MTech Project Report (TD 696)

on

Modelling and Water Balance for Highly Irrigated Area in Sinnar

Submitted in partial fulfilment for the degree of M. Tech.
in Technology & Development

by

Anish Holla V

(Roll No. 153350008)

Under the guidance of

Prof. Milind A Sohoni

Centre for Technology Alternatives for Rural Areas (CTARA)
Indian Institute of Technology, Bombay,

Powai, Mumbai – 400076

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Dissertation Approval Sheet

This dissertation titled **"Modelling and Water Balance for Highly Irrigated Area in Sinnar"** prepared by Anish Holla V (Roll no: 153350008) is approved for the degree of **Master of Technology** in Technology and Development.

Examiner I

(Prof. T.I. Eldho) 7/7/17

Examiner II

Bakul Rao

(Prof. Bakul Rao)

Supervisor

(Prof. Milind A Sohoni)

Chairperson

(Prof. Avijit Chatterjee)

Date: 07/07/2017
Place: IIT Bombay, Mumbai

Declaration

I hereby declare that the report **“Modelling and Water Balance for Highly Irrigated Area in Sinnar”** submitted by me, for the partial fulfilment of the degree of Master of Technology to CTARA, IIT Bombay is a record of the work carried out by me under the supervision of Prof. Milind A Sohoni.

I further declare that this written submission represents my ideas in my own words and where other’s ideas or words have been included, I have adequately cited and referenced the original sources. I affirm that I have adhered to all principles of academic honesty and integrity and have not misrepresented or falsified any idea/data/fact/source to the best of my knowledge. I understand that any violation of the above will cause for disciplinary action by the Institute and can also evoke penal action from the sources which have not been cited properly.

Place: Mumbai

Date: 04-07-2017

Anish

Signature of the candidate

Acknowledgement

It is matter of great pleasure for me to submit this report on **“Modelling and Water Balance for Highly Irrigated area in Sinnar”** as a part curriculum of **TD-696** of Centre for Technology Alternatives for Rural Areas (CTARA) with specialization in Technology & Development from IIT Bombay.

I express my sincere gratitude to my guide **Prof. Milind A Sohoni** for guiding me and helping me comprehend the study in a better way. I specially thank Hemant Belsare and Gopal without whom this study would have not been possible. I am grateful to **Yuva Mitra** (NGO), which is based in Sinnar and works in strengthening community assets for sustainable livelihood resources and supporting community actions for human right and good governance, in the region of Sinnar taluk, their work in the field of Developing Community asset like DBI to provide cropping water security in the region is always been a key motivation for the present work. I sincerely thank Pooja for introducing me to the study area of Wadgaon Sinnar. I thank TDSC, Lakshmi, Sameer and Vishal for their selfless support. Finally I thank all my friends for their support.

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Anish Holla

Roll No. – 153350008

Abstract

In this paper, we analyze the water balance for a diversion based irrigation system from the viewpoint of assessing the utility of the diversion canal. The study is based on the Devnadi watershed in Sinnar taluka of Nasik district.

In Sinnar taluka, there is colonial time canal irrigation system called Diversion based irrigation system (DBI) which diverts a part of water from Devnadi River flowing through the Sinnar and takes it to farm lands. DBI is an important canal irrigation system in the region. One of the main aims of this study is to understand the impact of these DBI's at the village level. Also as most of the studies are focused on water balance and modeling in watershed level, this study tries to build water balance and modeling in village level. A village Wadgaon Sinnar in Sinnar taluka with DBI system was chosen as the study area. Then flows were measured at some locations in the village to estimate the seepage due to canal, 48 wells were marked as observation wells and well readings were recorded periodically to observe the groundwater levels variation. Simultaneously cropping survey was carried out in the village to collect cropping and pumping data in the village. Based on the data collected and field observations, boundary conditions were defined for the village. Groundwater model was built and simulated in steady state condition using MODFLOW software.

Some of the observations found by this study were that DBI acts as important agent of groundwater recharge in the study area. The impact of DBI is not restricted to the canal command area but it also improves ground water availability in the non-command area i.e. upstream by acting as a barrier for groundwater flow from upstream regions.

Abbreviations

AMC	Antecedent Moisture content
BC	Boundary Condition
DBI	Diversion Based Irrigation
DEM	Digital Elevation Model
DPA	Drought Prone Area
GIS	Geographical Information System
GMS	Groundwater Modeling Software
GOM	Government of Maharashtra
GRASS	Geographic Resource Analysis Support System
GW	Ground Water
HSG	Hydrological Soil group
JSY	Jalayukth Shivar
Mbgl	Meter below ground level
MSL	Mean seal level
NCIWRD	National Commission on Integrated Water resources
SCS	Soil conservation Service
SRTM	Shuttle Radar Topography Mission
TAO	Taluka Agricultural Officer
TCM	Thousand cubic meter
YM	Yuva Mitra

1. Introduction

1.1 Agricultural water

With increasing population and growing demand for water, there is a tremendous load on water availability for irrigation. Over the period of time, dependence of irrigation on groundwater has increased and its excessive use has had an adverse impact on the GW resources. Irrigation plays an important role in accelerating agricultural productivity and consistency. In India, water resource available is estimated at 1869bcm of which 1123bcm of water can be utilized. This estimate was based on physiographic condition, legal and constitutional constrains, socio-political environment and technological available at hand. The GW available is 433bcm (unconfined aquifer) [1], from 1951 per capita availability of water is declining which is at 1700 m^3 which is considered as water stressed condition. According to NCIWRD irrigation/agricultural water demand is set be 611bcm based on the assumption that irrigation efficiency will increase to 60% from the current 30-40%. CGWB has estimated the current GW draft at 230.6 BCM and overall stage of GW development in the country is 58% [2].

In our country about one third of total geographical area is recognized as drought prone area which in turn accounts to 42% of total cultivable area. Among states Maharashtra is ranked 5th in terms of drought prone areas. Over the period of 1951-2007 the irrigation from GW has increased by 6.3 times, as GW provides control over irrigation to farmers. Even in canal command areas GW is used to supplement canal water to maximize agricultural production. Hence there is a need to address the challenges of how to restrain and make more efficient, the use of GW to sustainable level in over exploited areas. As GW is an open resource and everyone can pump it from his/her land overexploitation becomes a common phenomenon especially in agriculture as mentioned before [3]. It is also noted that control in GW extraction has not yielded good results by command and control mechanism. So there is a need by State governments to work with co-operation of user group and community participation.

In Maharashtra around 52% of its cultivable area falls under DPA, having an average rainfall of less than 750mm. The State is experienced drought from the year 2012-2015, which heavily impacted farmers, rural livelihood and agricultural production. In 2012 drought there was reduction in food grain production by 18% [4]. All these factors contributed in focusing water management in village, i.e., local level rather than at watershed level which was followed before, in order to bring it closer to people and make implementation easier. For example GOM launched a scheme in 2014 called JSY (Jalayukt Shivar Yojana) as drought proofing scheme. The objective of the program was to harvest rainwater and increase the GW level in village level. One of the activities involved is to prepare water balance sheets for village level [5]. This is an important step in the public comprehension of the acute problem of scarcity.

1.2 Scope of study

This thesis is a part of a broader attempt to refine and yet make more accessible, the computation of water budgets for different irrigation scenarios. While the most important scenario village is obviously the rain-fed and/or groundwater based irrigation village, such village frequently sit right besides those with some amount of surface water irrigation. In this thesis we look at a village with Diversion based canal, i.e., diversion of some of the flow of a river to make it pass through field. Such diversions are less capital intensive and yet the beneficiary group can be large.

It is important to analyze such a village with a canal to quantify the impact on cropping and GW because of canal dynamics at play. Based on these quantification there is need to develop a basic water balance model in the village. As most of the studies and are focused on watershed level balance and modeling, there is as such, no clear methodology which is available in research or studies carried out to understand the effect of canal in a village level. There is a need to study two core issues i.e. modeling the impact of canal in a village level and developing crop water balance in an village level.

1.3 Objectives of the study

- To understand impact of Diversion Based Irrigation system on cropping and groundwater scenario in Wadgaon Sinnar.
- To develop a conceptual model for estimating groundwater flows in and out of the village
- To delineate different zones at village level based on various parameters like soil thickness, land use and water availability
- To build a crop water balance in the village level

1.4 Report layout

There are five chapters in the report. Chapter 1 lays out the introduction, literature and describes the background of the study region giving an introduction to types of systems existing in the study area. While chapter 2 gives a detailed picture of the study area describing various factors like terrain, watershed etc. The chapter 3 is about the field level survey conducted in the study area and analysis of the data thus obtained. Introduction to basics of groundwater flow in given in chapter 4 and chapter 5 discusses about the process of developing a conceptual model for the study area. Results and conclusions are given in the chapter 6 followed by annexure.

1.5 Overview of methodology

This section provides an overview of the methodology adopted in developing the modelling for an area under irrigation.

- **Selection of Study area**: A study area is selected based on the thesis proposed. Wadgaon Sinnar was selected as it was a village in an agricultural watershed which was classified as over-exploited (Chapter 2.1) and had canal system in place.
- **Understanding study area**: Modelling of a natural system requires a good understanding of the region. As modelling of natural system is normally based on empirical data there is need for data. Hence one of the common issues faced in these scenarios is the lack of data which has to be collected through various methods and techniques. Some of the secondary data used are rainfall in the study area, village level sowing report, specific yield and hydraulic conductivity etc.
- **Field survey**: These are conducted to get required data for example water level data was obtained by selecting some wells in the region as observational wells and monitoring it at regular intervals. Similarly other data like cropping pattern, well recharge, water extraction, soil thickness were collects by field surveys.
- **Preparation of conceptual model**: Once all the data are collected a conceptual model is built to mimic the observed natural system in the study area. Here data in form of rainfall data, GW fluctuation, terrain model, geological zones, GIS etc were used.
- **Boundary condition**: In groundwater modelling defining the BC is important aspect, as it separates study area from vicinity of other area and more importantly defines flow in and out of the system. In case of villages which are usually part of a larger watershed,

determining the BC in village level becomes more complex than defining BC for complete watershed.

- **Simulation**: Here after developing conceptual model and boundary condition the model has to be simulated in steady state/transient state to assess the changes in GW dynamics and other parameters of the study area.

1.6 A brief introduction to village level water balance

Water balance techniques, one of the important part of hydrology are a means of solution for theoretical and practical hydrological issues. Further water balance in a village level becomes tricky and complex issue especially if there is irrigation canal present in the area. To understand various parameters which affect the groundwater dynamics of village a comprehensive understanding of the village is required. With the growing dependence of irrigation on the groundwater and it's over extraction results in impact on the water resource domain [6]. There have been various methods developed to asses water stress in an area like WPI (Water poverty index) which considers factors like resources available, access to water, capacity, use and environment to determine stress. Considering weighted average of each of these factors a WPI is developed [7]. In paper on WPI Sullivan et al (2003) stresses the point that to accurately characterize groundwater resource, local data is a must.

The study of water balance equation is generally application of principle of conservation of mass, in other words continuity equation. This states that, for any arbitrary volume and during any period of time, difference between total input and output will be balanced by the change of water storage within the volume [8]. Equation (1) is a basic water balance equation for a given system/area and over a period,

$$P + Q_{SI} + Q_{UI} - ET - Q_{SO} - Q_{UO} - \Delta S = 0 - - - - - (1.1)$$

Where

P is the precipitation

Q_{SI} and Q_{UI} are the surface and subsurface water inflow

Q_{SO} and Q_{UO} are the surface and subsurface outflows

ET is the evapotranspiration load

ΔS is the total water storage in the body

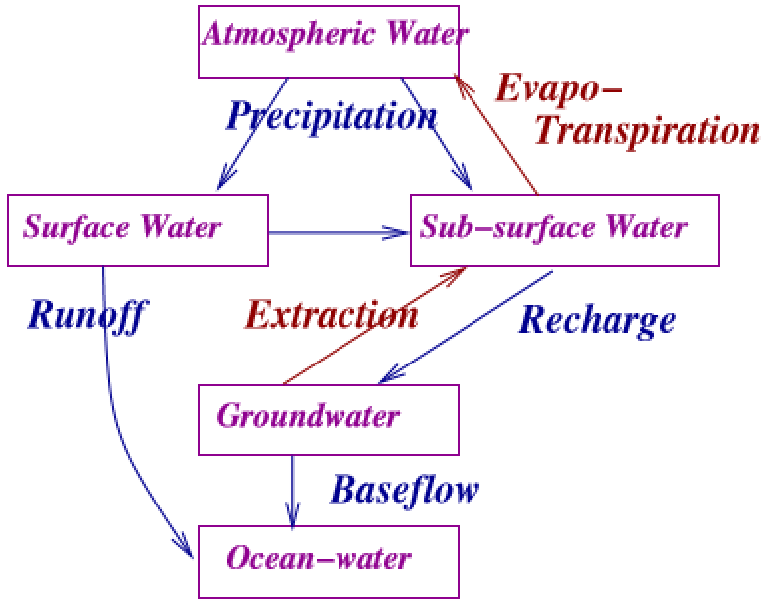


Figure 1.1: Water balance in a typical System

The figure 1.1 (source: TD603 class notes) represents a simple water balance, eqn.(1) explains the GW as a stock in the system. It states different parameters affecting the stock like precipitation, base flow etc.

There is various interlinks involved while considering the canal flow in a study area which is briefly described here. In a study on effects of irrigation on water balance, yield and WUE of winter wheat in North China plain it was found that there was linear relationship between increasing irrigation and increase in ET load [9]. In every region the water discharged by evapotranspiration from the soil and by transpiration of plants is derived from groundwater in the zone of saturation. ET load is considered to decrease the GW level during day and it recovers during night. In a paper on effect of ET load by White (1932) mentions that direct effect of ET load on GW becomes negligent if water table is below 3.5mbgl [9]. In an irrigated watershed this scenario can't be considered as water is supplied through pumps and through irrigation canals to the farm lands.

Other parameters like hydraulic conductivity, specific yield which is used to determine the GW flow in and out of the area can be calculated using pumping test. In pumping test the change in

GW level is measured with certain intervals along with discharge from the pump which is later used to calculate Hydraulic conductivity and specific yield [10]. In the field i.e. an agricultural village with canal irrigation conducting these test are complex as well where this pumping test has to be conducted should be away from the influence radius of other wells. So the values for these have to be assumed from the literature. Runoff in the village can be calculated using SCS runoff curve number [11].

