms the potential aquifers. The northern and northeast parts of the district forms younger alluvium whereas the southern and central parts are formed with older alluvium (Fig. 3.1). The population of the district is 27.20 lakh with population density of 1136 inhabitants per square kilometer.



**Figure 3.1.** Study area (Bhojpur District) with geological map.

### 3.1 Agricultural practices

Agriculture is the principal economic activity in the Bhojpur district. The district is considered as the rice bowl in the state and Rice- mill is a traditional industry. The major food crops apart from rice are wheat, pulses, oil seeds and maize etc. The geographical area is 233, 729 ha out of which 188,134 ha is net cultivable area with nil forested area as per data of Department of Agriculture, Govt. of Bihar. The area covered under different crops in the Bhojpur district is shown in Table 3.1. The net irrigation area in Kharif season is 100,407 ha and in Rabi season it becomes 68,781 ha (Table 3.2). In the Kharif season, the irrigated area covered by canal, private tube well, lift irrigation, state tube wells and other sources are 72,952, 24,478, 838, 454, 1,685 ha where as in Rabi season the areas covered by the irrigation sources are 29,700, 36,717, 153, 526 and 1,685 ha respectively. The major Kharif crops in the district are rice, maize and gram etc and major Rabi crops are wheat, pulses, gram, mustard, potatoes etc.

**Table 3.1:** Area covered under different crops of the Bhojpur District

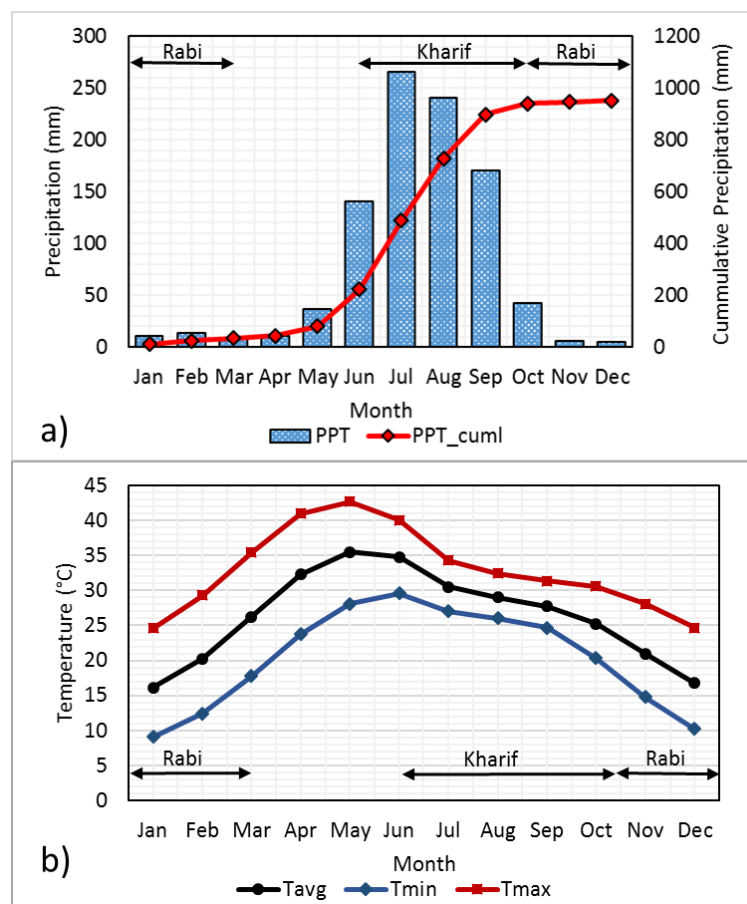
<b>Kharif (ha)</b>		<b>Rabi (ha)</b>		<b>Summer (ha)</b>	
Rice-	120500	Wheat-	103800	Green Gram-	20
Maize-	7000	Maize-	2295	Maize-	30
Pulses-	5000	Pulses-	42600	Vegetable-	400
Red Gram-	3500	Gram-	20500	Onion-	125
Black Gram-	1000	Pea-	2500		
Green Gram-	1080	Others-	4500		
Oil seed-	525	Oil seed-	10140		
Sesame-	215	Rabi/Mustard-	6100		
Castor-	285	Sunflower-	40		
Sunflower-	25	Vegetable-	2000		
Vegetable -	750	Potato-	3525		
<b>Total</b>	<b>1,34,355</b>		<b>164360</b>		<b>575</b>

**Table 3.2:** Net Irrigation area under Kharif and Rabi Season

<b>Sl. No</b>	<b>Source</b>	<b>Kharif Area (ha)</b>	<b>Rabi Area (ha)</b>
<b>1.</b>	Canal	72952	29700
<b>2.</b>	Private Tube well	24478	36717
<b>3.</b>	Lift Irrigation	838	153
<b>4.</b>	State Tube well	454	526
<b>5.</b>	Other Sources	1685	1685
	<b>Total</b>	<b>1,00,407</b>	<b>68,781</b>

### 3.2 Hydroclimatology

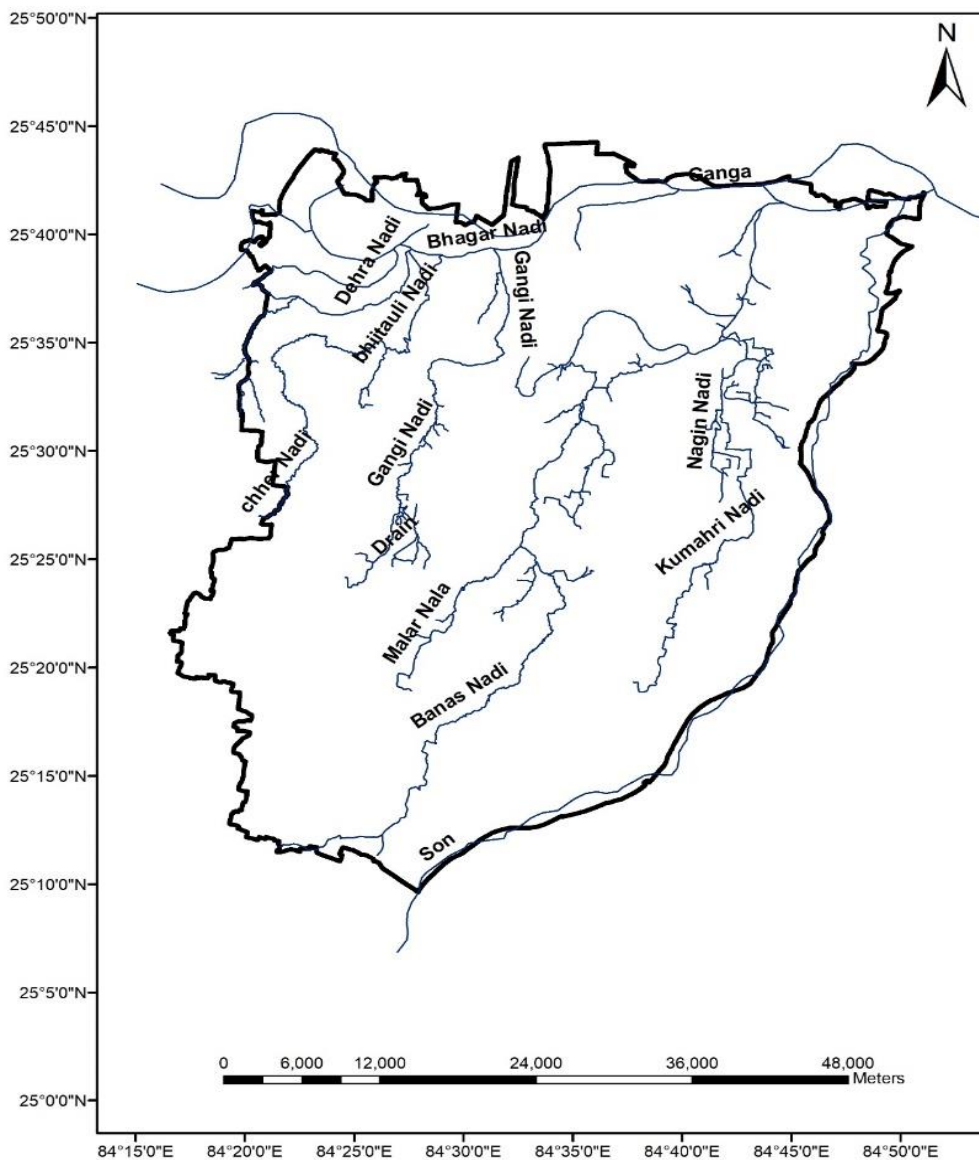
Figure 3.2 shows the mean monthly precipitation for thirty years (1991-2020) for the Bhojpur district. It is shown that June to October months reflect the Kharif season while October to March represent the Rabi season. It can be seen that the average monthly precipitation is highest in the Kharif season accounting 266 mm in July. Almost ~87% of average annual precipitation occurs during Kharif season and most of the rainfall (about 85%) occurs in the South-West monsoon (CGWB, 2013). The cumulative precipitation increases from January to December reaching its maximum value of 950 mm. The April and May are the hottest month such that average monthly temperature reaches to 35°C whereas January experiences lowest mean minimum monthly temperature falling up to ~9°C. The average monthly temperature ranges between 25°C to 35°C in Kharif season while ~15°C to 25°C in Rabi season.



**Figure 3.2** ( a) Average monthly precipitation and cumulative rainfall (b) average, minimum, and maximum monthly temperature highlighting the Kharif and Rabi season (Kumar et al., 2021)

The study area has a common slope towards the North and North-East. The common elevation with respect to mean sea level is 50-90 m and gradient is 0.6 m/km from South to North. The

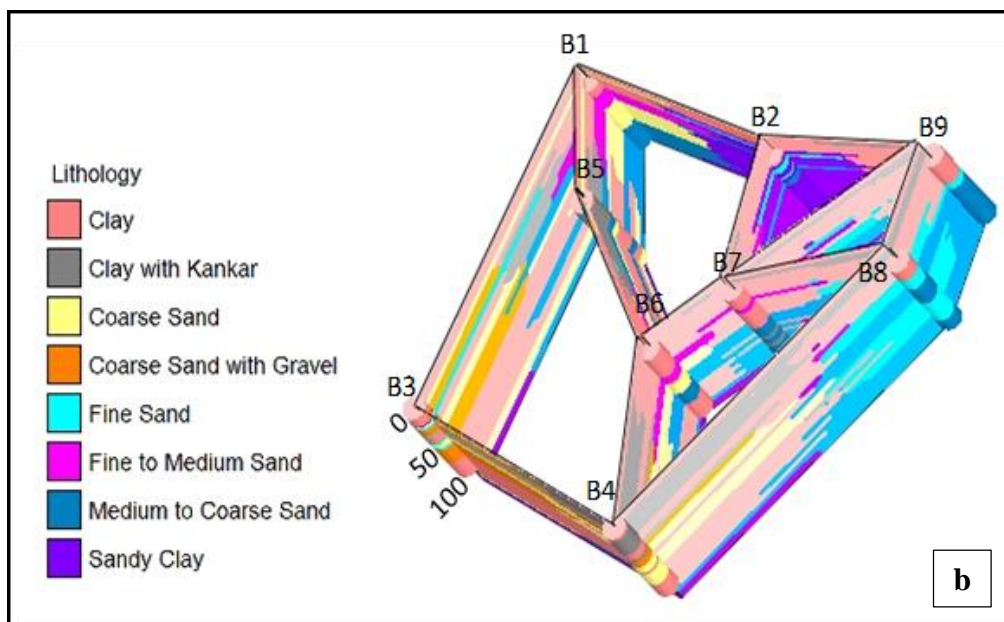
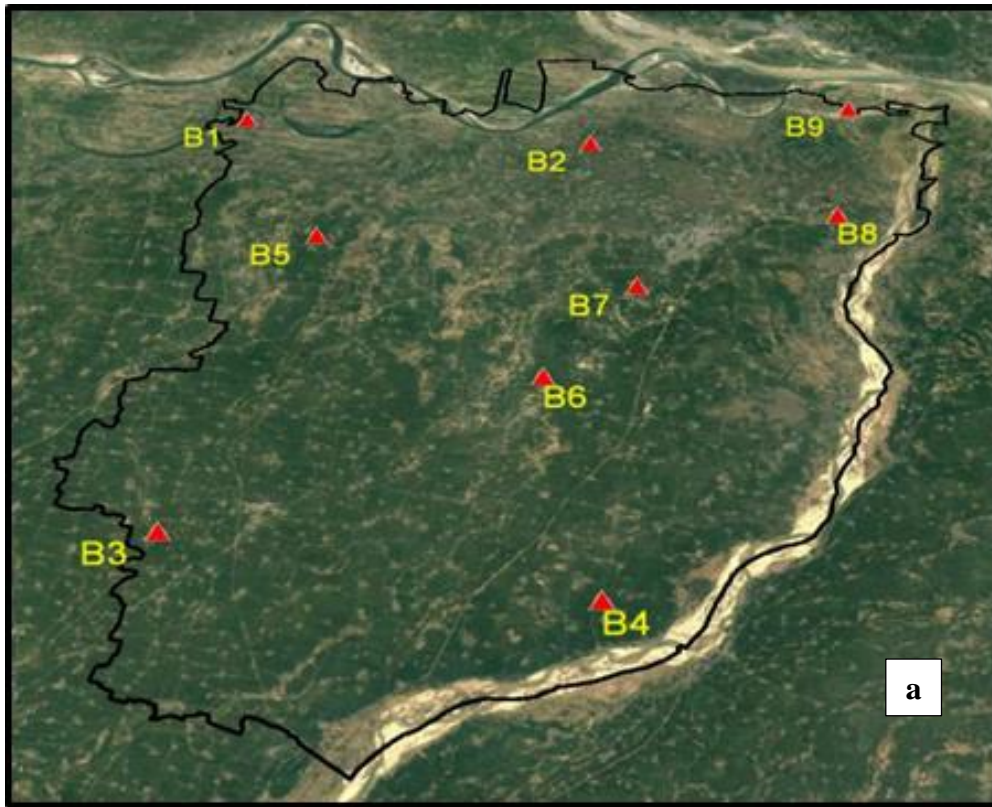
district in general possesses alluvium soil and the soils are of poorly drained type. The area adjoining the rivers Ganga, Son, Dharmawati, and Gangi consists of sandy loam, loamy sand and sand, whereas, the area away from the river channels consist of silty sand to sandy silt. Fig. 3.3 shows the drainage network of the study area. The soils in common are fine textured away from the river course and rivulets and coarse textured along the river courses. The district is bounded by Ganga river in North and Son river in East. The entire district consisting of 14 blocks forms an interfluvial zone of Ganga and Son rivers.



**Figure 3.3:** Drainage network of the study area

### 3.3 Hydrogeology

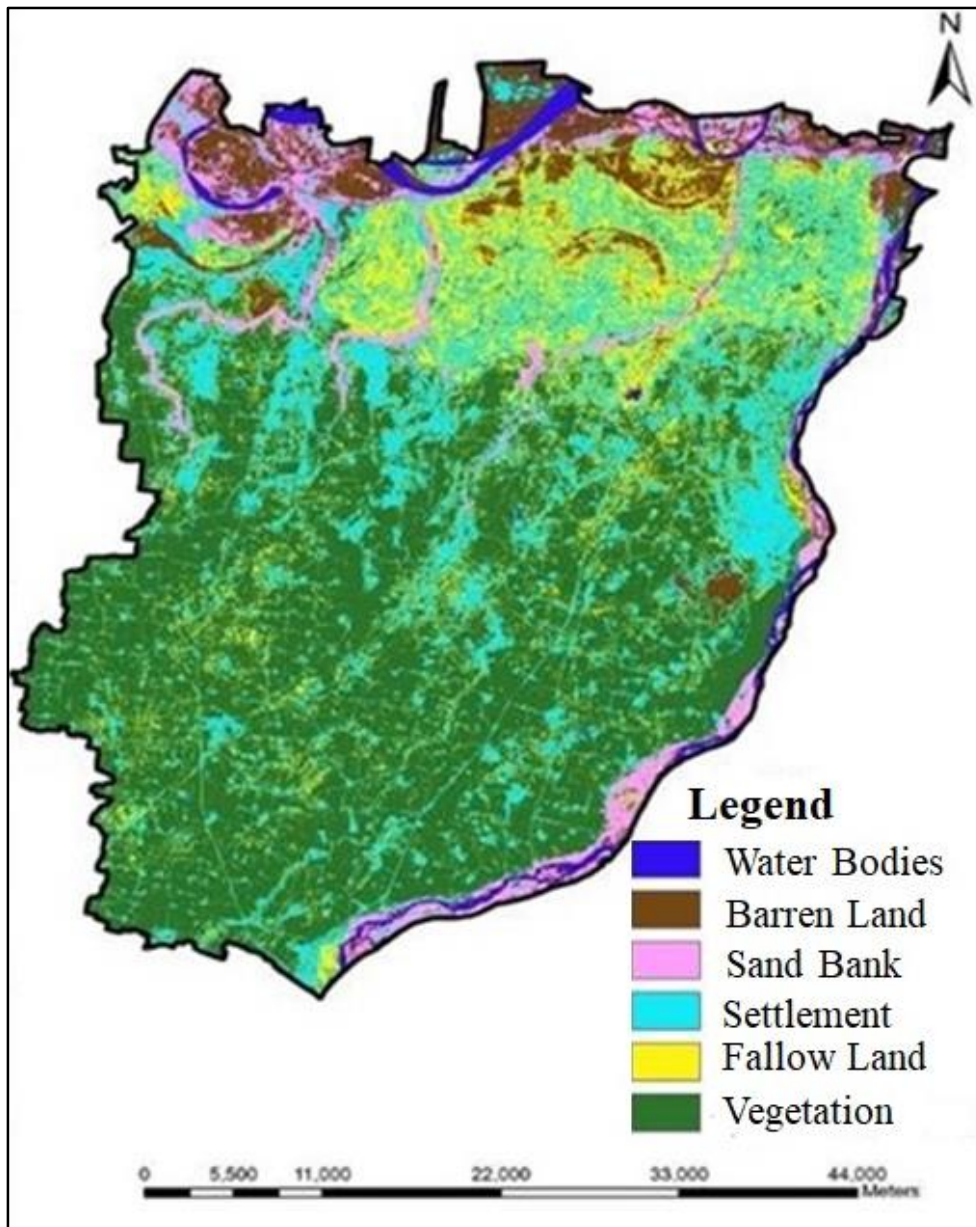
The Ganga river originates from the Himalaya and transports sediments through its course of travelling in the plain area. The deposited sediments determine the water chemistry of the area due to several processes such as rock weathering, rock-water interaction etc. Alluvial soils are mainly formed due to sediment deposits by the Indo-Gangetic-Brahmaputra rivers and Himalayan rocks form the parent material. Geologically, the alluvial soils are divided into younger and older alluvium and they are best suited for agriculture. The older alluvium represents the upland alluvial tract whereas younger alluvium forms the flood plains. The Bhojpur district is occupied by Quaternary alluvium, which forms the potential aquifer. The Bhojpur district is covered by alluvial formation; northern part is enclosed by younger alluvium whereas central and southern part is covered by older alluvium as discussed in the study area section. The older alluvium of the study area consists of dark coloured clay and silt rich with lime nodules locally known as Kankars. It is generally poorly sorted and less permeable. The unconsolidated younger alluvium occurs along the flood plain of Ganga and Son rivers and it is characterized by sandy clay, loam and contains less calcareous matter. In the study area, the top layer of geological stratum (within 30 mbgl) is an aquitard (Fig. 3.4), which supports dug wells and shallow hand pumps. In fact, it works as an unconfined aquifer. From 30 m to approx. 80-100 m bgl, medium to coarse sand forms the aquifer and after that a thick layer (20-30 m) of clay is present. The deeper aquifers (> 130 m bgl) are under either semi-confined or confined conditions which sustain the deep wells in the area (CGWB, 2013).



**Figure 3.4:** (a) Borelogs location in the study area (b) Fence diagram representing lithological settings

### 3.4 Land Use Land Cover

The land use land cover (LULC) map has been prepared using Landsat-8 satellite imagery (year 2018, 30 m resolution) obtained from United States Geological Survey (USGS) website. The LULC classification (Fig. 3.5) shows the major land use/ land cover types - vegetation constitutes ~46.13 % of total area, followed by built-up area (21.64 %), fallow land (16.52 %), barren land (7.37 %), sand bank (6.08 %), and water (2.26 %).



**Figure 3.5:** The Land use and Land cover (LULC) classification in the study area

## 4.0 Methodology

For achieving the objectives framed under study, the following methods or methodology was adopted for the study: (i) a review of literature was done to understand the impact of agricultural water saving measures on Hydrology, (ii) various thematic map such as drainage, geological, depth to water level, LULC map for the study area were prepared, (iii) GWL data was analyzed to study spatio-temporal variation and trend analysis was done using Mann- Kendall test, and (iv) based on the available and generated data, a coarse groundwater modelling was attempted to study the SW-GW interaction. The detailed methodology for trend analysis and groundwater modelling are described below.

### 4.1 Mann - Kendall test for groundwater level trend analysis

The best known non-parametric test is based on the Mann-Kendall's test and has been used by various researchers to understand long-term trends in groundwater levels (Tabari et al., 2011; Vousoughi et al., 2013; Machiwal and Jha, 2014; Ribeiro et al., 2014). The non-parametric Mann-Kendall (MK) test is commonly used to detect trends that are monotonic but not necessarily linear. Assumptions of normal distribution are not required in the MK test which only indicates the significance and direction of trend, not its quantitative measure (Helsel & Hirsch, 1992). Assumptions of the MK method include a stable, independent and random time series with equal probability distribution (Yue et al., 2002). The time series data used for MK test should be uncorrelated otherwise it might result in an erroneous rejection of the null hypothesis due to the presence of serial correlation (Helsel & Hirsch, 1992; Yue *et al.*, 2002; Yue & Wang, 2002; Yue & Pilon, 2003).

The computational procedure for the MK test is described in Adamowski & Bougadis (2003). Let the time series consist of  $n$  data points and  $T_i$  and  $T_j$  be two sub –sets of data where  $i = 1, 2, 3, \dots, n-1$  and  $j = i+1, i+2, i+3, \dots, n$ . Each data point  $T$  is used as a reference point and is compared with all the  $T_j$  data points such that:

$$Sign(T) = \begin{cases} 1 & \text{for } T_j > T_i \\ 0 & \text{for } T_j = T_i \\ -1 & \text{for } T_j < T_i \end{cases} \quad (4.1)$$

The MK test used in the present study is based on the test statistic,  $S$ , defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(T_j - T_i) \quad (4.2)$$

The variance for the  $S$ -statistic is defined by:

$$\sigma^2 = \frac{n(n-1)(2n+5) \sum_{i=1}^n t_i(i-1)(2i+5)}{18} \quad (4.3)$$

in which  $t_i$  denotes the number of ties to extent  $i$ . The summation term in Equation (4.3) is only used if data series contains the “tied” values. The test statistic,  $Z_s$ , can be calculated as

$$Z_s = \begin{cases} (S-1)/\sigma & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ (S+1)/\sigma & \text{for } S < 0 \end{cases} \quad (4.4)$$

in which  $Z_s$  follows a standard normal distribution. Equation 4.4 is useful when the record length is more than 10 and the number of tied data is low (Kendall, 1975). The test statistic,  $Z_s$  is used as an index of the significance of trend. In fact, this test statistic is used to test the null hypothesis, “ $H_0$ : There is no monotonic trend in the data”. If  $|Z_s|$  is greater than  $Z_{\alpha/2}$  where  $\alpha$  represents the chosen significance level (usually 5%, with  $Z_{0.025}=1.96$ ), then the null hypothesis is rejected, meaning that the trend is significant.