A village level water balance in an irrigated area involves lot of parameters and due to lack of data, hence data has to be collected from surveys, literature and some assumption.

1.7 Sinnar Taluk

Region of study was chosen in Sinnar taluka of Nashik district as it's an agriculturally dominant taluka known for vegetables and horticulture.

Figure 1.2: Nashik district map

(Source:CGWB)

Nashik is one of the agriculturally developed districts in North Maharashtra with nearly 56% of the land use is for agriculture in the region. There are 15 tehsil in the district, Sinnar is a tehsil located south of Nashik city [12]. The population of Sinnar is around 3.5 lakhs with an area of 1352.61 km^2 and has 129 villages under it of which 68 villages were tanker fed (Source: Sinnar taluka office). Sinnar is known for horticulture and other major crops grown in this region is Bajra, onion and wheat. Sinnar has very high crop diversification with wide range of crops grown. Hence these are the regions where horticulture is the main source of income.

There are two rivers in Sinnar namely Devnadi and Shivnadi**,** Shivnadi joins Devnadi near Sinnar town. There is a unique irrigation system in the region know as Diversion Based Irrigation System (DBI) which was built during the British rule. These innovative irrigation systems are fed by Devnadi River. As DBI was an old system it had become defunct due to neglect over the period of time. As the Sinnar taluka faced continuous drought over past few years there was raised concern towards management and efficient use of water. Yuva Mitra (YM) an NGO based in Sinnar spearheaded a campaign to revive the DBI system on Devnadi and currently more than 12 DBI systems have been revived on the banks of Devnadi in Sinnar taluka. Considering these factors Wadgaon Sinnar a village in Sinnar taluka whose DBI system was revived in the year 2011 was chosen as the study area. Yuva Mitra was chosen as a partnering NGO in the region.

1.8 DBI

1.8.1 DBI System

A DBI is a system which diverts a portion of overflowing water from a river/stream and uses it for the purpose of irrigation or other domestic needs. This system has been in vogue for decades in regions that have appropriate features/topology. There are different names for this type of irrigation system in different part of the country like Phad in Maharashtra, Kul in Himachal Pradesh, Zebo in Nagaland.[13]

DBI is specific to topological areas where river flow has steep gradient which helps in construction of diversion weir to divert a part of flow into the system. Designing of the DBI is done based on slopes of the area and flow in DBI is through gravity. Post monsoon the base flow keeps the DBI functional till Rabi season providing irrigation water for crops. One has to note that initially the DBI was built with primary aim of providing crop water till the end of Rabi season to every farm in command area. Currently the flow in DBI dries up by the month of December (Wadgaon Sinnar) this is mostly because of the increased cropping area over the period of time. Hence the current role of DBI is more of a passive one where in it recharges the water table and maintains a constant GW level. In other words crop watering for Rabi season is done by pumping from the wells which in turn are recharged by the canal water, which is either flowing, or from water recharged by canal in the recent past.

Figure 1.3: DBI system

1.8.2 Design and working of DBI

DBI gets its water from overflowing CNB's which are constructed across rivers. If the water head is equal or greater than that of CNB wall, water will enter DBI through a rectangular opening as shown in the figure above. Normally a village has 1-2 DBI system in place. The process of selecting the site is carried out by taking into consideration the river base gradient and slope of command area. Series of Bandhara/CNB's are built across the river and with typical height of these ranging from 1-5 m. The height of diversion/DBI entrance is designed such that part of excess water from the river enters the main canal and excess water overflows over the CNB to downstream. The figure 2.3 shows the working of a DBI system [14].

DBI works in the following manner, water enters main canal and its network through the DBI entrance. Canals are built through banking and cutting depending on topology of the region. Length of canal varies from one DBI to other. Along the length there are sluice gate (inlet gates) provided at various location for letting the water into the field. Finally the main canal joins back to the river at the end of canal. To regulate excess water entering the main canal escape gates are provided which lets water from canal back to the river. As DBI are community owned systems, water usage and maintenance of the DBI depends on community participation. It's through WUA (Water user association) that farmers come together and decide who will get water for how many days when DBI is operational in other words water rotation is decided through annual or bi-annual meeting of communities.

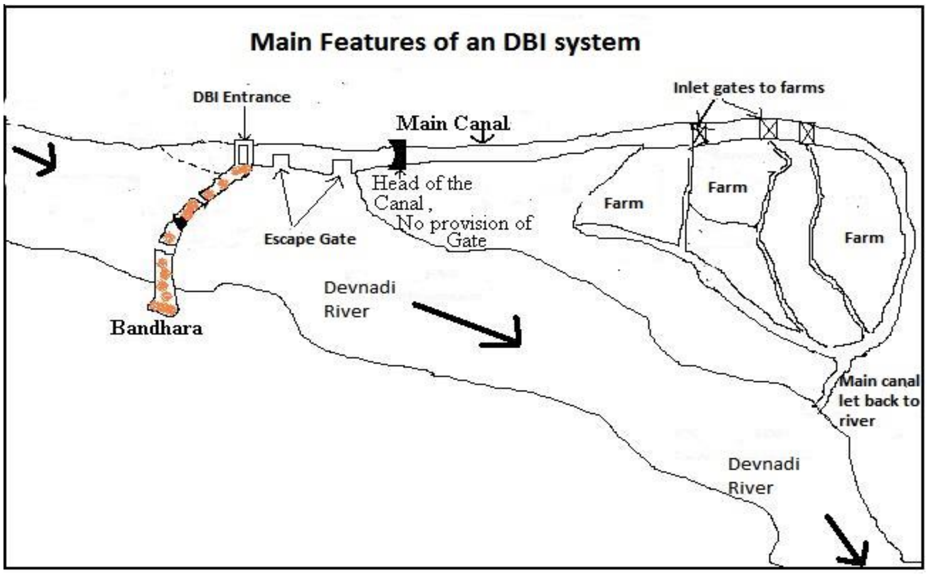


Figure 1.4: Design representation of DBI

Some of the advantages of DBI over conventional canal system are mentioned below

- Utilizing overflowing water for irrigation.
- Increasing irrigation command area.
- Low cost of construction, operation and maintenance.
- Acts as an important agent in recharge of groundwater.
- Creates new livelihood options by providing water to un-irrigated lands.
- Canal management is based on bottom-up approach by building community based management structure and association.

2. Wadgaon Sinnar

2.1 Introduction to study area

The study area is located at an latitude 19.853059°, longitude of 74.00° and elevation of 690m southeast of Nashik and at a distance of 30km from it. Following table gives the demographics of the area [15]

Table 2-1: Demographics

Area of village (ha)	815
Population	2722
No. of Household	466
Percentage of cultivators and Agri Labourers	54% and 36.8%
Cultivable land (ha)	693

Source: Census data 2011

Study area was chosen because of the village was within watershed GV-21 which is a over exploited, which means that the stage of GW development is greater than 100% in this watershed [16]. Other reason is the presence of DBI in the area, this village along with the neighbouring village Lonarwadi were the first villages where DBI was rejuvenated by YM in the year 2011.

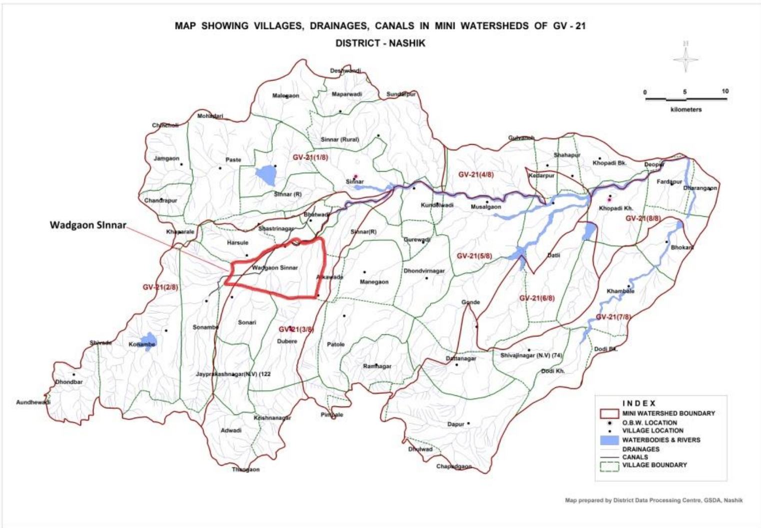


Figure 2.1: GV-21 watershed

(Source: CGWB)

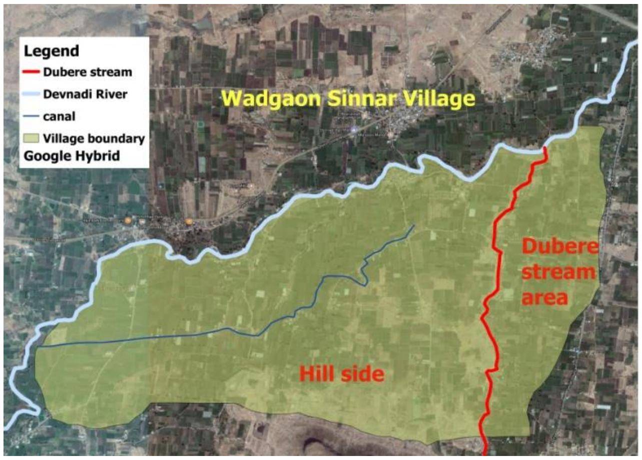


Figure 2.2: Wadgaon village

During the drought year 2015 certain parts of this village was under tanker fed area during summer. The following table further gives some socio-economic information about the village obtained by survey.

Table 2-2: Socio-economic and general information

Sr. No	Attributes	Details	Wadgaon
1	Family Size	1 to 5	14%
		6 to 10	45%
		> 11	41%
2	Earning Members	1 to 2	54%
		3 to 4	44%
		>5	2%
3	Education	Technical	7%
		Post Graduate	7%
		Graduate	33%
		HSC	31%
		SSC	22%
4	Main Occupation	Farm	95%
		Service	3%
		Agri. Labor	2%
5	Caste	OPEN	42%
		OBC	12%
		NT	35%

		SC	9%
6	Ration Card	Yellow	54%
		Kesari	46%
7	House Type	Kaccha	47%
		Pakka	53%
		Both	91%
8	Total Land Holding	1 to 5 Acre	67%
		5 to 10 Acre	26%
		> 10	7%

Source: Field survey (sample size 43, Gopal APS-1)

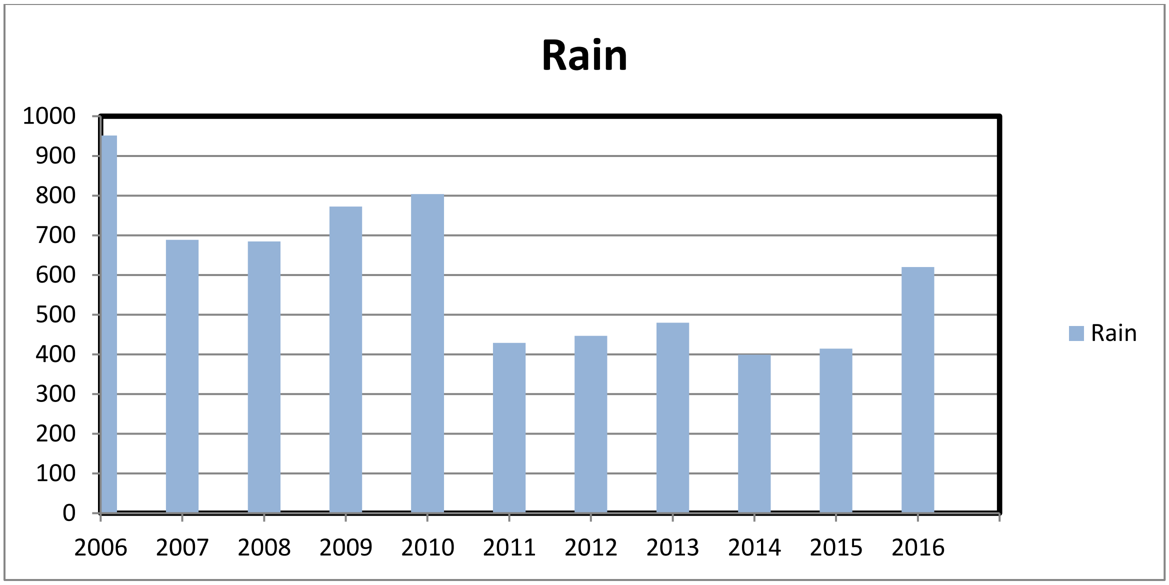
2.2 Village level watershed

Study area is a part of the Devnadi watershed and is locates upstream of the river. The aim of this section is to discuss various geological, climatic and other components of the study area.

2.2.1 Climate and Rainfall

The maximum temperature varies from 42.5°C in summer to minimum temperature of 6°C during winter, while the humidity ranges are from 43% to 62%. Climate is characterized by general dryness throughout the year except during south-west monsoon. Winter season is from the month of December till February, followed by summer up to May. While monsoon season is from the month of June till September [17]. After monsoon the area doesn’t receive any rainfall.

Normal rainfall in the study area is 615mm. The following figure gives the yearly rainfall if the region for past 10 years. Lowest rainfall was recorded during the years 2011, 2014 and 2015. According to agro climatic zoning by Dept. of Agriculture, GOM study area falls under Transition zone 1i.e. zone located on eastern slopes of Sahyadri ranges [18].



Source:maharain.gov.in

Figure 2.3: Rainfall in last decade

As one can see the actual rainfall for the past 5 years was below average in the study area resulting in drought like situation. But in the current year the rainfall was good/normal at 620mm. Rain circle used to record the rainfall in the study area was Dubere circle. For the current year (2016) the daily rainfall is given by figure 2.3.