MK test holds well in the case of non-auto correlated time series data. For auto-correlated data, modified Mann-Kendall (MMK) test proposed by Hamed & Rao (1998) was used, which is robust in presence of autocorrelation. It is based on the modified variance of  $S$  given by Equation (4.5).

$$V^*(S) = \text{var}(S) \frac{n}{n_s^*} = \frac{n(n-1)(2n+5)}{18} \frac{n}{n_s^*} \quad (4.5)$$

The recommended approximate value of  $\frac{n}{n_s^*}$  is given by the following equation

$$\frac{n}{n_s^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-1)(n-i-1)(n-1-2)\rho_s(i) \quad (4.6)$$

where  $n$  is the actual number of observations and  $\rho_S(i)$  is the autocorrelation function of the ranks of the observations. The accuracy of the approximation given by the Equation 4.5 was found to improve as  $n$  increases. The autocorrelation between ranks of observations  $\rho_S(i)$  is first evaluated. The value of ranks of observations  $\rho_S(i)$ , however, must be calculated after subtracting a suitable non-parametric trend estimator. Due to the nature of calculation in Equation 4.4, which involves large number of terms, it was found that insignificant value of  $\rho_S(i)$  will have an adverse effect on the accuracy of the estimated variance of  $S$ . Therefore, only significant values of  $\rho_S(i)$  are used in Equation 4.5. This is achieved by requiring a suitable preset significance level for the autocorrelation to be included in the calculations, which can be taken equal to that of the rest.

## 4.2 Groundwater model development

The groundwater (GW) model is used for understanding the behaviour of GW flow system and prediction of system's response due to forcing function. It also acts as an assessment tools for evaluating recharge, discharge and for quantifying sustainable yield of aquifer. Typically, a GW flow model comprises of an equation (algebraic or differential) governing the flow and numerical solution to compute the head distribution in space and time.

Mathematical model of a groundwater system is defined by a governing equation (partial differential equation), initial and boundary conditions. The governing equation is essentially an expression of continuity equation i.e. the difference between inflow and outflow rates equals the rate of change of storage in any selected domain of saturated flow (Fitts, 2002). The governing equation is derived by using continuity equation and Darcy's law. In a typical mass balance analysis, the net flux of mass through the boundary of an element is equated to the rate of change of mass within the element. The elementary volume for deriving equations is shown in Fig. 4.1.

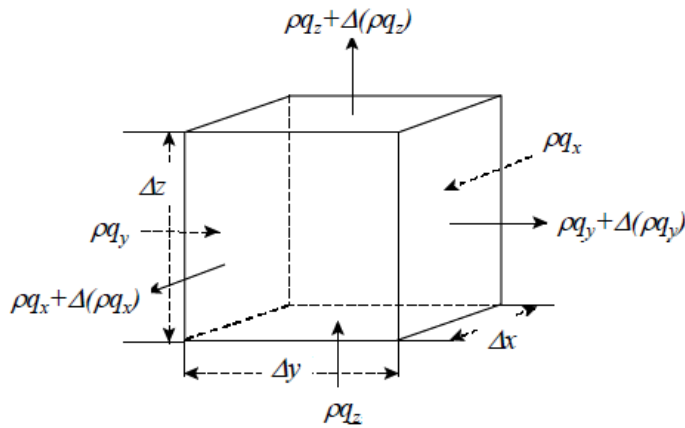
The mass flux (mass/time) in through back face of X-axis (Fig. 4.1) is given by

$$\rho_w(x) q_x(x) \Delta_y \Delta_z \quad (4.7)$$

Where  $\rho_w(x)$  is the water density at coordinate  $x$  and  $q_x(x)$  is the specific discharge at coordinate  $x$ .

The corresponding flux out through the front face of the element is

$$\rho_w (x + \Delta x) q_x(x + \Delta x) \Delta y \Delta z \quad (4.8)$$



**Figure 4.1:** Elementary volume in saturated flow with dimension  $\Delta x$ ,  $\Delta y$  and  $\Delta z$

As per mass balance, the mass flux into the element minus mass flux out is the rate of change of mass stored in the element.

$$\rho_w (x) q_x(x) \Delta y \Delta z - \rho_w (x + \Delta x) q_x(x + \Delta x) \Delta y \Delta z = \rho_w S_s \frac{\partial h}{\partial t} \Delta x \Delta y \Delta z \quad (4.9)$$

Rearranging the equation (4.9) and using Darcy's law, the general GW flow equation can be written as

$$\frac{\partial}{\partial x} \left( K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_y \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_z \frac{\partial h}{\partial z} \right) = S_s \frac{\partial h}{\partial t} \quad (4.10)$$

If the hydraulic conductivity is assumed to be homogeneous (independent of  $x$ ,  $y$  and  $z$ ), the general equation can be written as

$$K_x \frac{\partial^2 h}{\partial x^2} + K_y \frac{\partial^2 h}{\partial y^2} + K_z \frac{\partial^2 h}{\partial z^2} = S_s \frac{\partial h}{\partial t} \quad (4.11)$$

If the hydraulic conductivity are assumed to be homogeneous (independent of  $x$ ,  $y$  and  $z$ ) and isotropic ( $K_x=K_y=K_z$ ), the general equation can be written as

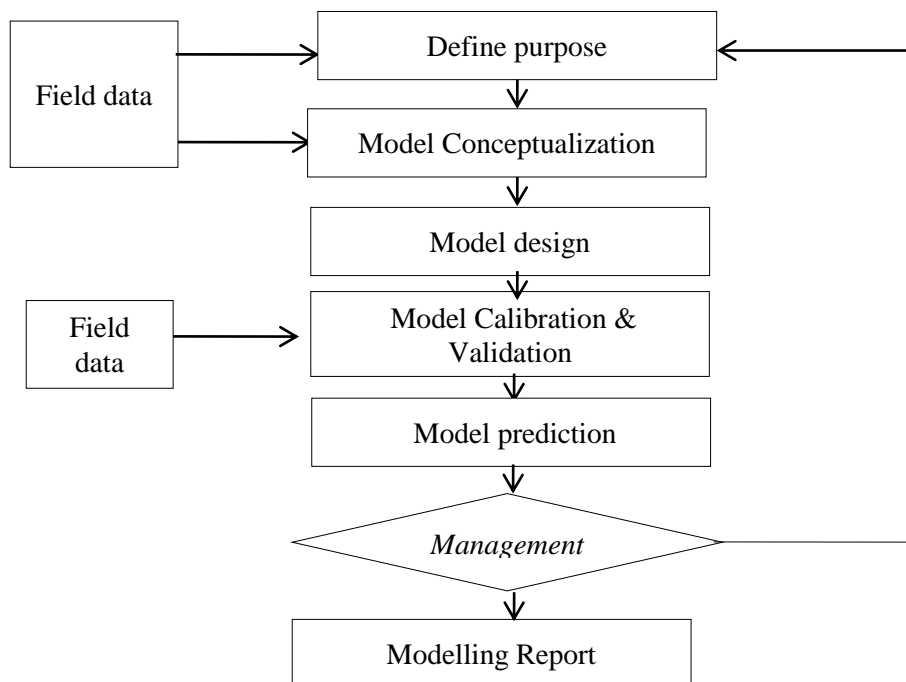
$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \nabla^2 h = \frac{S_s}{K} \frac{\partial h}{\partial t} \quad (4.12)$$

A computer program or code solves a set of algebraic equations generated by approximating the partial differential equations that forms the mathematical model. The hydraulic heads are

obtained from the solution of three dimensional groundwater flow equation through MODFLOW software (McDonald & Harbaugh,1988). The equations are solved by finite difference method (FDM), a continuous medium is replaced by a discrete set of points called nodes and various hydrogeological parameters are assigned to each of these nodes. Accordingly, difference operators defining the spatial-temporal relationships between various parameters replace the partial derivatives.

#### 4.2.1. Modelling process

The modelling process involves several steps which are shown in Fig. 4.2. A first step in modelling process is to define purposes. The modeller needs to answer the questions viz. whether the model is to be used for prediction, system understanding or generic exercises etc before starting modelling.



**Figure 4. 2:** Flow chart of processes involved in GW modelling

#### 4.2.2 Conceptual and numerical model construction for the study area

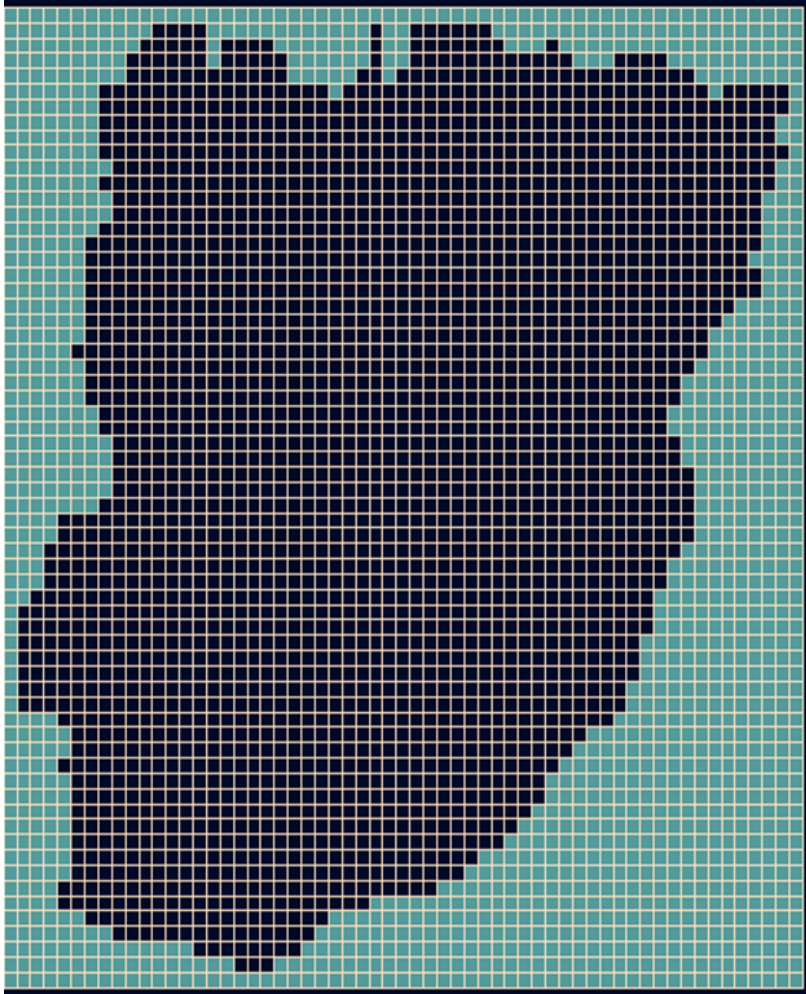
Conceptual model is the base for model analysis. It is a representation of groundwater systems in terms of hydrogeological units, boundary conditions, hydrogeological parameters, hydrological stresses, flow patterns etc. The purpose of building a conceptual model is to

simplify the field problem and organize the associated field data so that the system can be analyzed more readily (Anderson et. al., 2005). The conceptualization include synthesis and framing up of data pertaining to geology, hydrogeology, hydrology, and meteorology etc. Aquifer geometry geologic information including geologic maps, cross sections and well logs are combined with information on hydrogeologic properties to define hydrostratigraphic units for the conceptual model (Anderson et. al., 2005). Numerical model is designed based on the developed conceptual model. The design of numerical model comprises the size of model grids, defining stress periods and time steps and setting model initial and boundaries conditions. The grid size and time steps depend on the purpose of the modelling as the memory and computing time of computers/computer code may have limitations. The present model in this study was conceptualized with one-layer model (unconfined aquifer system); the unconfined aquifer thickness is taken as 80 m. The four stress periods (i. July, August and September; ii. October, November and December; iii. January, February & March; iv. April, May & June) were taken in a year to simulate GW flow on daily basis. The calibration was done for one year (July, 2015 to June, 2016), validation for 1 year (July, 2016 to June, 2017) and then prediction (July, 2017 to June, 2018) was done with the help of developed model. The calibration and validation period was less due to non-availability of required data. This is a scoping study, and coarse GW modelling was attempted based on data available with certain assumptions. The data used in this model has been taken from CGWB and Water Resources Department, Govt. of Bihar. However, this model needs to be further refined based on field survey, investigation and monitoring/collection of further data.