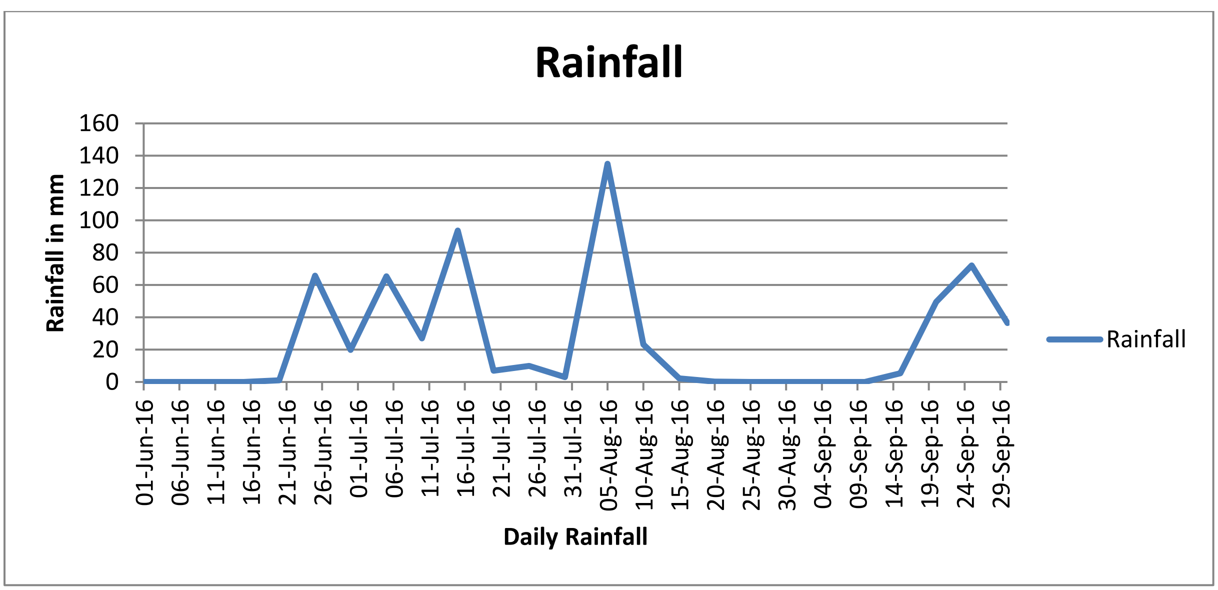


Figure 2.4: Rainfall in days

2.2.2 Geomorphology

The region forms the part of Western Ghat and Deccan Plateu, Sinnar falls in Godavari basin. The district is monotonously covered by the basaltic lava flows, called the 'Deccan trap'. These rocks have been considered to be a result of fissure type of lava eruption during the cretaceous – Eocene period. Soils of the region are weathering product of Basalt and have various shades of Gray to black. Soils are classified into four types namely lateritic black soil, reddish brown soil, coarse shallow reddish black soil and medium light brownish black soil [17].

Soil thickness in study area varies from 1m to 18m, on an average soil thickness can be assume to 2-3m. Murum is the second layer which is again of 3-4m followed by hard rock. There are around 7 types of soil in Sinnar taluka but the study area mainly has two types of soil textures namely gravelly clay loam and clayey soil.


Figure 2.5: Hard rock layer and soil

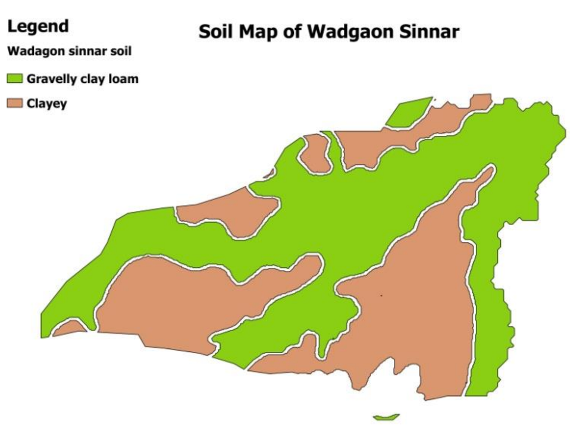


Figure 2.6: Soil map

(Source: MRSAC)

2.2.3 Terrain

The terrain in the study area has less undulation i.e. a gradual slope. Elevation in the area varies from 675m to 725m as there is a hill in the boundary of the village. One side of the village boundary is along the river hence the slope of the village has gradient towards it but it's mostly less than 5%.

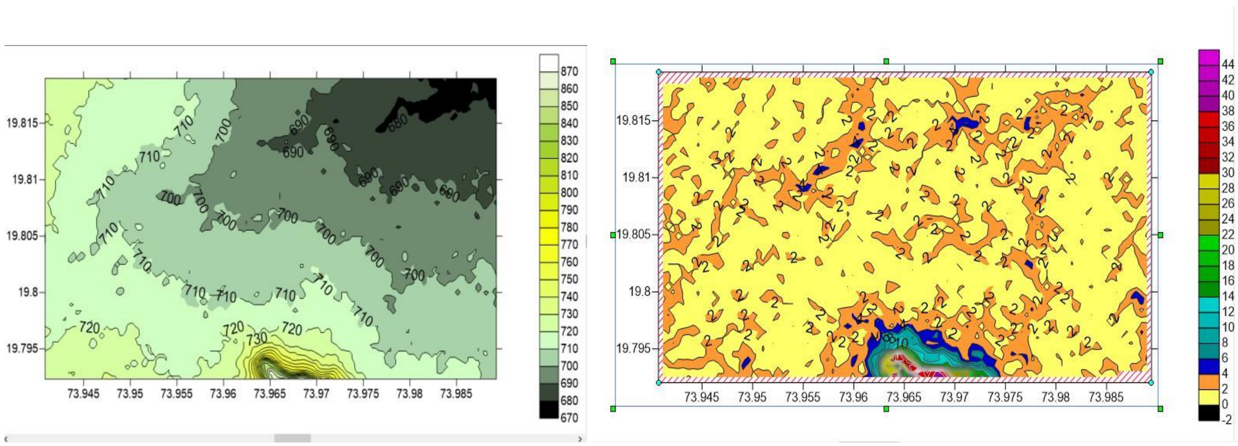
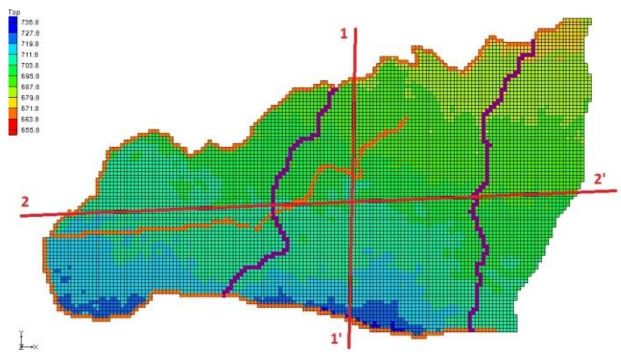


Figure 2.7: Contours and the slope of the study area

To further understand the gradient of the region a cross section of the village was taken as shown in figure 3.7 and it's elevation transect was plotted using Google earth. Drop in 1-1' which is towards the river is greater for a small distance while the drop in 2-2' is gradual. Ground water which usually follows the terrain of the region will move towards the river.



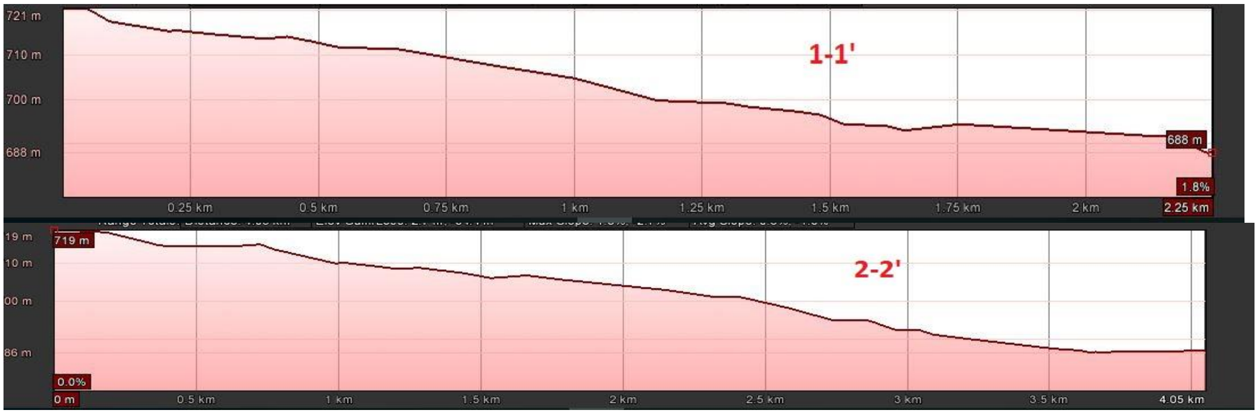


Figure 2.8: Cross sections of study area

2.2.4 Watershed delineation

As mentioned before this village fall under Devnadi watershed. Watershed was delineated using GRASS (Geographic resource analysis support system) plugin in QGIS software. The DEM was obtained by SRTM is used for the delineation. Cells which are drained by 100 cells are delineated as streams. Figure 2.9 represents two watersheds namely watershed of Devnadi river as a whole and the watershed of Devnadi river at end point of Wadgon Sinnar village. This village lies in the upstream of the river i.e. before Devnadi joins the Shivnadi near Sinnar town.

From figure 3.5 LULC, cropping along the river is higher when compared to that of areas away from the river. Hence the stress in watershed at the exit of the village will be relatively greater than the whole watershed.

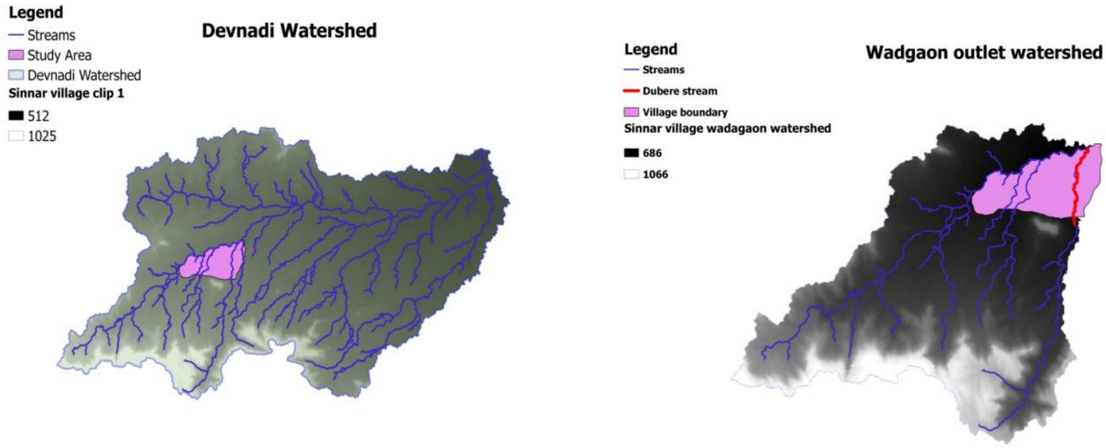


Figure 2.9: Watershed of Devnadi and Wadgaon village exit

Figure 2.9 depicts the watershed in river level and the village exit level. The pink area shows the village boundary. There are two streams of second order flowing through the village. Dubere stream (red line) is an important aspect of the village water supply.

Table 2-3: Catchment area of river and some major stream

Watershed	Catchment area (ha)
Devnadi river	38500
Devnadi at Wadgaon village exit	8880
Shivnadi river	6152
Sonambe stream	953
Dubere Stream	2063
Jayaprakash Stream	1124

Source: Qgis delineation

2.2.5 Flow measurements

In brief, flow measurements were recorded to understand the amount of water flowing in the area. Flow rate was measured using Pygmy Current meter and values obtained by using area-velocity method. The table below shows the amount of water lost/percolated when flow was measured between two points (figure 2.10).

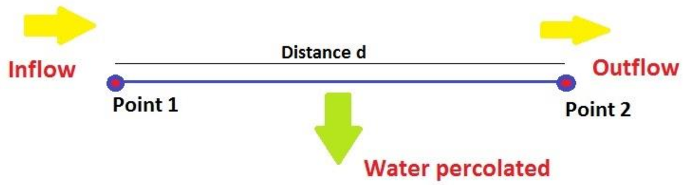


Figure 2.10: Flow measurement

Table 2-4: Measurement data

Date	Location	Point 1(lps)	Point 2 (lps)	Distance (km)	Percolate (lps/km)
26/10/2016	Sinnar Vijayvaran	126.6	102.4	1.5	16
27/11/2016	Wadagon Sinnar	28.4	4.8	2.6	9

Source: Field flow measurement

In the study area the flow measurement of Dubere stream was recorded during the month of November and a reading of 40lps was found. Also it was observed that water level in check dams built across Dubere stream lasted up to the month of January. For last few years this was not the scenario on the account of below normal rainfall but in current year with normal rain fall, stream got a good base flows and acted as a “ground water pocket” in that area. This clearly indicates contribution of Dubere stream to the areas adjacent to it.

2.2.6 Initial zoning

Based on the initial study and past year scenario the village was zoned according to the region of impact of canal, river and the stream as shown below (figure 2.11). Zoning was done to simplify the understanding of village for analysis. Initial zone contained three zones namely R-C zone (green) one between river and canal, C-S zone (light green) area between canal and the Dubere stream and S-S zone (red) area after Dubere stream. Reason behind this being that R-C zone will have good water scenario as river and canal contributed to its water resources. C-S zone will get its contribution from hill side and S-S zone was critical zone as it was tanker fed part of the village last year.

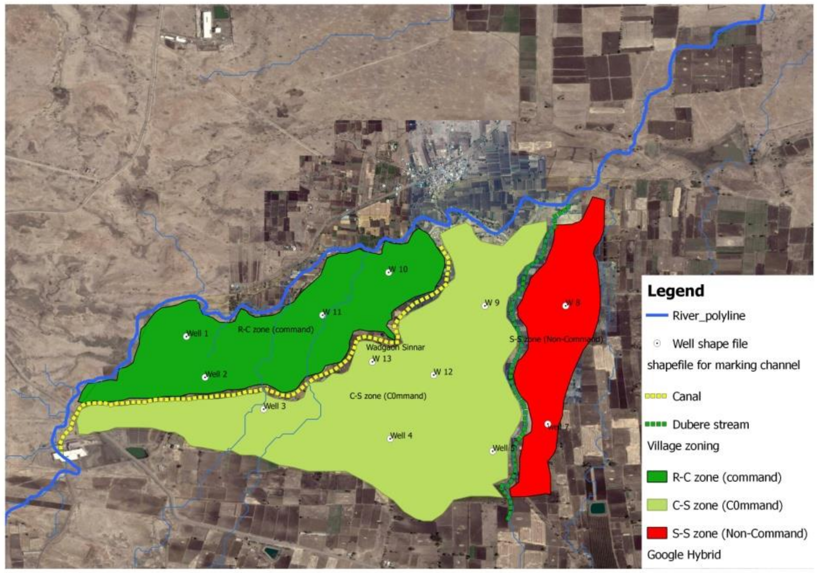


Figure 2.11: Initial zoning of village

Current zoning adopted in ground water modelling is explained in chapter 5.

3. Field level observation and analysis

Groundwater hydrology is an interpretive science; because we cannot observe the resource directly, we must interpolate and extrapolate our understanding from known points of data and observations. Also understanding these natural systems requires field level observation to record its behaviour as observed in real time. Hence this chapter explains the observation recorded in the Wadagon Sinnar village conducted through field visits over the duration of eight months.

3.1 Observation wells

Water-level measurements from observation wells are the principal source of information about the hydrologic stresses acting on aquifers and how these stresses affect groundwater recharge, storage, and discharge. Ideally the well chosen will provide data representation of various parameter like water level, topographic condition, land use condition etc. In the study area as most of the crop water requirement for the Rabi cropping is met by groundwater it becomes imperative to understand the dynamics of the same in the area. Additionally the aquifer in the region is unconfined as mentioned before. Hence the main purpose of the observation wells is to survey and monitor the changes in groundwater aquifer studied for required time period.

3.1.1 Well network

A well network is a set of wells which are regularly measured. In a watershed the wells are sampled based on various methods like random sampling, contour sampling where wells are considered along a contour, cluster sampling etc. In the study area the sampling method adopted to monitor 48 wells was transect sampling where in the wells where considered along four different transect lines across the village. Transect method was adopted because of the presence of the canal in the village. As seen in figure 3.1 there are four transects with each transect having an average of 10 wells each. Wells were chosen in such manner that they are present on either side of canal, river and within the village boundary. All the observation wells were located in the farms, most of these wells served both the purpose of providing crop and drinking water requirement. In this way the effect of canal, river on the groundwater can be monitored by the routine well measurements[19]. In study area very few bore wells are present as compared to open dug wells but they are not considered in the study.

Table 3-1: Well attribute list

Well no.	Depth (m)	Soil depth (m)	HR depth (mbgl)	Well dia (m)	Elevation (m)	Min dist from river (m)	Min dist from canal (m)	mbgl(1)	mbgl(2)	mbgl(3)
WM 1	11.8	7	9	6	703	81	693	5	5.2	6.4
WM 2	14.7	6	12	6.5	704	118	706	5.5	5.8	6
WM 3	15.8	7.5	12.3	6.5	705	149	601	5.5	5.7	7.5
WM 4	14	5.8	8	6.5	707	225	480	4.3	5	8.6

Source: Observation wells recording

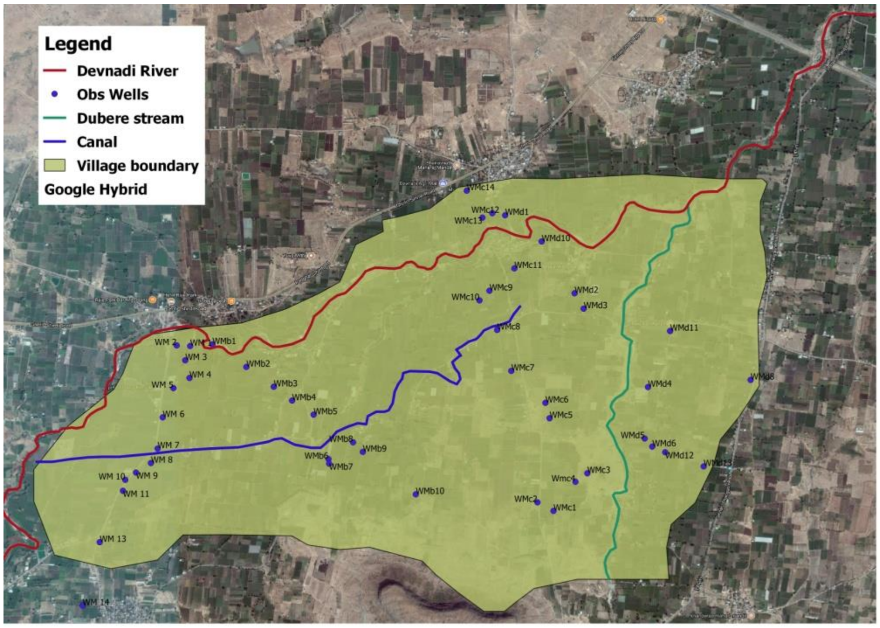


Figure 3.1 Observation Wells

3.1.2 Readings and analysis

Frequency of well measurement is an important part of water table monitoring system. The interval between well readings in the study area was taken as 20 days. A total of 8 readings were recorded starting from the month of November 2016 till April 2017. During well measurement, care was taken to consider the water table level (mbgl) from the visible wetness in the well wall and not actual water level to compensate the pumping from the well if present. Following figure gives the elevation profile of wells in transect zone 1.

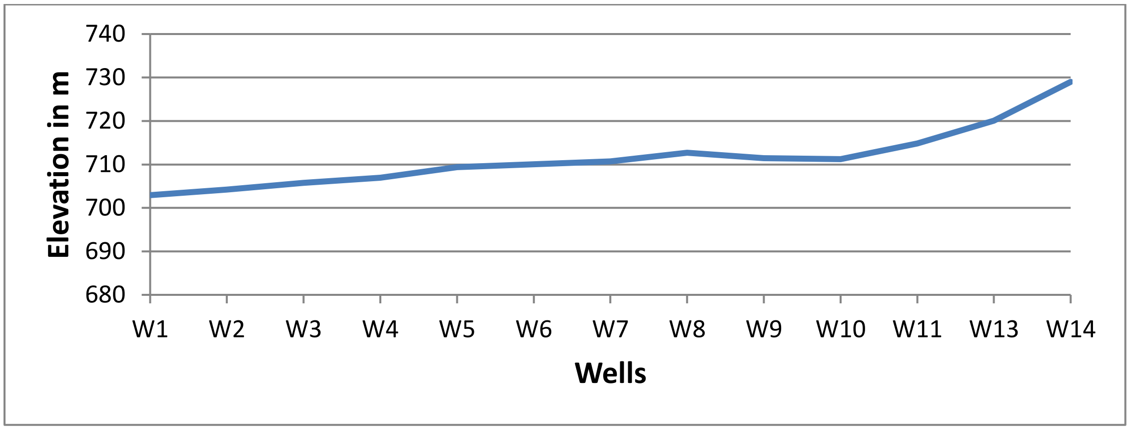


Figure 3.2: Well location elevation profile

As seen before the topology of the region slopes towards the river from the hill side part of the village. Slope near the hill side is above 5% while near the river topology flattens out with slope less than 5%. Other three transect also follow the same trends in terms of topology. Water table contour map was plotted using the well level data for the month of November as seen in figure 3.3.

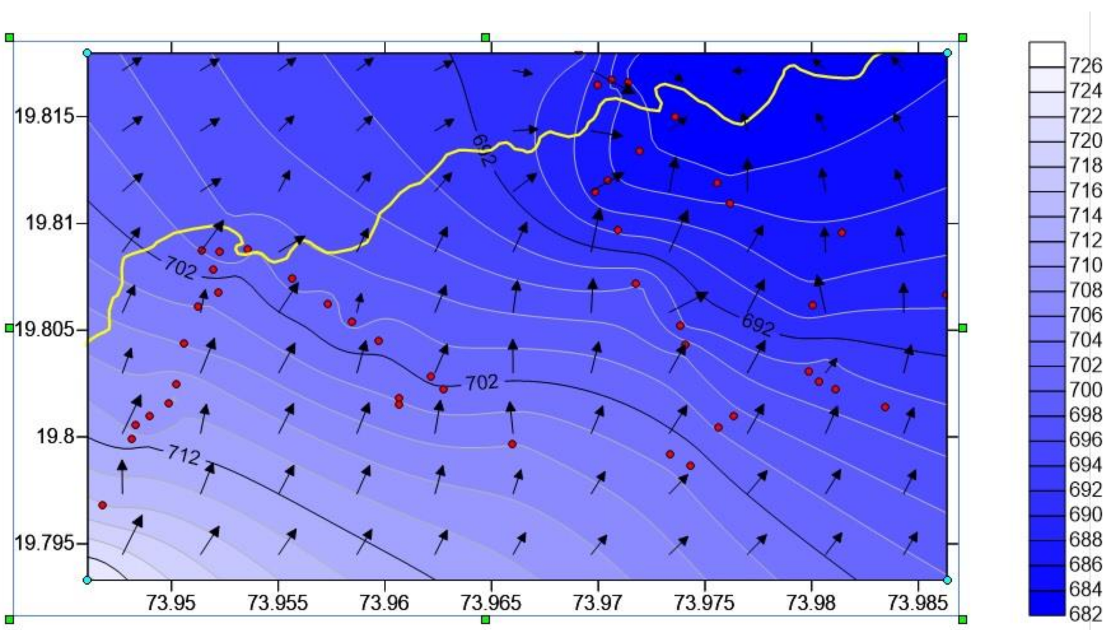


Figure 3.3: Ground water contour map

The contour map gives initial water table scenario in the village which follows the regional topology with the flow of water being towards the river. Wells near the river has better water availability as its water table is recharged by both the topological gradient flow and canal flow. The following table gives the average change in water levels in the wells between canal and river during canal flow and after it ceased to flow (reading was recorded with interval of 21 days).

Table 3-2: Water table change in canal command and non command area

		Average drop in water level well (m)
Command Area	During canal flow	0.5
	After canal flow ceased	1.9
Non Command Area	During canal flow	1.9
	After canal flow ceased	2.5

Source: Field survey

Some of the physical observation based on the data obtained was

- In the areas where the soil thickness was more than 10m the drop per reading was on average 1m.
- Soil thickness and slope had a direct correlation with water level in the well. As the wells located in the hill side of the village had soil depth in the range if 1-3m which is less than average thickness of soil in rest of the region and most of the wells had gone dry by the month of January.
- There was transfer of water by pumping from the wells present near the canal and river to the wells farm wells in hill side of the village.
- Water table/water availability on the Dubere side of the village was directly influenced by filling of check dams built on the Dubere streams only.

The following table gives the recharge rates observed in some wells in different months. This was done by taking the reading of well after the pumping stopped followed by next reading after a period of few hours.

Table 3-3: Well recharge rates

Sl no.	Month	First reading	Second reading	Recovery	Time (hr)
1	November	5.2	4.5	.6	1
2	January	8	7	1	13
3	March	14.3	14	0.3	6
4	April*	20.5	19.9	0.5	5

Well recharge rate for month of April was taken in the Dubere region (figure 2.2). In the complete village this was the only region which had some farmers going for summer crops. Main source of water for this part of village was through a stream called Dubere stream and it had a significant impact on the wells in area. Interestingly this area was tanker fed area in summer of 2016 when the rainfall previous year was low. Many farmers mentioned that their wells got filled to brim current year after a gap of 5 years. Finally the issues faced while recording these observation wells were

- Inter well pumping- Here water is pumped into the wells from other wells which are located near stream, river. This effects recording of wells as the water level is not the true water level of the area. Prominent reason of pumping being that most of these wells are located in hill zone (figure 2.2) where the water flows off too quickly due to low soil thickness. One farmer in this area had a farm pond of 20m*20m*6m dimensions with a of volume which took one month to fill with 2 pumps of 5hp capacity, when water is available during the month of November he fills the farm pond so that Rabi crop water is taken care off. Other reason being unbalance due to excessive cropping.
- Funny wells- these type of wells are very few but they always contradict the general pattern of other wells in the area. It may be because of cracks present in murum layer/hard rock, a natural water inflow path/spring etc.

3.2 Cropping data

Data on crops is an important aspect of analyzing the effect of groundwater dynamics in the region. It helps in a getting a broader view of water stress/load in various part of the area. Hence it is required to develop methodology to collect data of crops and its associated parameters.

3.2.1 Field survey

Survey was carried out in the Wadgaon Sinnar during the end of rabi season to record the cropping patters in the village. It was seen to that most of the farm plots selected for survey was the same plots where the observation wells were located. In this manner there could be a sort of balance between the well reading and crop water requirement. There are three cropping seasons namely

- Kharif season (June to September)
- Rabbi season (October to January)
- Summer season (February to May)

In study area 30 farms were surveyed asking various information like crops grown in various season, number of watering per crop etc. Survey form is given in appendix A, most of the surveyed plots had cropping for both Kharif and Rabbi seasons. Following graphs represents the various observations recorded. The location of surveyed farms is given in figure 3.4.

Table 3-4: Cropping pattern of Major crops

Season	Crops	Cropping percent	No. of watering	Type of irrigation	Source
Kharif	Soya bean	60	2	Rainfall/flood	Canal/well
	Other	40	-	Flood	Well/canal
Rabi	Wheat	38	8	Flood	Well
	Onion	41	7	Flood	Well
	Others	22	5-8	Drip/flood	Well

Survey sample is 25 farmers with an total area of 32ha

Rabi season sees mostly the cropping of Onion and Wheat in the area. Other than wheat and onion, crops like harbhara, garlic, potato etc are also grown. The dominant method of irrigating the crops is flooding. It was noticed that the source of water for Rabi crops provided directly through DBI system was negligible. Other observation was the regulation of flow into the canal as the farms near the mouth of the canal had water logging condition. Around 2% of the area is under horticulture which is mainly pomegranate. As horticulture requires water throughout the year with the peak being during the period from flowering to harvesting (Jan-June) and next harvest season (Sep to Jan), pomegranate farmers have bore wells and drip irrigation is used with return flow fed back to the well. In the case of Kharif the major crop is soya bean followed by corn, carrot, cauliflower etc, watering for these crops is through rainfall and flood irrigation which depends on rain pattern. Summer cropping is sporadic in nature, but in the current year 2016-17 pockets of lands near Dubere stream had summer cropping because of good rainfall. Crops usually grown during summer is Ground nut, Bajiri, cattle feed (grass) etc.

The cropping trend has not changed significantly over past few years, but there are few farmers who have started cultivating sugarcane. Areas at the foothills of hill zone (figure 2.4) which traditionally didn't have cropping because of thin soil layer and lack of water availability during Rabi season has seen cropping current year. The reason for this change is the availability of water through wells located in canal command zone, stream and good rainfall. Figure 3.4 shows the surveyed farm plots along with some plot taken from APS report of Gopal, some sugarcane fields near to canal and cropping intensity. Its color coded to show the cropping season for farm.