The geographical area of the study domain is 2395 Km<sup>2</sup> and the grid size was taken 1Km x 1Km m with 64 number of rows and 59 columns (Fig. 4.3). The model domain is defined as

Xmin 225775, Ymin 2785100

Xmax 284700, Ymax 2848700

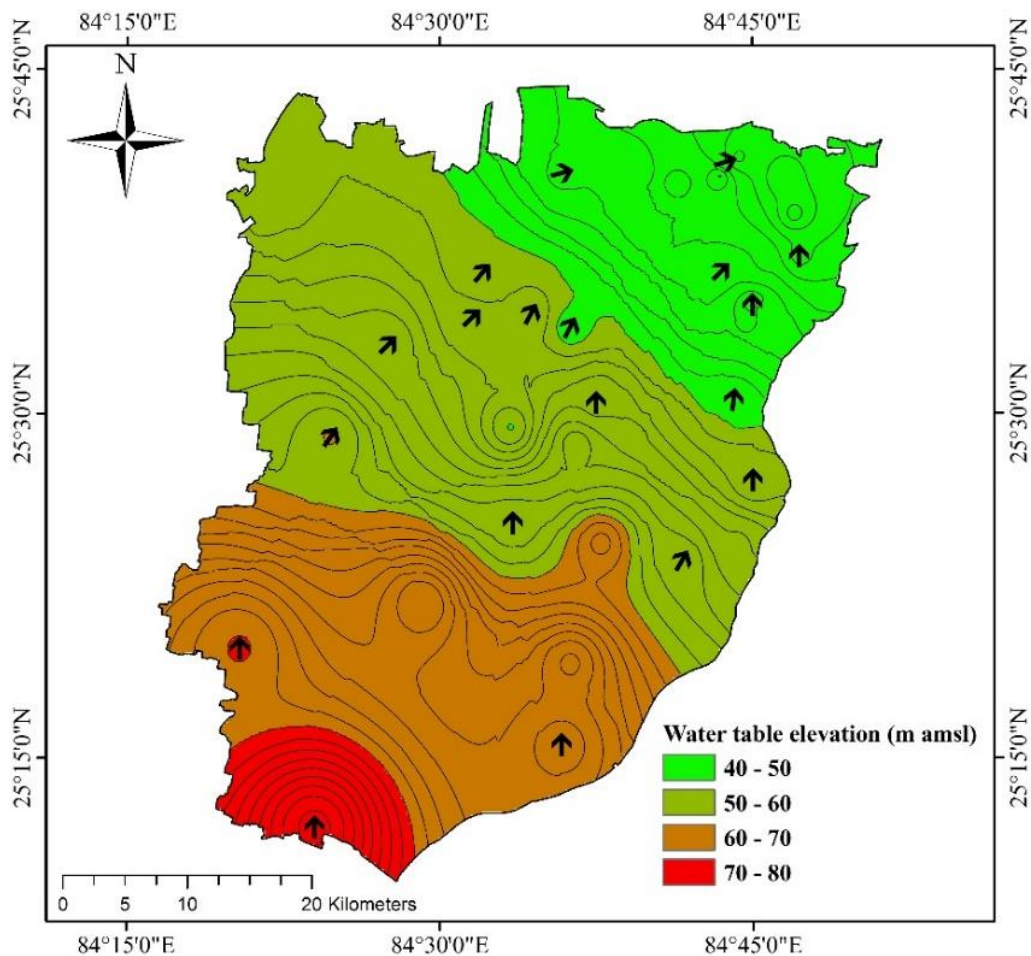


**Figure 4.3:** Grid created for modelling domain

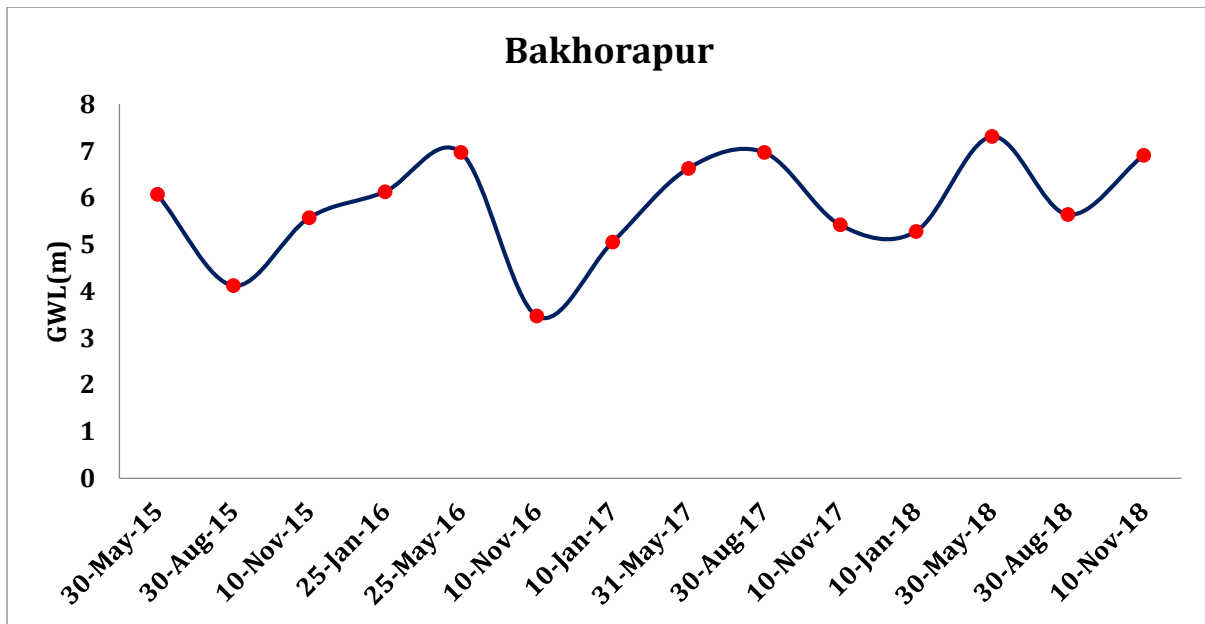
## 5.0 Results and Discussions

### 5.1 Trend analysis of groundwater level

The groundwater level data analyses (data collected from CGWB) shows variation of groundwater level across the study area. The deepest groundwater level was observed in the North and North-East part of the study area. The unconfined aquifer has average groundwater level ranging from 3 m bgl to 9 m bgl (pre-monsoon season, May 2017); the hydraulic gradient is about 0.0005 and groundwater flow directions are North and North-East (Fig. 5.1) towards the river Ganga. In the pre-monsoon season, groundwater feeds into the Ganga river. The fluctuation of groundwater level can be noticed between pre and post monsoon season (Fig. 5.2 has been shown as representative for a well hydrograph) which indicates that natural recharge is good in the area.

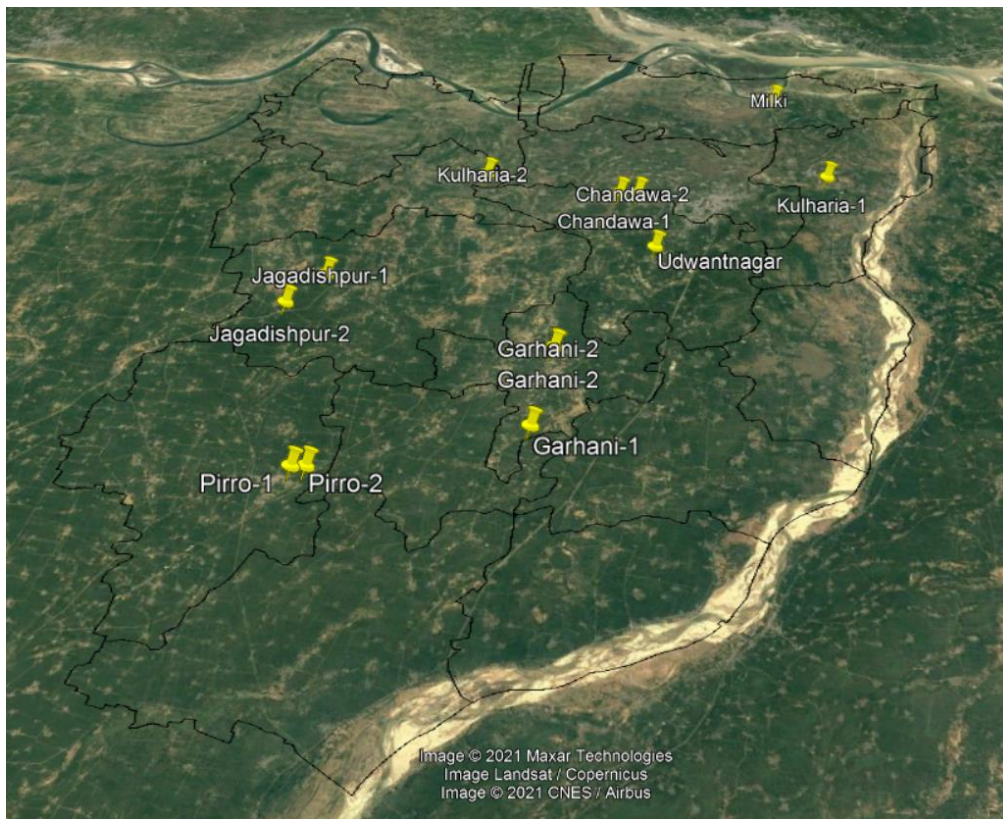


**Figure 5.1:** Water table elevation and groundwater flow direction in the study area



**Figure 5.2:** A well hydrograph showing groundwater level fluctuation

For trend analysis, groundwater level data comprises of pre-monsoon, monsoon and post-monsoon monitored data from 13 wells within the study area as shown in the Fig. 5.3. The length of data for the above well ranges from 5 -18 years as per availability. Therefore, 3 time-series (pre-monsoon, monsoon and post-monsoon) for each well were prepared for trend analysis. A total of 39 time-series were analysed using the Mann-Kendall test method and the results are given in the Table 5.1. The limitation of the trend analysis is in the short duration of data availability, never the less, the present analysis provides an overview of the trends of rising as well as declining ground water levels in the study area. It can be seen from Table 1 that only one station namely, Kulharia-1 shows a statistically significant (@5% significance) declining trend of ground water level during pre-monsoon as well as monsoon period. During post-monsoon season, the trend remains declining but it is not significant. For rest of the 12 wells, the trends are not statistically significant. The reason could be short length of data. 5 more wells (Jagdishpur-1, Udwantnagar, Pirro-2, Milki, Pirro-1) show a declining trend of ground water levels, mostly in the pre-monsoon and monsoon periods with no trend during post-monsoon period. 2 wells (Bihiya, Garhani-1) show rising trends of ground water level while 2 wells (Garhani-2, Chandawa-1) show rising trends in pre-monsoon period and declining trends in monsoon period with no trends in post-monsoon period. There are 3 wells (Kulharia-2, Chandawa-2, Jagdishpur-2) that show neither rising nor declining trends of ground water levels.



**Figure 5.3:** Location of GW monitoring wells for trend analysis

**Table 5.1:** Trends of groundwater level in the study area

Location	Trend @ 95% CL		
	Pre-monsoon	Monsoon	Post-Monsoon
Jagadishpur-1	Declining (NS)	Declining (NS)	Declining (NS)
Udwanthnagar	Declining (NS)	Declining (NS)	Declining (NS)
Kulharia-1	Declining	Declining	Declining (NS)
Bihiya	Rising(NS)	Rising(NS)	Rising
Pirro-2	Declining (NS)	No Trend	Declining (NS)
Garhani-2	Rising(NS)	Declining (NS)	No Trend
Milki	Declining (NS)	Declining (NS)	No Trend
Chandawa-1	Rising(NS)	Declining (NS)	No Trend
Kulharia-2	No Trend	No Trend	No Trend
Garhani-1	Rising(NS)	No Trend	No Trend
Pirro-1	No Trend	Declining (NS)	No Trend
Chandawa-2	No Trend	No Trend	No Trend
Jagadishpur-2	No Trend	No Trend	No Trend

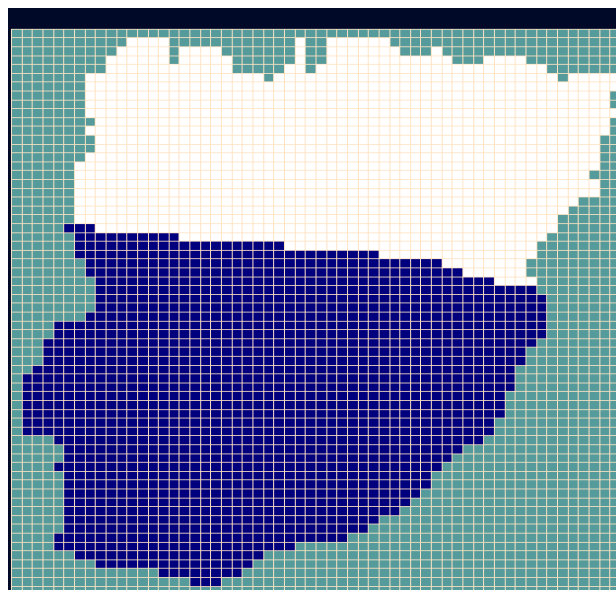
CL=Confidence Limit  
NS= Not Significant

## 5.2 Groundwater Modeling

### 5.2.1 Model inputs

The inputs to the groundwater model include initial (initial heads) and boundary conditions, hydrogeological parameters such as transmissivity/conductivity and storativity/specific yield, and hydrological stresses. The input data have to be entered to all grid points for all stress periods. Initial conditions, as the name implies it refer to the spatial distribution of heads everywhere in the model domain at the beginning of a reference time. Initial condition is necessary for arriving at a unique solution of the governing differential equation. Conceptually, they can be visualized as the initial condition before application of external forces such as pumping, recharge etc. The initial heads were taken as observed groundwater heads (May, 2017) for the unconfined aquifer.

Hydraulic conductivity (K) and storage coefficient (specific yield,  $S_y$ ) are the two parameters of unconfined aquifer which define the physical framework of an aquifer and control the movement and storage of groundwater. The hydraulic conductivity and specific yield/specific storage, were estimated and assigned to single layer unconfined aquifer based on the literature data. The hydraulic conductivity values for the younger and older alluvium were assigned as 40 m/day and 30 m/day respectively as shown in Fig. 5.4. A specific yield of 0.10 was applied uniformly to the entire area.

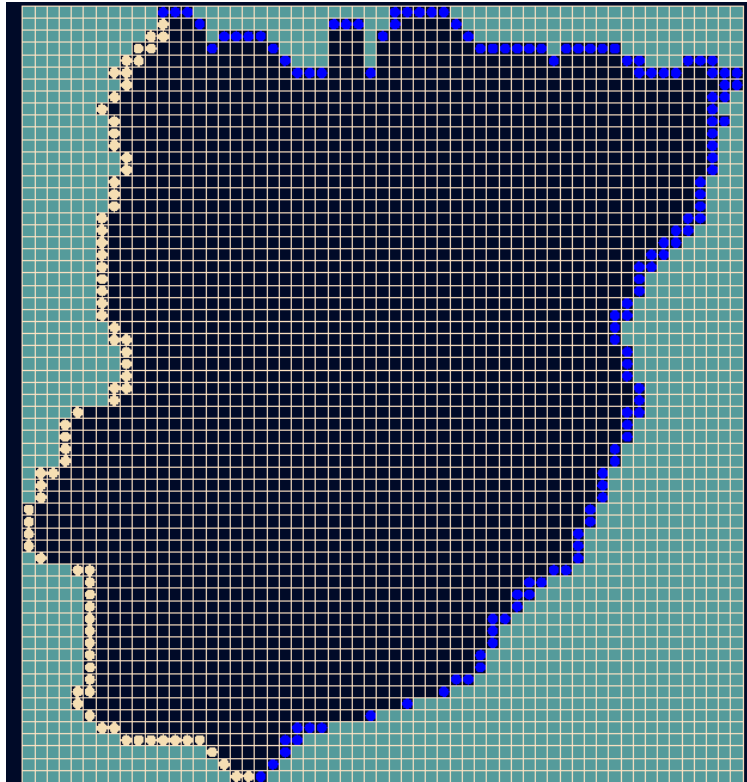


**Figure 5.4:** Distribution of hydraulic conductivity for younger (white zone) & older alluvial (blue zone) formations

### 5.2.2 Boundary conditions

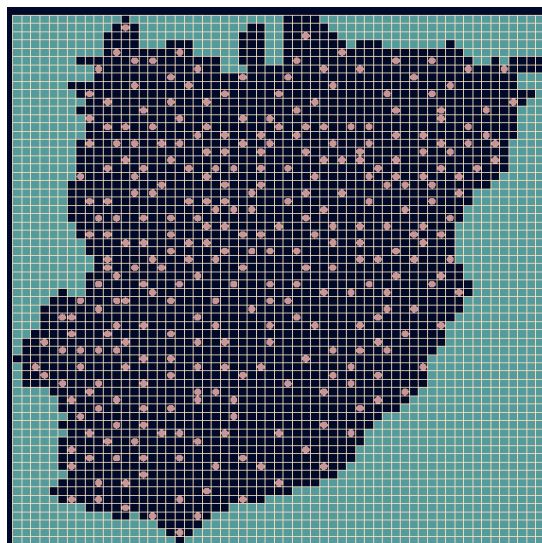
Boundary conditions specify the head or flux of GW flow at the boundary of model domain. Physical boundaries of groundwater flow systems are formed by the physical presence of an impermeable body of rock or a large body of surface water. Other boundaries form as a result of hydrologic conditions. These invisible boundaries are called hydraulic boundaries which include groundwater divides and streamlines. For the present case, the physical boundaries in North and East are rivers Ganga and Son. No flux boundary was assigned in West (as plotted water table contours are parallel to each other) and specified flux boundary was assigned in south-west (Fig. 5.5). The flux for unconfined aquifer was calculated based on the hydraulic gradient and hydraulic conductivity. The river heads and bed bottom elevations at the initial and final point of river Ganga are 52 and 48 m amsl and 48.75 and 44.75 m amsl, during 1<sup>st</sup> stress period; 51 and 48 m amsl and 47.75 and 44.75 m amsl, during 2<sup>nd</sup> stress period; 50.5 and 48 m amsl and 47.25 and 44.75 m amsl, during 3<sup>rd</sup> stress period; 50 and 48 m amsl and 46.75 and 44.75 m amsl, during 4<sup>th</sup> stress period respectively. Similarly, the river heads and bed bottom elevations at the initial and final point of river Son are 74 and 72 m amsl and 46.75 and 44.75 m amsl, during 1<sup>st</sup> stress period; 73.5 and 72 m amsl and 46.25 and 44.75 m amsl, during 2<sup>nd</sup> stress period; 73 and 72 m amsl and 45.75 and 44.75 m amsl, during 3<sup>rd</sup> stress period; 72.5 and 72 m amsl and 45.25 and 44.75 m amsl, during 4<sup>th</sup> stress period respectively. The river head data during monsoon season were taken from Water Resources Department, Govt. of Bihar website and it was assumed for other periods. The river widths were taken from Google earth.

Annual recharge value of Bhojpur district (block-wise) has been taken from CGWB (2013) report and have been distributed in the stress period (75%, 15%, 5% and 5% during 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> stress period). The block wise recharge values for different stress periods were assigned as shown in Table 5.2 and then applied to the respective grids in the model using recharge boundaries for the aquifer.



**Figure 5.5:** Map showing Boundary conditions in the study area

Groundwater draft was also taken from CGWB report for Bhojpur district. The annual GW draft was distributed block-wise for four stress period as shown in Fig. 5.6 and Table 5.3. Total 288 wells were estimated to be operated in the study area. The withdrawal pumping rate for stress periods 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> & 4<sup>th</sup> are - 1800, -3022, -3445 and -4607 m<sup>3</sup>/day/pump respectively. The pumping well package of MODFLOW was used for incorporating GW draft in the model.



**Figure 5.6:** The distribution of pumping well in the study area

**Table 5.2:** Blockwise recharge (mm/day): Annual recharge was distributed in 4 stress period: 75%, 15%, 5% and 5%

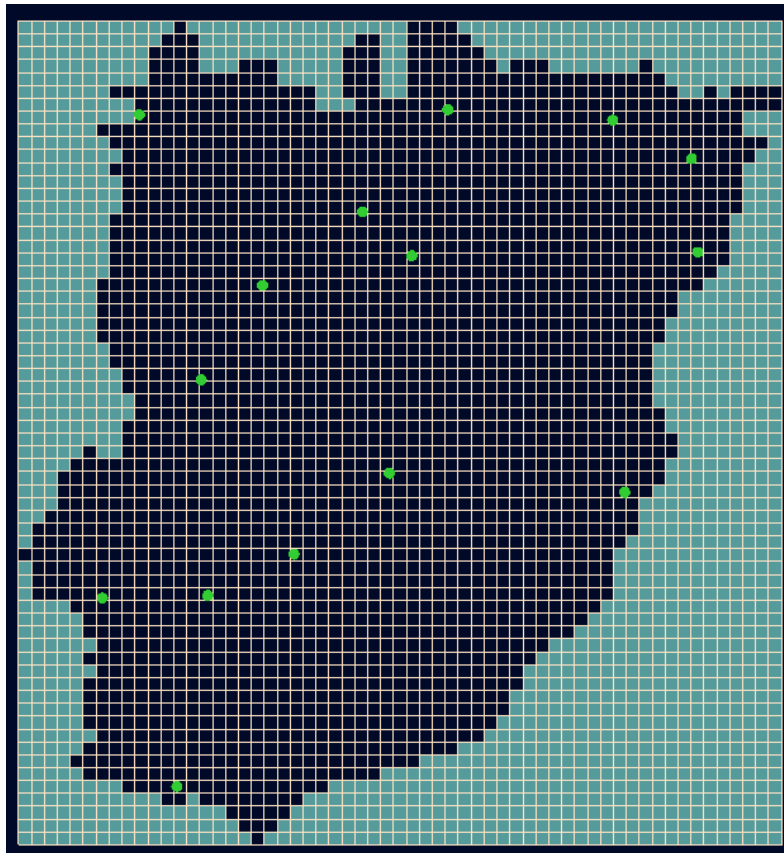
Stress Period	Agiayon	Ara	Barhara	Behea	Charpokhri	Garhani	Jagdishpur	Koilbar	Piro	Sahar	Sandesh	Shahpur	Tarari	Udwantnagar
1	2.77	2.93	2.35	2.57	2.80	2.79	2.85	1.84	2.67	2.61	2.83	1.95	2.48	3.41
2	0.55	0.59	0.47	0.51	0.56	0.56	0.57	0.37	0.53	0.52	0.57	0.39	0.50	0.68
3	0.18	0.20	0.16	0.17	0.19	0.19	0.19	0.12	0.18	0.17	0.19	0.13	0.17	0.23
4	0.18	0.20	0.16	0.17	0.19	0.19	0.19	0.12	0.18	0.17	0.19	0.13	0.17	0.23

**Table 5.3:** Blockwise draft (m<sup>3</sup>/day): Total annual draft was distributed as 10%, 24%, 28% and 38%

Stress Period	Agiayon	Ara	Barhara	Behea	Charpokhri	Garhani	Jagdishpur	Koilbar	Piro	Sahar	Sandesh	Shahpur	Tarari	Udwantnagar
1	23747	49736	26026	38304	18161	17542	67205	36986	52006	13416	22043	35775	32404	38746
2	47517	84594	45446	76546	37149	35468	139797	71115	103480	23742	46134	67888	66420	83265
3	54309	94553	50995	87472	42574	40590	160537	80867	118187	26693	53017	77063	76139	95985
4	72985	121941	66254	117520	57492	54674	217573	107683	158631	34806	71946	102295	102866	130964