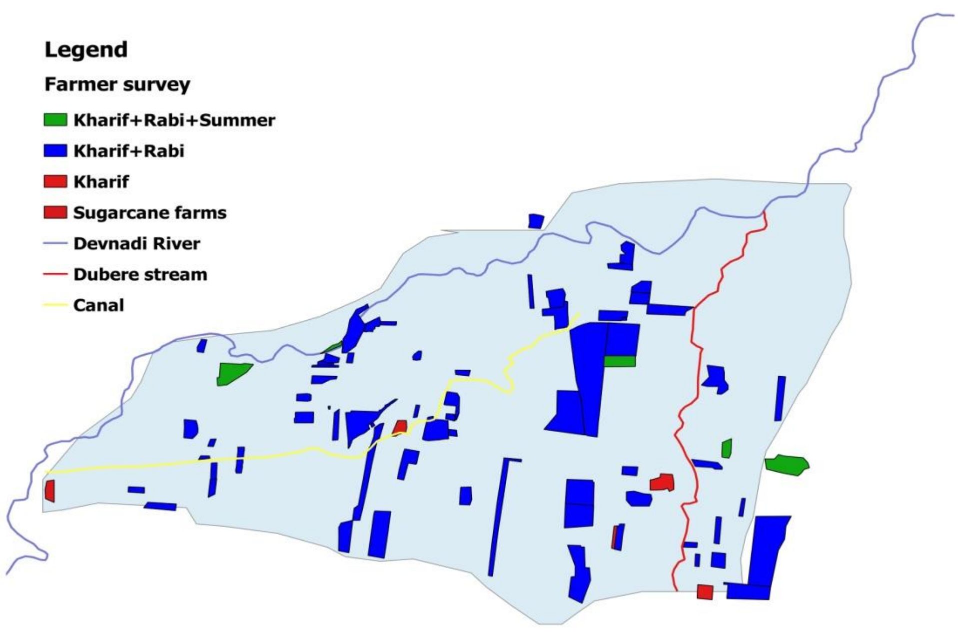


Figure 3.4: Seasons of cropping for farm lands and survey location

3.2.2 LULC

Land use land cover (LULC) using remote sensing data gives a complete profile from bird point of view of the study area in terms of cropping area, water resources and habitation in an area with reasonable accuracy. LULC helps in mapping the modification in the cropping area over the period of years. It is documented that there is significant impact on LULC change on a larger agricultural watershed [20]. Datasets used for LULC is the USGS Landsat-8 and Sentinel satellites imagery. Resolution of landsat-8 is 30m*30m while that of Sentinel 2 varies from 10m*10m in visible band to 60m*60m. One of the major limitations of these dataset is coarser spatial resolution and inability to clearly distinguish between various crops. Also Landsat-8 images cannot be used for classification during monsoon season because of cloud cover over the area.

Following figure gives the comparison between the LULC classification from Landsat-8 for the Rabi (December) for the current year 2016-17 and previous year 2015-2016. Semi-automatic QGIS plugin was used for classification. During classification, NDVI values were used with the range of +1.0 to -1.0. Main classification in study area was of three type i.e. Crops, bare soil and water bodies. As per literature, the Crops have a NDVI range of 0.6 to 0.9, shrubs and grass lands have a range 0.2 to 0.3 while soils have a range of 0.1 to 0.2 [21]**.** Figure below depicts two types of classification namely cropping and other being mixture of soil and sparsely spread shrubs/grassland.

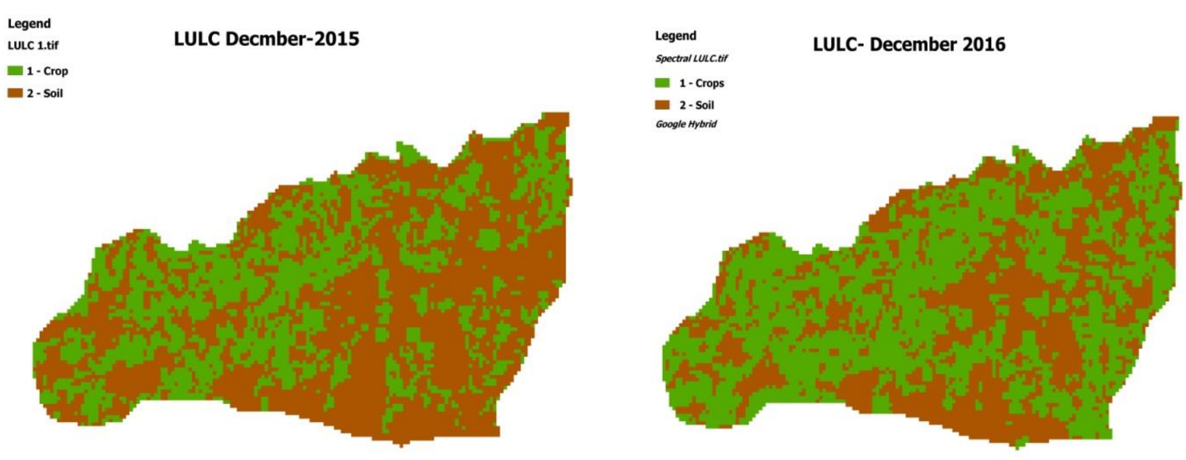


Figure 3.5: LULC for December 2015 and 2016

Comparing the LULC classification result of two consecutive years i.e. December 2015 and December 2016 there is an increase in cropping area by 16%. This clearly indicates the effect of good rainfall on the cropping area in the study area. The table below gives area of cropping and soil area in the study region.

Table 3-5: LULC of study area

LULC	Cropping area (ha)	Cropping percent (of geographical area)	Cropping percent (of cultivable area)
December 2015	300	38%	43%
December 2016	425	54%	61%

Source: LULC classification

3.2.3 Secondary cropping data (TAO) and LULC

Every Taluka maintains the cropping data in its administrative area for both Kharif, Rabi and summer season. Data shown below was collected from Taluk agricultural officer (TAO) in Sinnar Taluk for the study area.

Table 3-6: Cropping report and LULC comparison

Village		Area (ha)	Cultivable land (ha)	Rabi total (ha)	Cropping percent
Wadgaon		815	693		
Rabi	TAO			160	23%
	LULC			425	61%
Kharif	TAO			562	81%

Source: TAO data 2016-17 and LULC classification Dec 2016

It can be seen from the table that there is difference in cropping percent for Rabi as calculated by LULC and cropping report. A difference of 38% between LULC and cropping report is observed. According to cropping report only 23% of cultivable land is cropped in study area even though there was good rainfall during monsoon 2016. Table 11 shows the cropping area of major crops as a percent of total cropped area in Rabi season comparing it with the data obtained during the field survey (Table 8).

Table 3-7: Cropping report and field survey data

Data source	Rabi crops	Cropping area (ha)	Cropping percent
Cropping report	Wheat	70	10%
	Onion	35	5%
Field survey	Wheat	12	38%
	Onion	14	41%

Source: TAO cropping data 2016-17 and field survey

There is lot of discrepancy in terms of cropping data recorded by agricultural office and the sample data obtained by survey. Cropping report plays an important role in planning of water management or development in the region. Usually the method adopted for collecting these data is through agriculture assistant who visits village conducts surveys or collects data from the Talathi. Basically they form the primary source of data collection. In these scenarios there are chances of discrepancy in data as shown in the above table (which is of significant margin). Hence it becomes imperative of TAO/administration to develop secondary methods of cropping data verification like LULC mapping which can keep a check on data discrepancy. Adopting such steps will tremendously improve the reliability and consistency of data obtained on cropping.

3.3 Well loads

This section tries to calculate the water required on average per well for the cropping happening in its vicinity. One of the assumptions considered is that most of the pumping happens during the Rabi season. As for the Kharif season crops, major source of water is through rainfall and soil moisture.

3.3.1 Cropping load

Taking the field survey data to consideration average area under each well comes around 1.5ha. Wheat and onion are the main crops during Rabi season with around 80% cropping area. Considering the ET load from the table below

Table 3-8: Crop water requirement

Sr. No	Crop	Sowing time	Duration (days)	Transition zone-I		Scarcity zone	
				Water need (mm)	Irrigation need (mm)	Water need (mm)	Irrigation need (mm)
1	Soybean	July	105	350-400	100-150	350-400	100-150
2	Bajari	July	90	250-300	0-100	300-325	50-100
3	Groundnut	July	120	450-500	200-250		
4	Wheat	Nov.	12	500-550	500-550	500-525	400-500
5	Harbhara	Nov.	105	300-450	300-450	300-425	350-400
6	Grapes	June	-			1700-1800	1000-1200
7	Pomegranate	July	-			1200-1500	900-1000
10	Sugarcane	Jan.	365	2000-2100	1600-1700	2000-2200	1600-1700

Source: WALMI crop water requirement booklets for farmers

By assuming 50% of cropping per farm as onion and rest of it wheat, table below computes an average crop water requirement for a farm over a season

Table 3-9: Water requirement per farm

Water requirement for Wheat	3750m^3/ 0.75ha
Water requirement for Onion	3000m^3/ 0.75 ha
Total water requirement	6750m^3/ 1.5 ha

3.3.2 Water abstraction

The dug wells are common modes of groundwater abstraction for both drinking and irrigation purpose. Waters are abstracted using centrifugal pumps of 3HP and 5HP capacity, according to field survey 90% of the pumps in study area are submersible type. The factors which control draft for irrigation in area are crop type and crop stage. But only the crop type is considered here for determining the water abstraction. Number of pumping hours in the area varies from 8 hours during the month of November to 2-3 hours during March. The reduction in pumping hours during March is mainly attributed to the low water table in the area.

Few number of pumping discharge tests were carried out at different location in study area using bucket method, where in a bucket of 50 litre was taken to the field and time required to fill that was noted. Following pumping rate was obtained

Table 3-10: Pumping discharge rate

Sl.no.	Pump Capacity (hp)	Pump type	Discharge rate (m^3/h)
1	5	Submersible	32.04
2	3	Submersible	19.48
3	5	Non-Submersible	37.8
4	3	Submersible	20.44
5	5	Submersible	31.32

Source: Field survey

Variation in discharge rate is primarily due to changes in delivery head, condition of pumps in terms of age of the pump and frictional loss in delivery pipes, if the pump is located to far from the farm land [22]. From the above table average discharge rate for 5HP submersible pumps is considered as 31 m^3/h and that of 3HP pump as 20 m^3/h. As per the survey 70% of the farmers had 3hp pumps and rest had 5hp pumps.

Field observation gives an understanding of the region. These are the few questions that arise from the field survey, which was tried to be addressed through modeling and other methods

- How the cropping load is affected region wise within the village.
- Whether the canal acts as a water barrier in between the flow of water from hill side

towards the river.

- Does the canal water account for change in cropping intensity in the area.
- What amount of water enters the village boundary through upper regions supplementing the canal water for irrigation of crops.
- How the inter village groundwater flow happens

4. Introduction to basics of Groundwater Modelling

4.1 Need for technical analysis and Modelling

As seen in previous chapter the cropping water requirement in Wadagon Sinnar is largely dependent on the situation of groundwater in the village. The flow in the canal ceases by the month of November while the Rabi cropping of predominantly wheat and Rabi onion start during this month with a cropping duration ranging from three to four months. During this period the watering to the crops which is usually flood irrigation is provided by the wells in the farm. Hence it is imperative to understand the groundwater dynamics in the village, this can be done by building a groundwater model of the village. It also helps in understanding the flow of water into the village and the canal's region of impact within the village. Effects of future scenarios like less rainfall and other parameters on the groundwater can be analyzed.

Finally as the DBI systems are being revived in the region there is a need to have technical analysis to understand the current scenario in the village and impact of DBI system. So that it can be replicated in other villages.

4.2 Science of Groundwater flow

In this section, the basic groundwater flow equation will be derived, which forms the basis for groundwater modelling.
Some basic terms and terminologies*:*

Hydraulic head:

- The height of a column of water above datum is called hydraulic head or simply head or total head. In the study of groundwater, head is the elevation of water in a well, where mean sea level is used as a datum. Groundwater always flows in the direction of decreasing total head.

It has got three components.

a) Pressure head – It is measured from the bottom of the well to the top of the water level in the well
b) Elevation head – It is measured from the mean sea level to the bottom of the well.
c) Velocity head – It represents the energy of a liquid due to its bulk motion, and is generally neglected in groundwater flow study as is negligible.

Groundwater flow zones:

While studying groundwater flow, the subsurface is divided into three zones as follows:

- Unsaturated or vadose zone: It is the upper zone, just below the earth's surface. Water in this zone is dominated by the forces of adhesion and cohesion. It contains water held by the soils and roots of the plants, and is also the link between water infiltrating in the ground and moving down to the saturated zone. The pressure of water in unsaturated zone is less than atmospheric.

- Capillary fringe: This area is actually contained in both, the unsaturated and the saturated zones, but the water in this zone is under the influence of surface tension i.e. it is the water which has risen from the saturated ground water region due to capillary action. The pressure here too is less than atmospheric pressure.

- Saturated or phreatic zone: Groundwater in this zone is fully saturated and is gravity driven. The water here is at pressure more than atmospheric pressure. Water table is the imaginary surface dividing unsaturated and capillary zones from saturated zone, at which the pore water pressure is equal to atmospheric pressure. Below water table, all the pores of soil or rock are fully saturated and pressure increases with depth.

Porosity:

It is the measure of the void or empty spaces in a material, and is a fraction of the volume of voids over the total volume of the material and its value is between 0 and 1, or is expressed as percentage. More the porosity of soil or rock, more easy is the water movement and storage

Hydraulic Conductivity:

It is the property of the plants, rocks or soils which describes the ease with which water can move through pore spaces or fractures, which depends on the intrinsic permeability of the material and on the degree of saturation expressed in [L/T]

Heterogeneity and Anisotropy:

If the hydraulic conductivity K is independent of position within a geologic formation, the formation is **homogeneous**. If K is dependent on position within a geologic formation, which is always the case in groundwater systems, the formation is **heterogeneous**. In a homogeneous formation, $K(x, y, z) = C$, C being constant; whereas in heterogeneous formation, $K(x, y, z) \neq C$

If the hydraulic conductivity K is independent of the direction of measurement at a point in a geologic formation, the formation is **isotropic** at that point. If the hydraulic Conductivity K varies with the direction of measurement at a point in a geologic formation, the formation is **anisotropic** at that point. If an x, y, z coordinate system is set up in such a way that the coordinate directions coincide with the principal directions of anisotropy, the K values in the principal directions can be specified as K_x, K_y, K_z. At any point (x, y, z), an isotropic formation will have $K_x=K_y=K_z$, whereas an anisotropic formation will have $Kx \neq Ky \neq K_z$.

Specific storage:

It is the amount of water that a portion of an aquifer releases from storage, per unit volume of aquifer, per unit change in hydraulic head while remaining fully saturated.

Specific yield:

It is the quantity of water, unit volume of an aquifer will yield by gravity, when fully saturated and expressed as a ratio or as a percentage of the volume of the aquifer.

Continuity equation of groundwater flow:

Consider the flow of ground water taking place within a small cube (of lengths Δx, Δy and Δz respectively the direction of the three areas) in a saturated zone where ρ is the density of water and V_x, V_y, V_z are the velocity components of water in x, y and z directions.

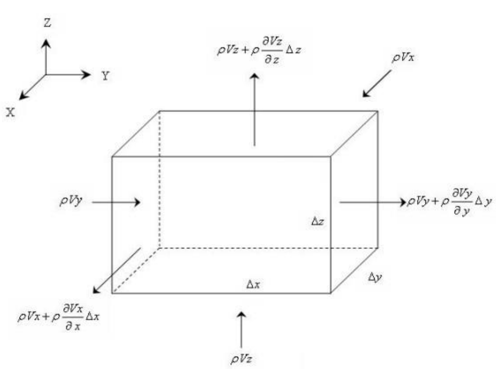


Figure 4.1:Continuity equation for ground water flow

The total incoming water in the cubical volume should be equal to that going out. Thus, defining inflows and outflows as

Inflows:

In x-direction**:** $\boldsymbol{\rho v_x}(\Delta \boldsymbol{y}.\Delta \boldsymbol{z})$

In y-direction**:** $\boldsymbol{\rho v_y}(\Delta \boldsymbol{x}.\Delta \boldsymbol{z})$

In z-direction**:** $\boldsymbol{\rho v_z}(\Delta \boldsymbol{x}.\Delta \boldsymbol{y})$

Outflows:

In X-direction**:** $\boldsymbol{\rho}\left(\boldsymbol{v_x}+\frac{\boldsymbol{\partial v_x}}{\boldsymbol{v_x}}\Delta \boldsymbol{x}\right)(\Delta \boldsymbol{y}.\Delta \boldsymbol{z})$

In Y-direction**:** $\boldsymbol{\rho}\left(\boldsymbol{v_y}+\frac{\boldsymbol{\partial v_y}}{\boldsymbol{v_y}}\Delta \boldsymbol{y}\right)(\Delta \boldsymbol{x}.\Delta \boldsymbol{y})$

In Z-direction**:** $\boldsymbol{\rho}\left(\boldsymbol{v_z}+\frac{\boldsymbol{\partial v_z}}{\boldsymbol{v_z}}\Delta \boldsymbol{z}\right)(\Delta \boldsymbol{x}.\Delta \boldsymbol{y})$

The net mass flow per unit time through the cube is,

$$\left[\frac{\boldsymbol{\partial v_x}}{\boldsymbol{v_x}}+\frac{\boldsymbol{\partial v_y}}{\boldsymbol{v_y}}+\frac{\boldsymbol{\partial v_z}}{\boldsymbol{v_z}}\right](\Delta \boldsymbol{x}.\Delta \boldsymbol{y}.\Delta \boldsymbol{z})$$

According to conservation principle sum of these three quantities should be zero, thus

$$\frac{\boldsymbol{\partial v_x}}{\boldsymbol{v_x}}+\frac{\boldsymbol{\partial v_y}}{\boldsymbol{v_y}}+\frac{\boldsymbol{\partial v_z}}{\boldsymbol{v_z}}=\mathbf{0}-----(\mathbf{4.1})$$

The above equation is the equation of continuity in groundwater flow.

4.2.1 Darcy's Law

The water flow just observed during the derivation of continuity equation is due to the difference in hydraulic head per unit length in the direction of flow. Henry Darcy, a French engineer was the first to suggest and derive a relation between the velocity as seen in the continuity equation and the hydraulic gradient.

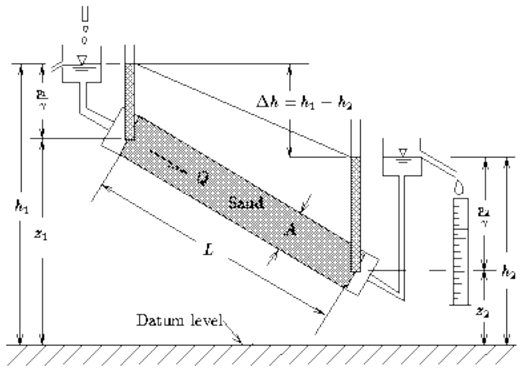


Figure 4.2: Darcy's law

According to his experiments, the discharge *Q* passing through a tube of cross-sectional area *A* filled with a porous material is directly proportional to the difference of hydraulic head *h* between the two end points and inversely proportional to the flow length *L*.

Thus, $\boldsymbol{Q} \propto \boldsymbol{A} \cdot \frac{\boldsymbol{h_1 - h_2}}{\boldsymbol{L}}$

He introduced the proportionality constant *K i.e. hydraulic conductivity* of the porous material, which finally makes the equation as

$$\boldsymbol{Q = -KA\frac{dh}{dL} - - - - - (4.2)}$$

Where,

-Negative sign is introduced because the hydraulic head decreases in the direction of flow.

-$\frac{dh}{dl}$ is the hydraulic gradient

4.3 Basic differential equation of groundwater flow

Substituting Darcy's Law in the equation of continuity we get,

$$\boldsymbol{\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right) = 0 - - - - - (4.3)}$$

Here, hydraulic conductivities in the three directions are assumed to be different i.e. for anisotropic medium. If isotropic medium with constant hydraulic conductivity in all directions is considered, the equation becomes,

$$\boldsymbol{K\left(\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2}\right) - W_s = 0 - - - - - (4.4)}$$

This equation, also known as Laplace's equation (appears in many places in mathematical physics) is known as the basic equation governing the groundwater flow. The basic problem in all the groundwater models is to find the solution to this Laplace's equation.

As the conservation principle has been applied for deriving this equation, it means that no mass is gained or lost or there is no net inward flux or outward flux to or from this system. Thus, this equation is for the steady incompressible groundwater flow where heads don't change with time.

Now, if the heads change with time, the conservation principle cannot be applied. Hence, some mass will be gained or lost with time depending upon the heads. So there will be change in volumetric water content of the material. The net water stored depends on specific storage which is defined as,

$$\boldsymbol{S_s = \rho g(\alpha + n\beta)}$$

Where $\rho$the density of water is, α is the compressibility of material, n is the porosity of the material and β is the compressibility of water. The groundwater flow equation now becomes,

$$\boldsymbol{\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right) - W = \frac{S_s}{K}\frac{\partial h}{\partial t} - - - - - (4.5)}$$

Groundwater flow modelling is basically solving this equation for water table heads in a given region / aquifer, with given initial and boundary conditions along with external parameters like rain, lake river etc. The most popular groundwater flow equation solver is MODFLOW developed by United States Geological Survey (USGS) which is used in the present study.

GMS (Groundwater Modelling Software) is a 3D visual interface between MOFDLOW and the user, which helps in visualizing the solution given by the equation solver. It is licensed software developed by Aquaveo, an US company and costs around $ 5000. It is widely used groundwater software in developed countries and developing, characterizing and visualizing groundwater models in 3D environment.

In the present study GMS version 10. (trial license) with MODFLOW version 2000 are used.

4.4 MODFLOW basics

MODFLOW is basically a computer program which numerically solves the three- dimensional groundwater flow equation (4.1) for a porous medium by using finite difference method, wherein the continuous system described the equation (1) broken down into finite set of discrete points in space and time, and the partial derivatives are replaced by terms calculated from the differences in head values at these points. This process leads to systems of linear algebraic difference equations whose solution yields values of head at specific points and times. The values obtained are approximates to the time-varying head distribution. that would have been given by analytical solution of the partial differential equation of flow [23]

The MODFLOW uses finite difference equation to solve the problem. This is done by applying the above continuity equation to the model which is the sum of all flows into and out of cell must be equal to the rate of change in storage within the cell. At the heart of MODFLOW lies spatial discretization of an aquifer system with a mesh of blocks called cells, the locations of which are described by rows, columns and layers.

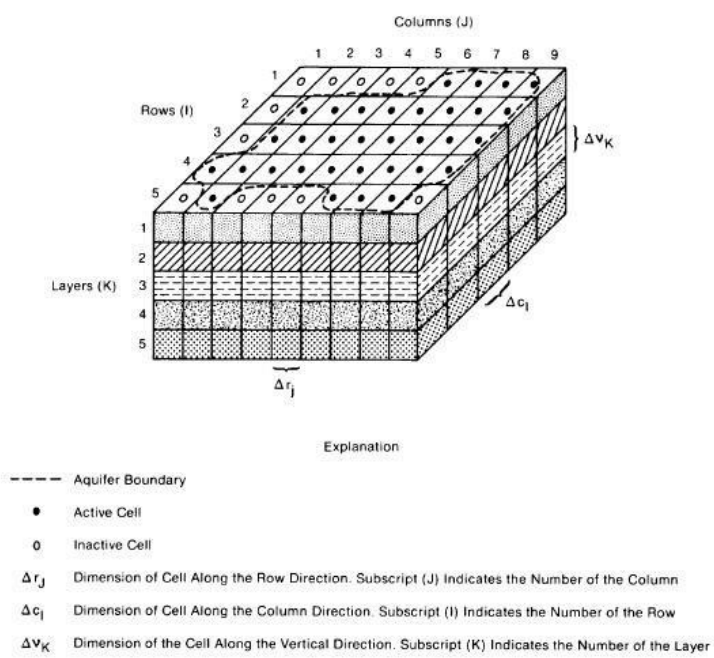


Figure 4.3:MODFLOW grid

The finite difference equation which forms the basis of MODFLOW, is derived by applying the continuity equation seen above i.e. the sum of all flows into and out of the cell must be equal to the rate of change in storage within the cell. Thus, assuming density of water as constant again, the continuity equation for the balance of flow in a cell will be

$$\sum Q_i = S_s \frac{\Delta h}{\Delta t} \Delta V$$

Where,

Q_i is the flow rate into the cell

S_s is the specific storage; volume of water which can be injected per unit volume of aquifer material per unit of change in head

ΔV is the volume of the cell and

Δh is the change in head over a time interval Δt

For the simulation to start, two types of inputs are necessary:

Initial head distribution – The initial head distribution provides a value of $h_{i,j,k}$ at each point in the mesh i.e. it provides the values of head at the beginning of the first of the discrete time steps into which time axis is divided in finite-difference process. The first step is to find solution for $h_{i,,}$ which marks the end of first step and so on.

Boundary conditions – The groundwater flow equation is solved by solving the boundary value problem. Boundary value problem is a differential equation with additional constraints, called boundary conditions. In MODFLOW, the boundary conditions can be set at the beginning, by entering the status of certain cells in the mesh in advance. There are three kinds of boundary conditions:

- Known head or constant head – the head for some cells is specified in advance, and this head remains constant throughout the simulation
- Known flow – the flow into or out of particular cell is known beforehand.
- No flow – These are the cells for which the flow into or out of the cell is permitted, in any time step in the simulation.

4.4.1 Iterative methods

Each time step in the simulation in MODFLOW starts by arbitrarily assigning a trial value or estimate for the head at each cell at the end of that step. A procedure for calculation is then started which alters these estimated values, producing a new set of head values which are in closer agreement with the system of equations. These new, or interim, head values then take the place of the initially assumed heads, and the procedure of calculation is repeated, producing a third set of head values. This procedure is repeated successively, at each stage producing a new set of interim heads which more nearly satisfies the system of equations. Each repetition of the calculation is termed as iteration. Finally the changes made by the succeeding stages become very small, and this smallness is utilized in determining when to stop the iteration also termed as closure criterion or convergence criterion.

Thus, during a MODFLOW simulation, series of iterations form one time step, series of time steps form one stress period and user can enter multiple stress periods each with specific stress data like monsoon period data, post-monsoon period data etc. [24]

4.4.2 Packages

The modular structure of MODFLOW consists of a Main program and a series of highly independent sub-routines called modules. The modules are in turn grouped into packages. Each package deals with the specific feature of hydrologic system which is to be simulated, such as simulation of a well, simulation of a lake, simulation of an underground barrier structure, simulation of stream, simulation of drains, rains etc. [24]

The packages used in the current modeling are

LPF: Layer property flow package, this package is used to define flow properties in the model. The parameters which are part of package and for which inputs are to be defined in array format are horizontal/vertical conductivity (HK/VK) for each layer. One can also enter horizontal anisotropy values on a cell by cell basis.

Drain: The Drain package is used to simulate the effect of drains on an aquifer. Drains remove water from the aquifer as long as the water table is above the elevation of the drain. If the water table falls below the elevation of the drain, the drain has no effect. The rate of removal is proportional to the difference in elevation between the water table and the drain. The constant of proportionality is the conductance of the fill material surrounding the drain. Other package is DRT package where in the removed water can be reintroduced to the aquifer at a specified grid cell.

Recharge: The Recharge package is used to simulate recharge to an aquifer due to rainfall and infiltration. Recharge is typically defined by specifying a recharge value for each cell for each vertical column in the grid. The recharge value represents the amount of water that goes into the groundwater system and not the amount of precipitation. The units of recharge are length/time. It can also be used in simulating evapotranspiration (ET) as the EVT package used for evapotranspiration in the MODFLOW is not able to successfully depict the ground condition. Here a negative value is given for recharge depicting the removal of water from the cell.

5. MODFLOW for Wadgaon Sinnar Area

To build a model lot of input parameters are required. Many of these parameters have already been calculated like the watershed boundary, catchment area, DEM of the region, streams, rivers etc. In addition to these there are some parameters which are vital for building of the model both conceptual and actual but have to be derived from the existing data set collected from field observations and surveys. This chapter lays out the process involved from deriving such a parameter to the MODFLOW simulation of the model. Initial section talks about the steps followed to get boundary head estimation equation using well readings which was used to define the boundary condition in the model. This part is followed by the section which explains the conceptual model of the study area which is paramount for modeling. Following which groundwater model is built and simulated in MODFLOW based on the conceptual model. The simulation and its resulting analysis are described in the third section of the chapter. Final section of this chapter is reserved for conclusion and future works. In brief four sections are

- Boundary head estimation equation
- Conceptual Model
- Model building and analysis
- Conclusion

As the village is part of a larger watershed, modeling requires defining of a boundary condition of the village. Determining boundary condition is important as it will determine the water inflow and outflow from the study area. In case the simulation involves complete watershed, then usually boundary conditions are considered as no flow regions because they lie along the ridge lines[25]. But this is not the case with respect to study area as it is a part of a watershed and it is pertinent to determine the boundary head values of the village. Following section will discuss about developing this boundary condition using numerical model.