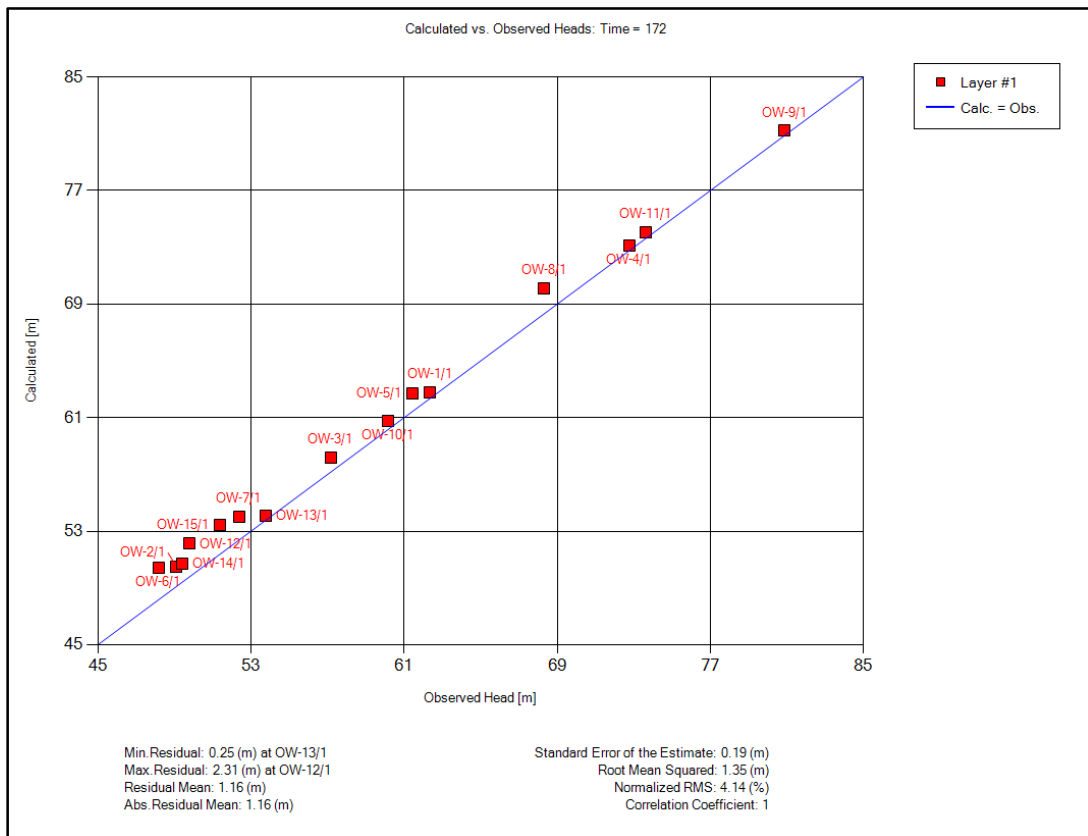
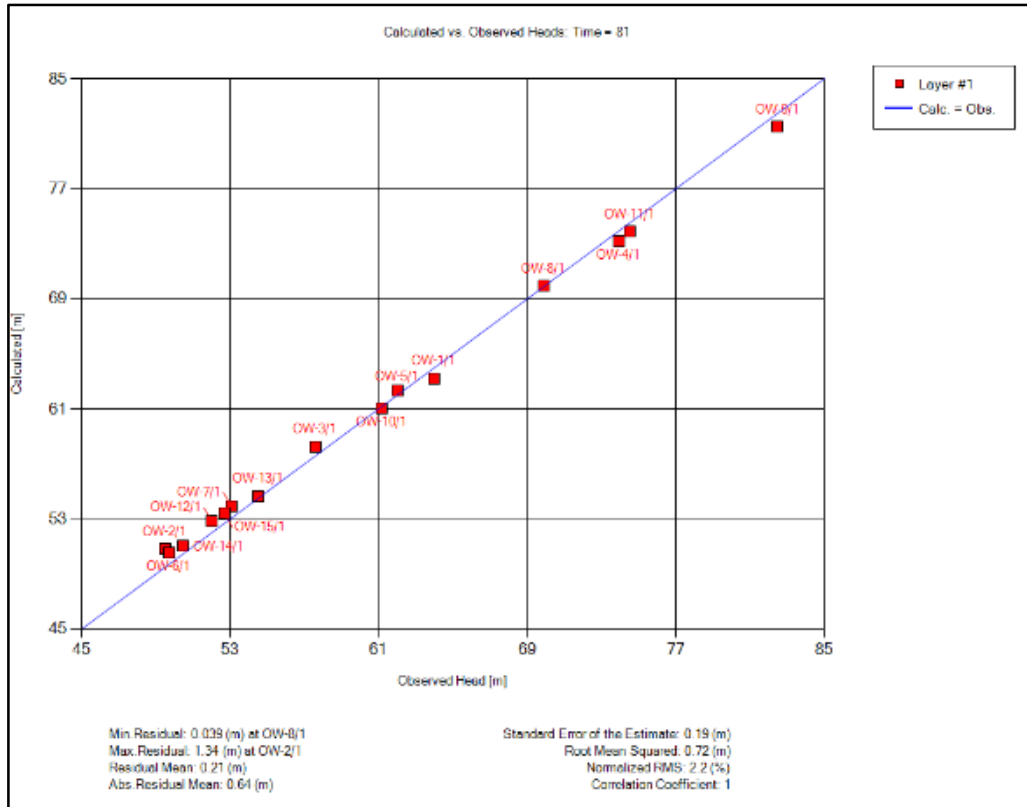
### 5.2.3 Calibration of the model

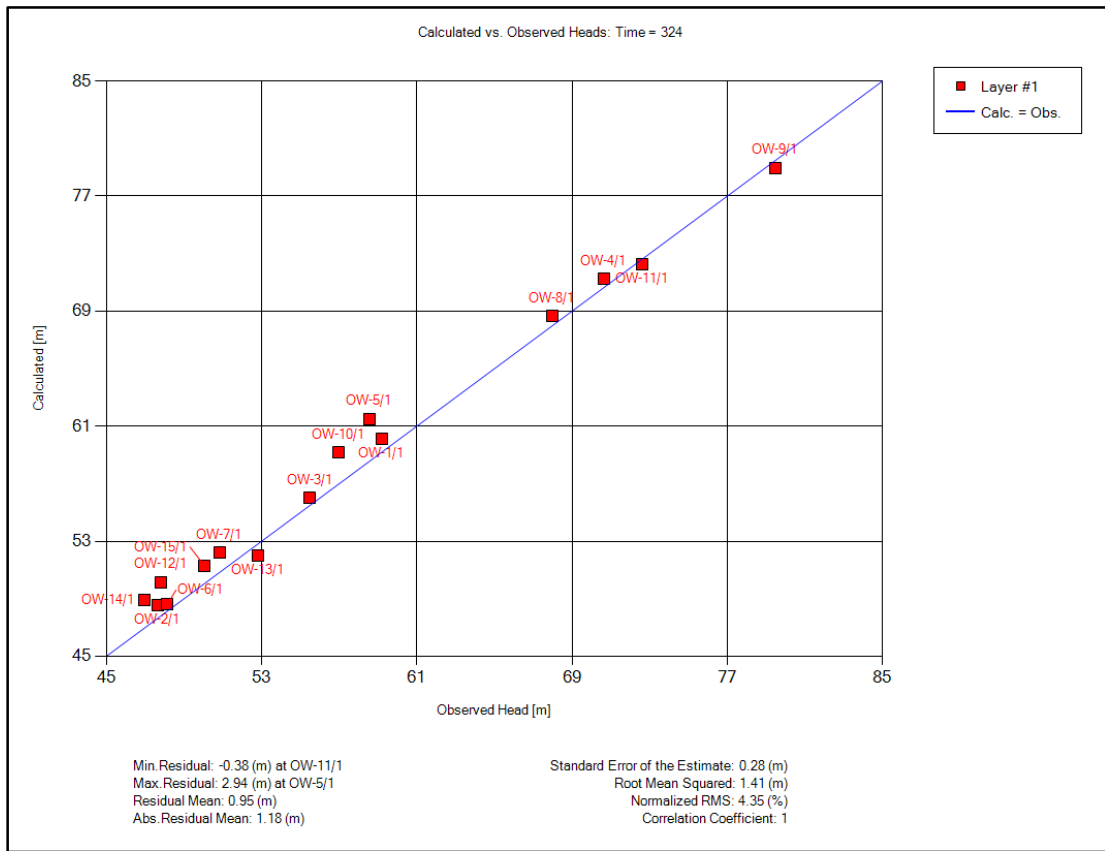
The model was calibrated by tweaking the input parameters (K, Sy, recharge, draft etc.) in such a way that it can reproduce the field measured groundwater heads (observation wells location is shown in Fig. 5.7). The alteration of aquifer parameters or stresses was done by trial-and-error method or automated parameter estimation method. The calibration for unconfined aquifer was made for one year (1<sup>st</sup> to 365 days) and simulated head values were compared with observed values of monitoring wells.



**Figure 5.7:** The location of observation wells in the unconfined aquifer.

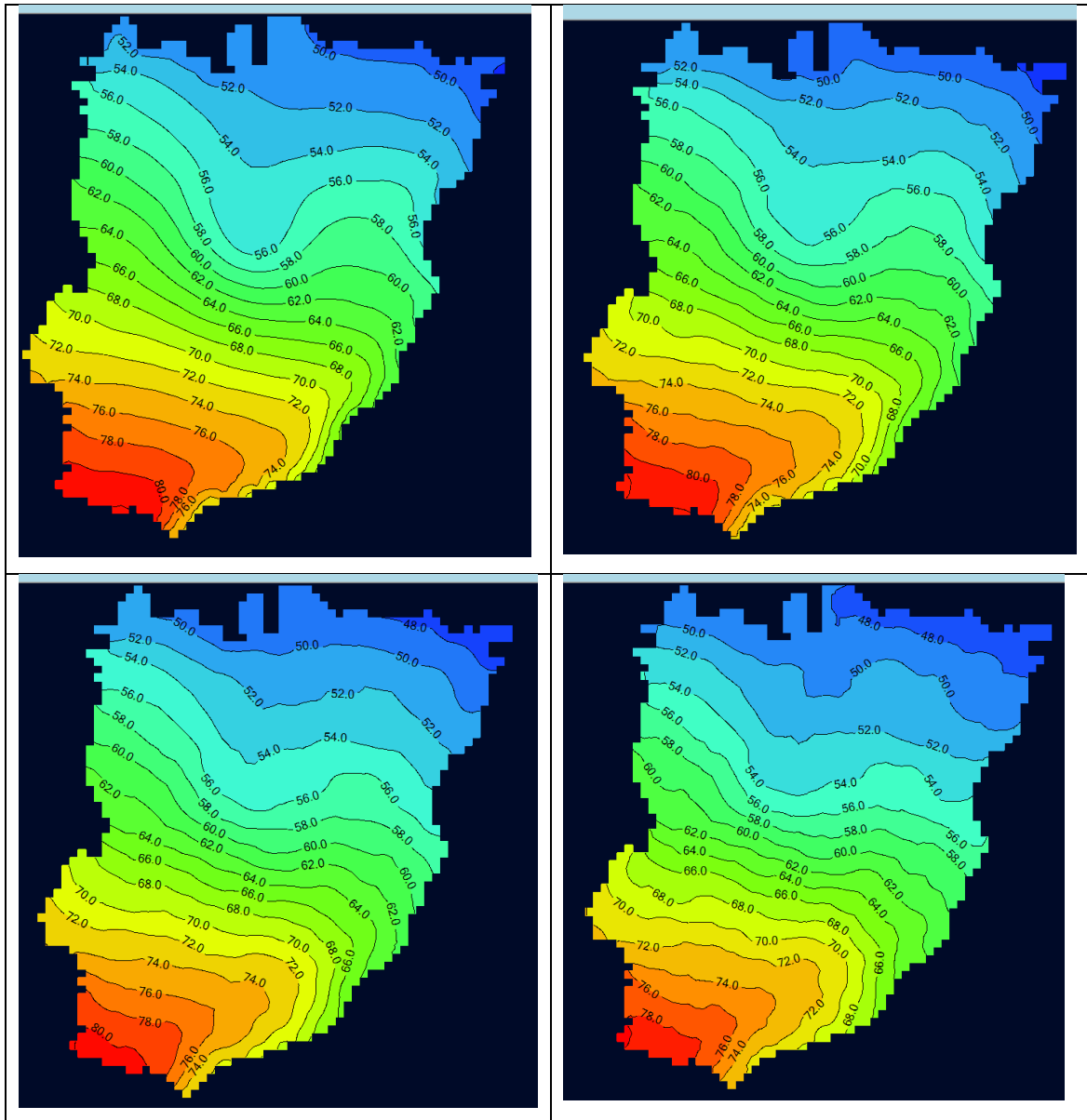
Hydraulic conductivities as reported in literature review were used as initial values for the simulation. By trial and error calibration, the conductivity values for younger and older alluvium were estimated to 30 m/day and 20 m/day respectively. The specific yield was adjusted as 0.06. The pumping rates were adjusted within the range of 15% for calibrating the model. The scatter plots between observed and calculated heads for the aquifers are presented in Fig. 5.8.