5.1 Boundary head estimation equation

GW table in study area is an unconfined aquifer and the head at any point is equal to elevation of the water table above the base of aquifer. An unconfined aquifer is bounded at the bottom by material that is considered impermeable. In chapter 4.1 there were 48 observation wells with 8 readings recorded. Basically in an aquifer the water table mimics the topology of the region.

Also the wells recording showed similar reading. There was a total of 384 data points, it was decided to develop linear regression model on these data set.

Water table is influenced by multiple parameters which have to be quantified and its impact on water table level to be determined. So a well point in the study area is dependent basically on two factors i.e. spatial and temporal. In case of spatial factor a well is affected by it location i.e. latitude and longitude and its elevation above MSL as shown in figure below

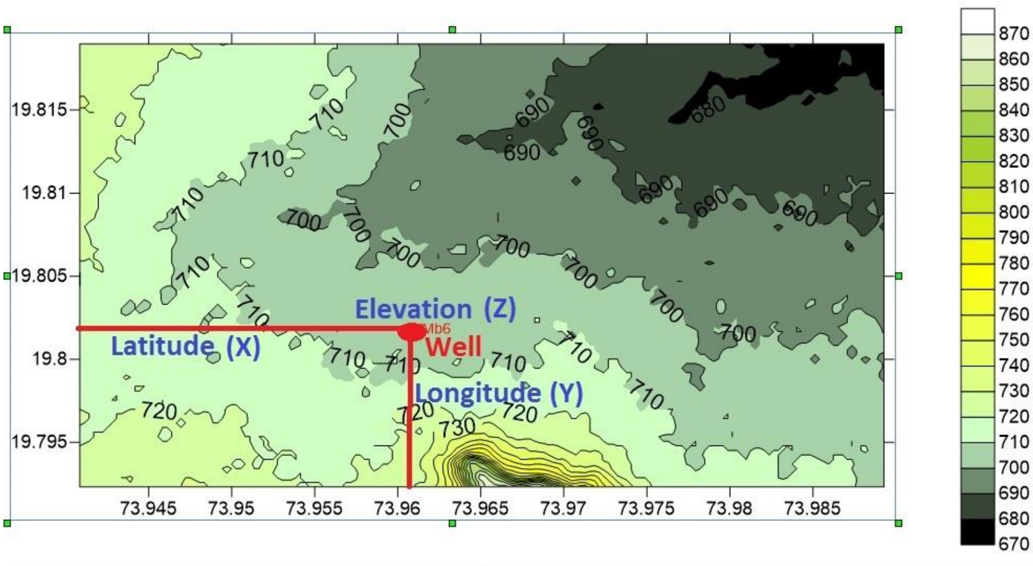


Figure 5.1: Topology of a well

The temporal factor is the change in water level in the well over interval of time. Other factors which were incorporated initially were minimum distance of well from the river, minimum distance of well from the canal, slopes between well, distance from contour lines. All these factor were parameterized and multiple linear regressions method was used. Initial linear equation was as follows

$$W = aX + bY + cZ + dR + eC + dT + eTZ + K ----(5.1)$$

In above equation

W is the water level in well

X is the longitude

Y is the latitude

Z is the elevation

R is the minimum distance from the river to the well

C is the minimum distance from the canal to the well

T is the time interval

K is the equation constant

Minimum distance algorithm was used to calculate the minimum distance to river and canal in QGIS. The various values thus obtained are shown in the snap shot of excel below

Wells	Lat	Long	Elevaton	Shortest Dsistance from river	Elevation of River	Shortest Distance from canal	Elevation Canal	Shortest Distance from Dubere Stream	Shortest Distance from Isoline 720
WM 1	73.95267	19.80886	703	81	703	693	710	2676	966
WM 2	73.95224	19.80888	704	118	703	706	710	2762	893
WM 3	73.95296	19.80801	705	149	703	601	710	2708	987
WM 4	73.95301	19.80737	707	225	703	480	710	2666	1031
WM 5	73.9517	19.80623	709	336	703	425	711	2761	923
WM 6	73.95152	19.8049	710	373	710	235	711	2822	788
WM 7	73.95059	19.80268	711	439	711	28	712	2857	579
WM 8	73.95004	19.80181	712	482	711	58	712	2905	482
WM 9	73.94957	19.80131	712	456	711	112	713	3005	438
WM 10	73.94879	19.80017	713	446	711	161	711	3078	404
WM 11	73.94881	19.79959	713	499	711	234	711	3084	329

Figure 5.2: Initial linear equation condition

Lat and long are of different units hence the current coordinate system is projected into pseudo Mercator 3857-WGS 54 system where the units are in meter/distance projection. Now all the parameters are in same unit and distance co-ordinate system. The problem faced at this stage was the enormity in the value of the data which led to scale issues while computing coefficients of linear regression equation a, b, c, d etc using matrix method. To overcome this error the well point with least latitude (Y_{min}), least longitude (X_{min}) and least geographical elevation (Z_{min}) in the study area was deducted from all the well points. Hence the values were rescaled through following changes.

$$X_{re-scaled} = X_{any-point} - X_{min} ------ (5.2)$$

$$Y_{re-scaled} = Y_{any-point} - Y_{min} ------ (5.3)$$

$$Z_{re-scaled} = Z_{any-point} - Z_{min} ------ (5.4)$$

Re-scaled values X and Y were then divide by 100 and following sheet was obtained

	B	C	D	E	F	G	H	I	J	K
1	Lat	Long	x in meters	y in meters	Re scaled X	Re scaled Y	Re scaled x/100	Re scaled Y/100	Elevaton	Re scaled Z
2										
3	73.95267	19.80886	390261.7448	2190650.786	694.8097889	1738.50736	6.948097889	17.3850736	703	16
4	73.95224	19.80888	390176.2681	2190655.173	609.3330509	1742.894761	6.093330509	17.42894761	704	17
5	73.95296	19.80801	390229.8287	2190555.102	662.8936881	1642.823743	6.628936881	16.42823743	705	18
6	73.95301	19.80737	390256.0341	2190436.414	689.0991008	1524.135151	6.890991008	15.24135151	707	20
7	73.9517	19.80623	390153.8176	2190368.952	586.8825467	1456.673176	5.868825467	14.56673176	709	22
8	73.95152	19.8049	390083.9666	2190172.933	517.0315858	1260.655082	5.170315858	12.60655082	710	23
9	73.95059	19.80268	390050.0727	2189963.808	483.137701	1051.530073	4.83137701	10.51530073	711	24
10	73.95004	19.80181	390007.2974	2189866.513	440.3623613	954.2348597	4.403623613	9.542348597	712	25

Figure 5.3: Re-scaled values

Once the values were set, outliers from well data were removed and 40 wells were chosen for analysis. Time of initial well reading was taken as t=0 and final reading as t=135 with the intervals of t=21, 42 etc corresponding to different well recordings (each time step had dataset of 40 well readings).

Linear regression for different parameter combinations were tried out and its R^2 determined. Table below represents R^2 for some of those combinations

Table 5-1: R-squared values

Combinations	R^2 value
X, Y, Z, R, C, T, TZ	0.35
X, Y, Z, C, T, TZ	0.43
X, Y, Z	0.38
X, Y, Z, T	0.61
X, Z, T	0.69

Source: Calculated values

It can be seen that the combination X, Z, T had the best R^2 value, hence it was selected as water table predicting equation. Now eqn.4 reduces to

$$W = aX + cZ + dT + K - - - - - (5.5)$$

The co-efficient obtained for above equation is as follows,

a= 0.0429; c= 0.1353; T=0.0754 and K= -1.1739

Now for any point in the study area and a given time a predicted well value can be determined by above equation.

5.2 Conceptual model

To solve an natural system or site specific problem, one must assemble and analyze relevant field data and articulate important aspects of GW system. The synthesis of what is known about the site is called conceptual model [26].

5.2.1 Methodology of building the conceptual model

To understand groundwater flow into a system/village it is important to understand boundary condition defining the village/system. So for better analysis of village, the boundaries of the village were defined on basis of topology and field observation in the village.

Groundwater flows: In the study area in-flow of groundwater after monsoon is from surface flows (canal) and subsurface flows. The Village is located in the plateau after the Sahyadri hill ranges and GW flows into the village from the south side boundary and joins the river as seen in figure 5.4.

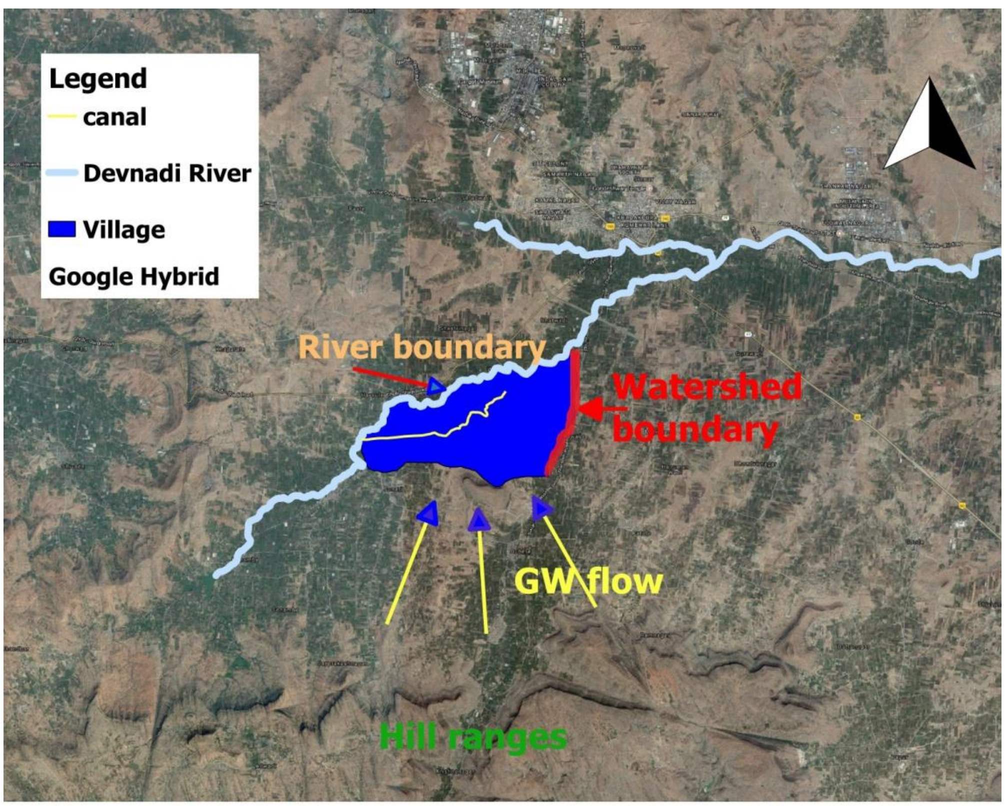


Figure 5.4: Boundary Condition

The contributor to these flows entering from the southern part of study area is the hill ranges present at a distance of 6km from the village. Factors which influence this subsurface flow are rainfall in the region, ET load from cropping in villages present between the study area and hill range, water conservation structures etc.

Now to know the amount of groundwater entering the village through southern boundary, groundwater heads (water table level) along the boundary has to be found. This can be found by two methods. First method is to develop groundwater model for the complete watershed of which the village is part off and then demarcate southern village boundary in the model to know the groundwater heads along the boundary. This method was not feasible due to the lack of data on the watershed level to build the groundwater model. Other method developed to determine the groundwater heads along the boundary was based on well readings recorded in the study area. Using eight well readings recorded over a period of six months a linear regression equation was built (Equation 8**)** which was based on three factors namely location of well, elevation of well and time period. The Linear regression equation was used to determine the heads along the southern boundary of the village.

Heads obtained along the boundary was considered as constant heads i.e. groundwater heads which remain constant for a given period of time, providing groundwater flows into the village.

Canal and river flow: Northern side of the village boundary borders along the river as shown in the figure above. As there is flow in the river the heads along the river are considered constant head with the heads being equal to the elevation of the river bed. Similarly the case with canal when it is operational, the canal provides a constant head along its length i.e. through constant seepage to groundwater. The region between the canal and river is influenced because of this constant head seepage from the canal. On the other hand the presence of constant groundwater head creates a water head lump as shown in the figure below (the figure shown below is obtained after simulating the model in MODFLOW, which will be explained in section 5.3). As a result of this lump, water flowing from upper region is ‘walled’ and more water is available to the upper region. In other words canal (DBI) not only provides water to the command area between canal and river but it also helps in improving water availability in the upper regions of the area to a certain extent.