**Figure 5.8:** Scatter plot between observed and calculated heads during calibration (a) 1<sup>st</sup> stress period (b) 2<sup>nd</sup> stress period, (c) 4<sup>th</sup> stress period.

The simulated GW heads for the unconfined aquifer during different stress periods are shown in Fig. 5.9. The GW heads are higher in southern side and lower in northern part, and overall GW head fluctuation is 2 m from 1<sup>st</sup> stress period to 4<sup>th</sup> stress period. The water budget for different stress period of the groundwater system is shown in Table 5.4. It is observed that groundwater is contributing more in monsoon season to river in comparison to non-monsoon season. It is also quite obvious that recharge is more in monsoon season and pumping rate is maximum in the pre-monsoon season (stress period 4). The present result may be the rough estimate of water budgeting and further refinement needs be done based on actual and accurate hydrological data.



**Figure 5.9:** Calculated GW heads during calibration (a) 1<sup>st</sup> stress period (b) 2<sup>nd</sup> stress period, (c) 3<sup>rd</sup> stress period (d) 4<sup>th</sup> stress period.

**Table 5.4:** Water Budget of the model during calibration for different stress periods

VOLUMETRIC BUDGET (RATES M <sup>3</sup> /DAY) DURING LAST TIME STEP OF STRESS PERIOD 1			
-----			
-----			
RATES FOR THIS TIME STEP			
-----			
IN:			
---			
STORAGE	=	1305.3325	
CONSTANT HEAD	=	0.0000	
WELLS	=	0.0000	
RIVER LEAKAGE	=	3596.8271	
ET	=	0.0000	
RECHARGE	=	2864317.2500	
SPECIFIED FLOWS	=	30680.5312	
<b>TOTAL IN</b>	<b>=</b>	<b>2899900.0000</b>	
OUT:			
----			
STORAGE	=	2110563.2500	
CONSTANT HEAD	=	0.0000	
WELLS	=	309000.0000	
RIVER LEAKAGE	=	480336.7188	
ET	=	0.0000	
RECHARGE	=	0.0000	
SPECIFIED FLOWS	=	0.0000	
<b>TOTAL OUT</b>	<b>=</b>	<b>2899900.0000</b>	
VOLUMETRIC BUDGET (RATES M <sup>3</sup> /DAY) DURING LAST TIME STEP OF STRESS PERIOD 2			

-----  
-----  
RATES FOR THIS TIME STEP      L\*\*3/T  
-----

IN:  
---

STORAGE	=	138296.6875
CONSTANT HEAD	=	0.0000
WELLS	=	0.0000
RIVER LEAKAGE	=	6127.0688
ET	=	0.0000
RECHARGE	=	1193465.3750
SPECIFIED FLOWS	=	23010.7109
<b>TOTAL IN</b>	<b>=</b>	<b>1360899.8750</b>

OUT:  
----

STORAGE	=	126988.1328
CONSTANT HEAD	=	0.0000
WELLS	=	933798.0000
RIVER LEAKAGE	=	296800.3125
ET	=	3313.3618
RECHARGE	=	0.0000
SPECIFIED FLOWS	=	0.0000
<b>TOTAL OUT</b>	<b>=</b>	<b>1360899.8750</b>

VOLUMETRIC BUDGET (RATES M<sup>3</sup>/DAY) DURING LAST TIME STEP OF STRESS PERIOD 3

-----  
 ----

RATES FOR THIS TIME STEP      L\*\*3/T

-----

IN:

---

STORAGE	=	1019666.3125
CONSTANT HEAD	=	0.0000
WELLS	=	0.0000
RIVER LEAKAGE	=	27452.5801
ET	=	0.0000
RECHARGE	=	119346.5312
SPECIFIED FLOWS	=	23010.1270
<b>TOTAL IN</b>	<b>=</b>	<b>1189475.5000</b>

OUT:

----

STORAGE	=	0.0000
CONSTANT HEAD	=	0.0000
WELLS	=	1064505.0000
RIVER LEAKAGE	=	124970.5234
ET	=	0.0000
RECHARGE	=	0.0000
SPECIFIED FLOWS	=	0.0000
<b>TOTAL OUT</b>	<b>=</b>	<b>1189475.5000</b>

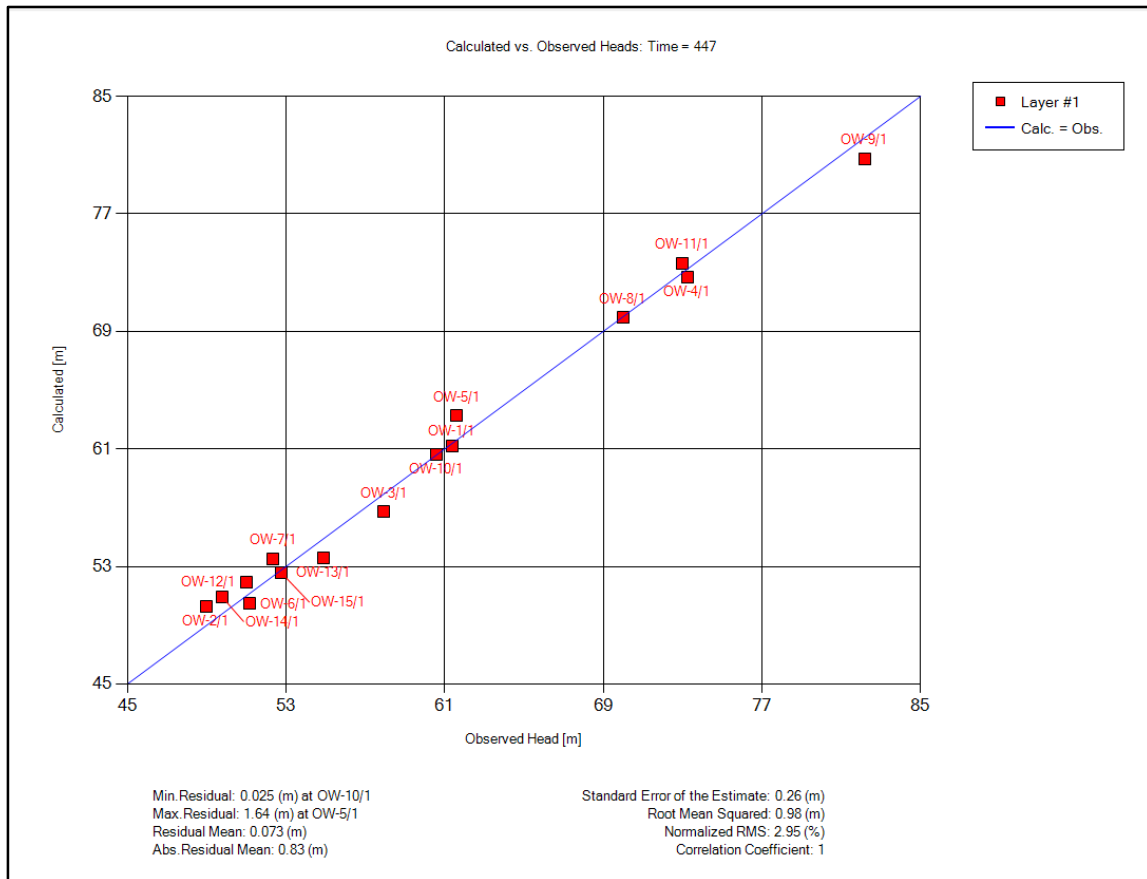
VOLUMETRIC BUDGET (RATE M3/day) DURING LAST TIME STEP OF STRESS PERIOD 4

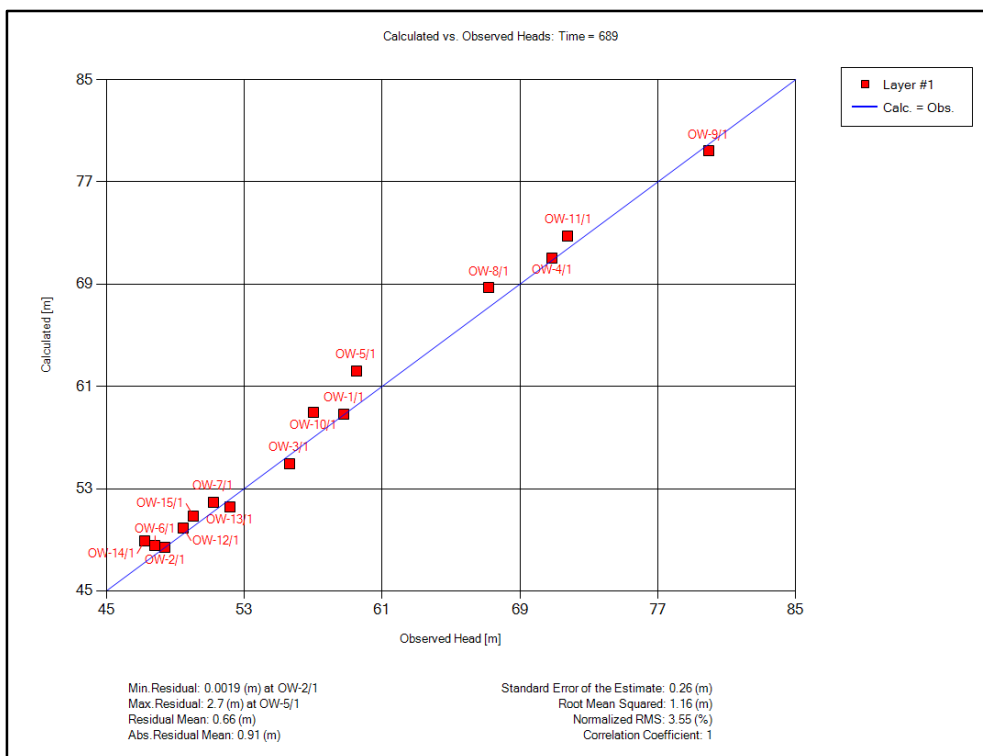
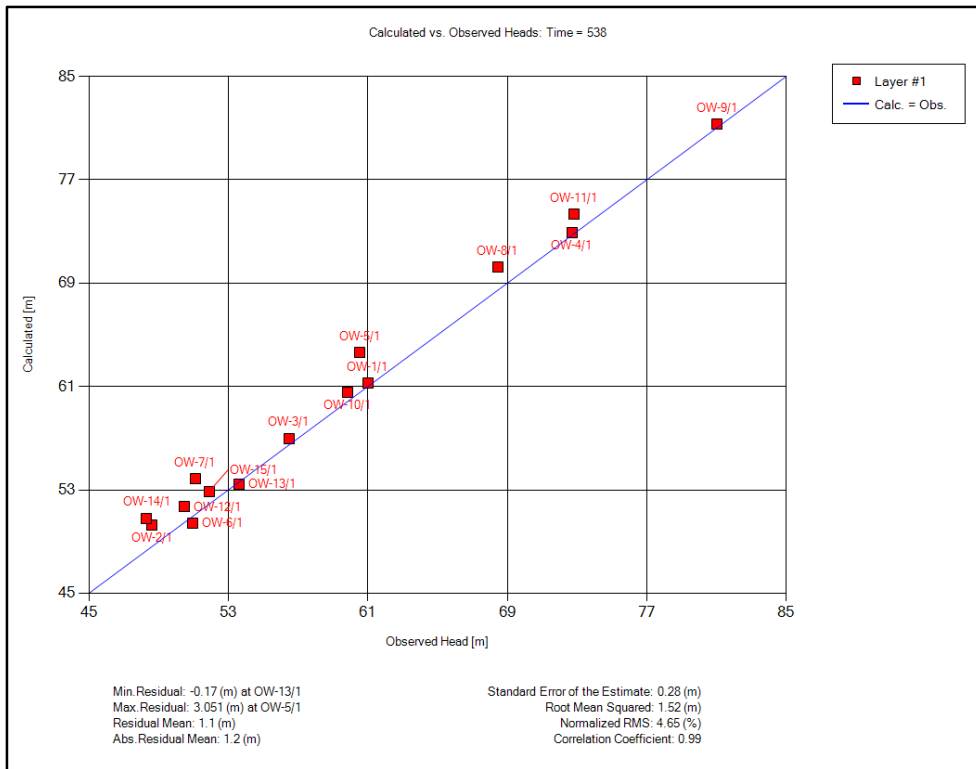
RATES FOR THIS TIME STEP		L**3/T
-----		
IN:		
---		
STORAGE	=	1354301.5000
CONSTANT HEAD	=	0.0000
WELLS	=	0.0000
RIVER LEAKAGE	=	70472.8203
ET	=	0.0000
RECHARGE	=	47738.6133
SPECIFIED FLOWS	=	12786.5771
TOTAL IN	=	1485299.6250
OUT:		
----		
STORAGE	=	0.0000
CONSTANT HEAD	=	0.0000
WELLS	=	1421400.0000
RIVER LEAKAGE	=	63899.5078
ET	=	0.0000
RECHARGE	=	0.0000
SPECIFIED FLOWS	=	0.0000
TOTAL OUT	=	1485299.5000

### 5.2.4 Validation of the model

The model has been verified with another set of field data (another period of time - 366 days to 730 days) to check whether the calibrated model has the predictive power. The model should

also be able to reproduce the field measured values of groundwater heads or concentrations with hydrological stresses in this process. For the present case, the validation period was from July 2016 to June, 2017. The scatter plots between observed and calculated heads confirm good match for different stress periods as shown in Fig. 5.10.

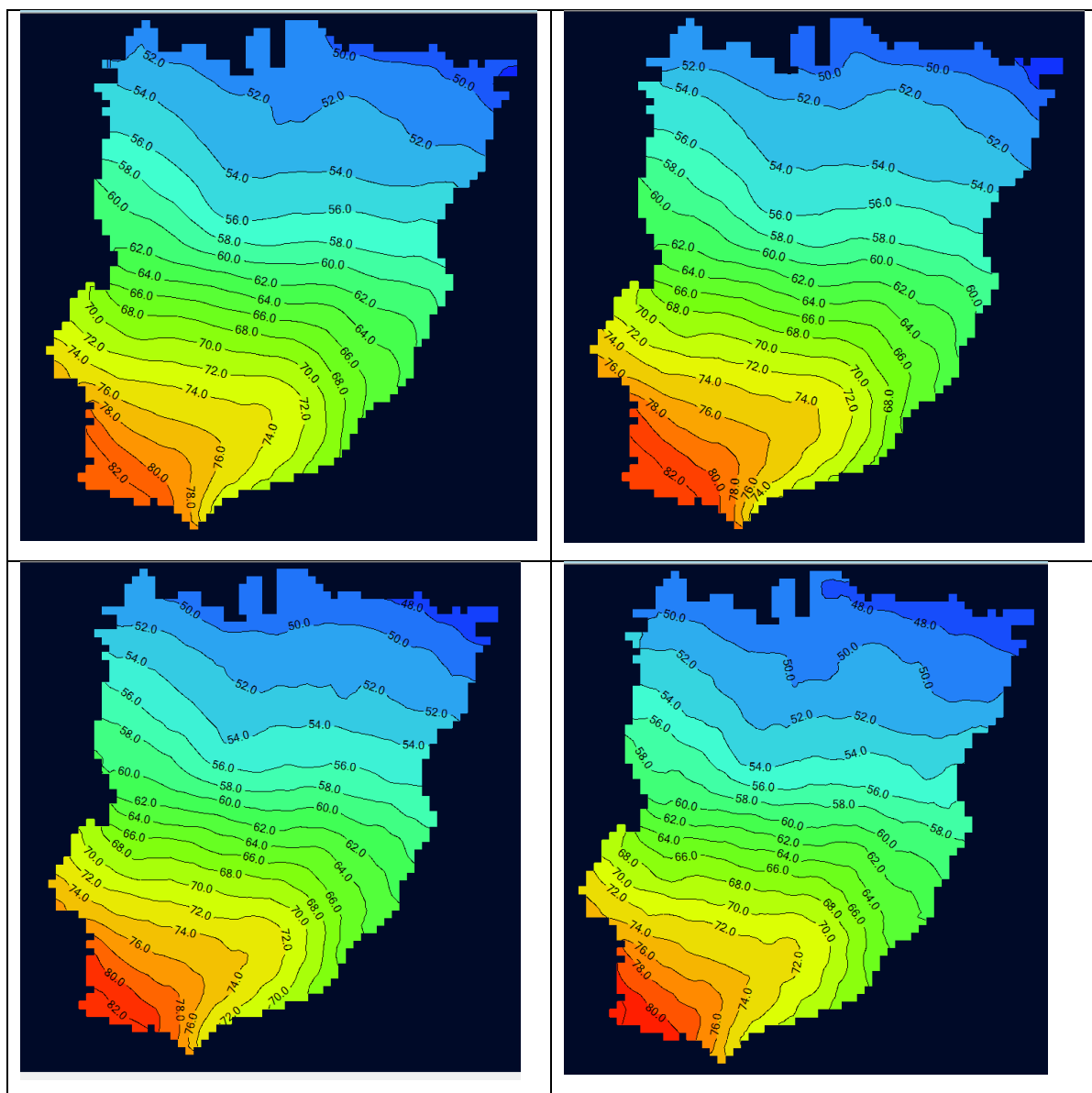




**Figure 5.10:** Scatter plot between observed and calculated heads during calibration (a) 1<sup>st</sup> stress period (b) 2<sup>nd</sup> stress period, (c) 4<sup>th</sup> stress period.

### 5.2.5 Prediction of groundwater heads

The calibrated and validated model was used to forecast the future changes that can occur under different stresses. The impact of reduction of pumping (GW withdrawal) on GW heads was investigated. The 10 % reduction in groundwater withdrawal was done in all stress periods of a year. It was observed that the groundwater head is showing similar pattern as it shown during calibration and validation periods. However, the groundwater head rises upto 2 m in the southern part of the study area and groundwater head rises upto 0.2-0.5 m in middle and northern part of the district. The predicted heads for different stresses are shown in Fig. 5.11.



**Figure 5.11:** The predicted GW head distribution in the study domain during different stresses (a) 1<sup>st</sup> stress period (b) 2<sup>nd</sup> stress period, (c) 3<sup>rd</sup> stress period (d) 4<sup>th</sup> stress period.

### 5.3 Discussion

The groundwater level trend and groundwater budgeting have been analysed for the Bhojpur district. The analyses revealed the mixed response for groundwater level pattern. i.e. some of the monitoring wells show declining as well as rising trend but not statistically significant and few of them shows no trend. The literature review and analysis revealed that the study area has surplus groundwater. The coarser GW model results show that groundwater is contributing to river Ganga and flow direction is from south to north direction. The GW head was also predicted by assuming that 10% GW withdrawal decreases in 5 years due to agriculture water saving measures. We found that GW level increases significantly particularly in southern part. The groundwater level data is available in the region but estimates for volume of groundwater use for irrigation and other purposes is lacking. The data sets like remotely sensed or independently estimated data pertaining to processes like evapotranspiration and recharge can be very useful in reducing predictive uncertainty in the regional scale models that are used for understanding the regional hydrological impacts of water saving measures. The multiple stresses such as climate change, rapid urbanisation, changes in river flow etc can interfere with the dynamics of the groundwater resource in Gangetic plains. A two-way approach that explores the system from local-to-regional and regional-to-local is needed to investigate and explore these effects. Integration of field/local scale data and coarser scale remote sensing data sets in scalable models is required for this. The results of this scoping study (analyses was done with the scarce data), it may be a good idea to have a comprehensive understanding of the groundwater resources and their future sustainability at regional scale in the Gangetic plains. The aim for the future work may be to provide options for sustainable groundwater management for irrigated crop production in the Gangetic plains considering future scenarios (such as population growth, economic development, climate change, etc.) and thus improve the livelihood of the farming communities including women and marginal farmers.

## 6.0 Summary and Conclusions

This study focusses on middle Ganga basin consisting of Bhojpur district of Bihar, India which is located in the western part of the state. It lies in between 25°10' and 25°40' North latitudes and 83° 45' and 84° 45' East longitudes. The district is bounded by Ganga river in North and Son river in East. The entire district consisting of 14 blocks forms an interfluvial zone of Ganga and Son rivers. The normal rainfall of the district is reported to be 1,080 mm/yr and the annual rainfall varies from 1,025 mm to 1,106 mm. Agriculture is the predominant economic activity in the district. Bhojpur is considered as the rice –bowl in the state and Rice- mill is a traditional industry. The major food crops of district are wheat, pulses, oil seeds and maize. The geographical area is 2,33,729 ha out of which 1,88,134 ha is net cultivable area with nil forested area. The net irrigation area in Kharif season is 1,00,407 ha and in Rabi season it becomes 68,781 ha. The geological characteristics of the district are alluvium in nature consisting of younger and older Gangetic alluvium which forms the potential aquifers. The Northern and North-East parts of the district forms younger alluvium whereas the southern and central parts are enclosed with older alluvium. The study area has a common slope towards the North and North-East. The common elevation with respect to mean sea level is 50-90 m. approximately and the gradient is 0.6 m/km from South to North. The district in general possesses alluvium soil and the soils are of poorly drained type. The depth to water level in pre-monsoon season (year 2018) varies from 3.0 to 9.0 m bgl with minimum and maximum values observed in South-Western part and North-Eastern part. The hydraulic gradient indicated groundwater movement towards the river Ganga. It is observed that there is no or very less declining trend of groundwater level in the study area, however, fluctuation of groundwater level can be noticed between pre and post monsoon season which indicate that natural recharge is good in the area. The M-K test shows that there is no significant declining trend of the groundwater level in the study area. The major land uses in the study area are vegetation (46.13 %) followed by built-up area (21.64 %), fallow land (16.52 %), barren land (7.37 %), sand bank (6.08 %), waterbodies (2.26 %). A coarser transient groundwater modelling was attempted with data collected and making certain assumptions. The developed GW model results shows that groundwater head is higher in southern part in comparison to northern part of the study area and GW is contributing to the river Ganga. It was also investigated the impact of reduction of pumping (GW withdrawal) on GW heads. The 10 % reduction in groundwater withdrawal has impacted the groundwater head and the rises upto 2 m in the southern part and 0.2-0.5 m in middle and northern part of the district.

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