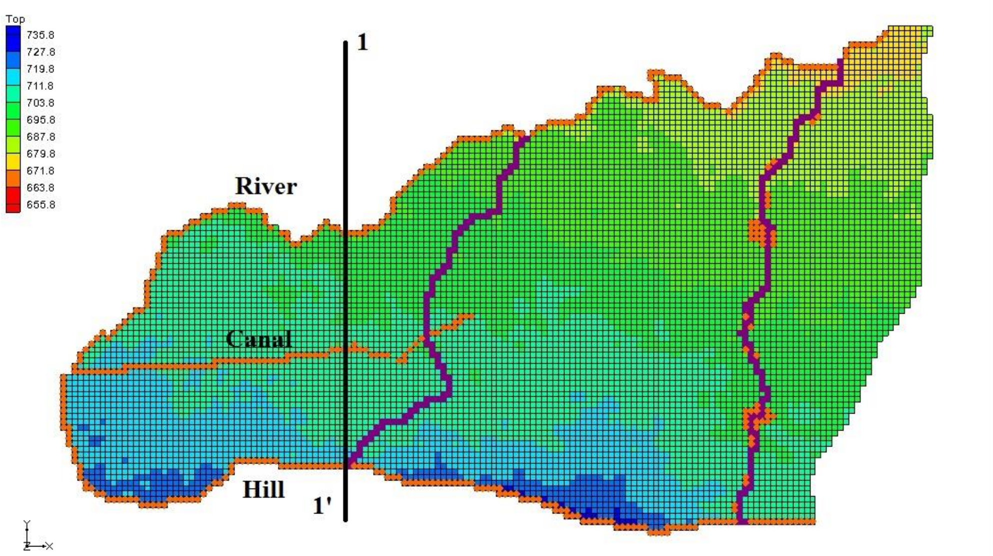


Figure 5.5: Cross section of canal

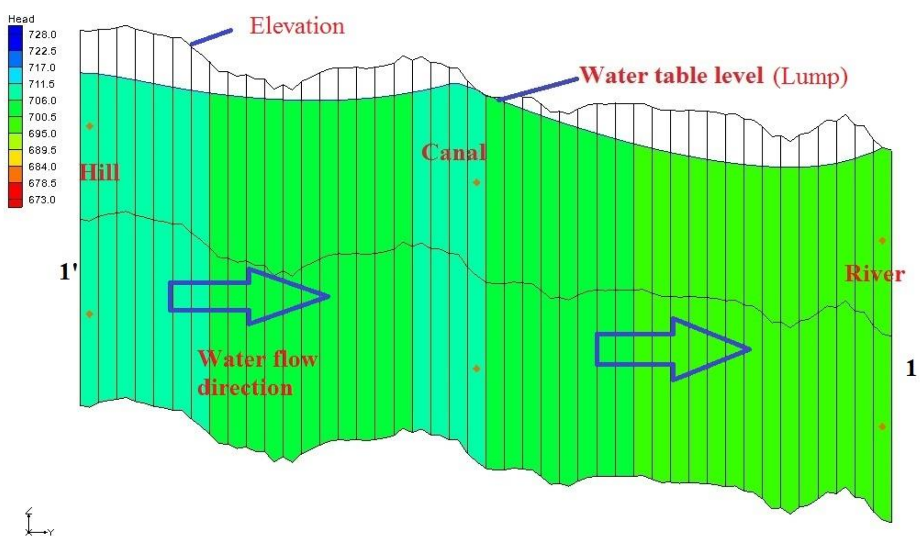


Figure 5.6: Lump effect

(Source: MODDFLOW)

Watershed Boundary: Here Eastern boundary of the village is along the watershed boundary of the region and hence it's considered as no flow boundary (figure 2.9). So there three boundaries defined for the study area i.e. GW flow boundary in southern part of the area, river constant head boundary on the northern part and no flow boundary on eastern side. All these boundaries will help in determining the flow in the study area.

Steady state and Transient state: In steady state condition hydraulic head doesn't change with time i.e. the amount of water that flows into the system, is the same as that flows out of the system equation 2 (chapter 4) . Transient condition is a case where hydraulic head varies with time which is given by equation 3 (chapter 4). In a complete watershed when all the boundary condition is considered no flow which means the boundary condition remains constant over the period of time.

Considering modeling transient condition in the study area required continuous change in the boundary condition of the study area i.e. boundary condition changes over the period of time. Simulating which became complex due to lack of data. Hence in the current study a steady state is considered which capture an instant of transient state condition on a typical DBI operational day.

5.3 Modeling and analysis

5.3.1 Initial Condition

In many GW models, hydrological parameter estimation often remains the most difficult problem that many studies try to overcome by assigning uniform values or by dividing the parameters values into classes corresponding to different part of the area which can be adjusted by calibration [27]. Modeling was based on distributed parameter model which helps in representing more realistic distribution of system properties.

Conceptual model was built in MODFLOW using 9 coverages for the study area. Coverage defined properties like hydraulic conductivity, ET load zones, budget zones, specific head etc. Thickness of aquifer was divided into two layers. The boundary of the village was drawn according to the administrative boundary. There are two drains/stream in the villages which were mapped and the conductance was kept initially as at 25 m^2/day/m. Dubere stream which had check dams were modeled defining check dam regions as constant heads. The initial range for conductivity of the top layer as per literature was considered in the range of 1 to 3 m/d, while hydraulic conductivity of the lower layer had the range of 0.5-0.89m/d [28]. Vertical conductivity was considered half of horizontal conductivity. Different recharge zones were demarcated and mapped. Wells and drainage coverage was set based on the observation well data and QGIS derived data.

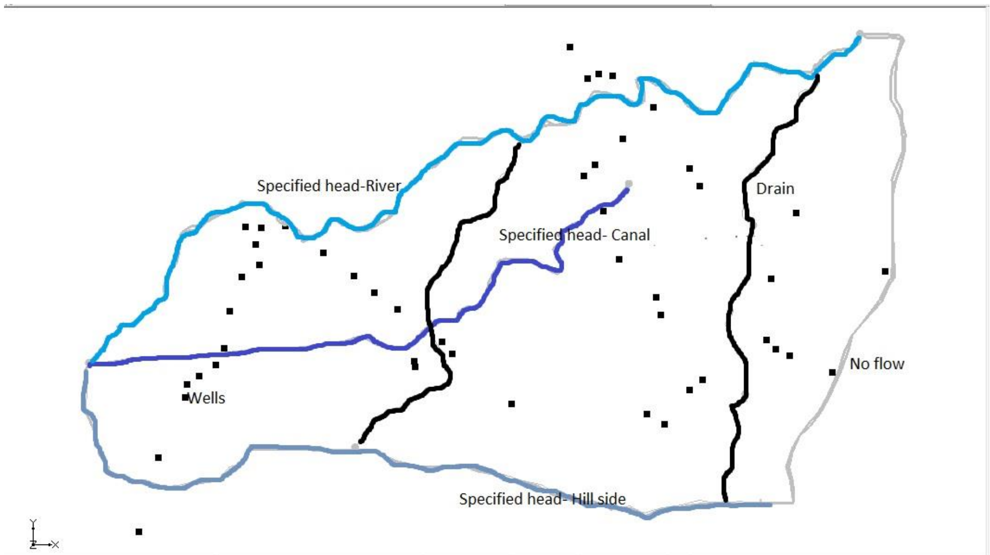


Figure 5.7: MODFLOW Conceptual model

3-d grid model

A Grid was generated by taking a cell size of 30m*30m, elevations of the grid was taken from DEM and mapped to the top layer of the grid. Thickness of first layer varied from 15m to 20m and second layer had the constant thickness of 10m. For boundary condition the specified heads at river and canal was defined as top layer elevation while the specified head at hill side was defined using **eqn.8**. as explained in conceptual model.

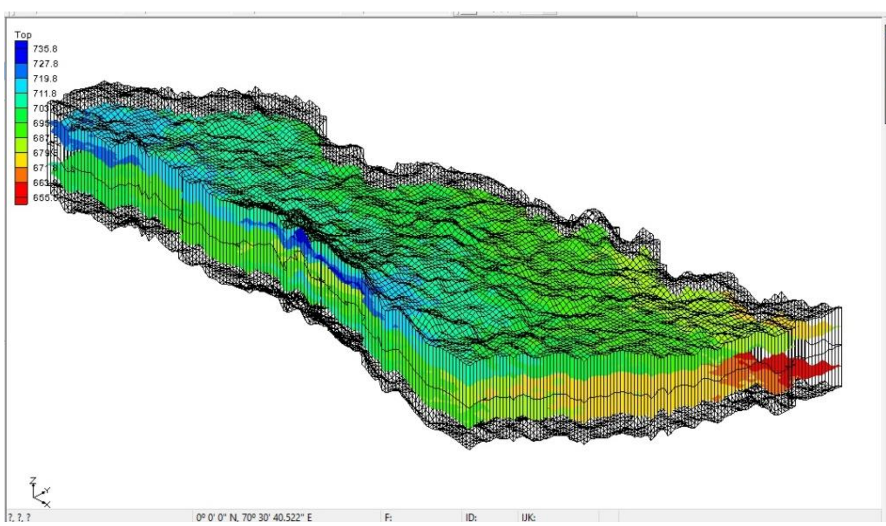


Figure 5.8: 3-d grid model

Steady state condition

Once the grid was generated, coverage in conceptual model was mapped to the gird. Model was checked for errors before simulation and errors shown were rectified. Model simulation was initially started by assuming some K values and the output was calibrated with the well reading. If calibration was found unsatisfactory the model was re-iterated with changed hydraulic parameters. The input model parameters which could be varied were conductivity, ET load zones and conductance of the drain.

5.3.2 MODFLOW conditions

To understand the effect of canal in the area two scenarios has to be simulated:

Scenario 1: In this scenario the model is simulated in 'as is' condition, which is based on condition observed on field on 27/11/2016, such as flow in the canal, cropping area, length of canal flow etc.

Scenario 2: In this scenario the model is simulated in 'what if' condition. Here the model will be based on the condition what will be the conditions if the canal were not present in the region and the cropping was such that the observed water levels and trends were maintained as on 27/11/2016.

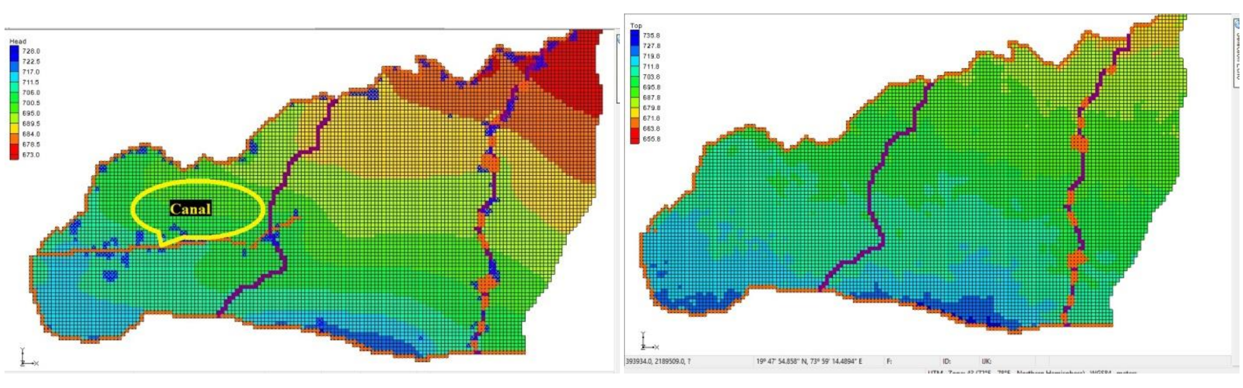


Figure 5.9: Model with canal (1) and without canal (2)

Assumptions made while modelling steady state conditions are:

- Cropping pattern in the area is categorized into Onion, Wheat and Others. The ET load for same is considered as 400mm, 500mm and 350mm.
- Cropping ratio for Onion, Wheat and Others is divided into 35%, 35% and 30% respectively.
- Similarly cropping duration is considered as 120 days for Onion and Wheat and 90 days for other crops. (Based on the field survey)
- Sowing for Rabi crops started after the festival of Deepawali in month of October.

The ET load is obtained from the literature for each crop. Study area is divided into ET zones as shown in figure. Zones were determined based on factors like land use, canal flow region, topology etc.

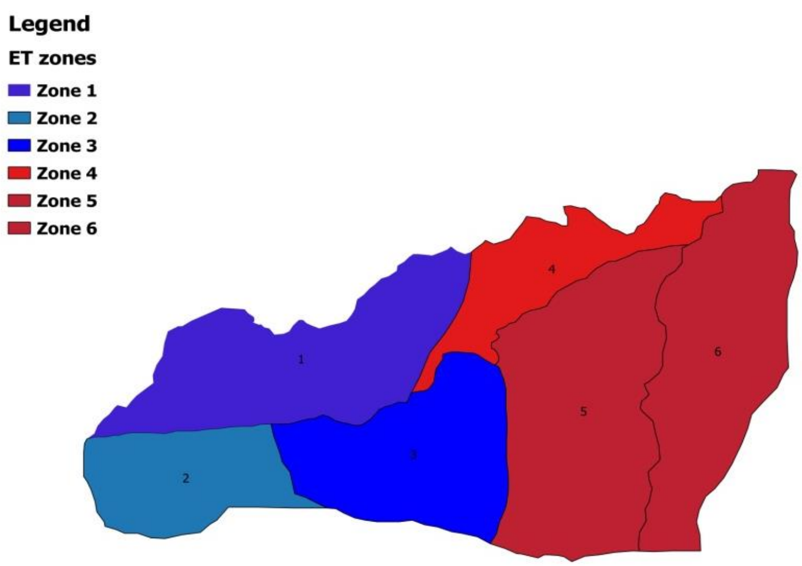


Figure 5.10: ET zones

Table 5-2: ET load for zones

Zone id	Soil Area (m^2)	Crop area (m^2)	Total area (m^2)	ET Load			Total water (TCM)	Avg. Water load (m/season)	ET load (mm/day)
				Onion (TCM)	Wheat (TCM)	Other (TCM)			
1	548436	1046263	1594699	146	183	110	439	0.28	2.51
2	272649	577334	849983	81	101	61	242	0.29	2.59
3	564104	712601	1276705	100	125	75	299	0.23	2.13
4	307420	471935	779355	66	83	50	198	0.25	2.31
5	1167262	770428	1937690	108	135	81	324	0.17	1.52
6	658640	994451	1653091	139	174	104	418	0.25	2.30

Source: LULC and calculation

The hydraulic properties of the simulation are as mentioned

Table 5-3: Hydraulic properties

Properties	Layer 1	Layer 2
Thickness (m)	15-20m	10m
Hydraulic conductivity (m/d)	1-2	0.03-0.08
Drain conductance (m^2/d/m)	75	-

Source: Literature

Two steady state simulation scenarios were considered, the hydrological parameters are same for both the scenarios. Both the simulations are initially runs without any ET loads and later ET loads are applied in an iterative manner till predicted and observed heads are calibrated. Some terms used in MODFLOW.

MODFLOW ET load: ET load applied in the MODFLOW model.

Actual ET load: ET truly acting in the area/zones calculated by LULC mapping.

Calculated drop: The drop in the water table in a given period of time due to applying MODFLOW ET load instead of actual ET load.

Obs. Drop: Drops observed in the field recorded by well level reading.

So drop from MODFLOW ET load is calculated by

$$W_S = W_t - S_y \frac{\Delta h}{\Delta t} - - - - - - (5.6)$$

Where M_ET is the ET applied in MODFLOW model

ET is the actual ET calculated

S_y is the specific yield considered as 2.5%

Δh is the change in the water table

Δt is the change in time considered as 21 days.

Scenario 1: In this scenario canal is active and flowing. The model is run for a condition nearly mimicking the actual situation present in the village i.e. by considering the actual cropping in the village, flows in the canal etc. and model is iterated till the predicted head matches the observed head (well reading) in the study area. By simulating the model with above mentioned conditions we get following output (Table 17).

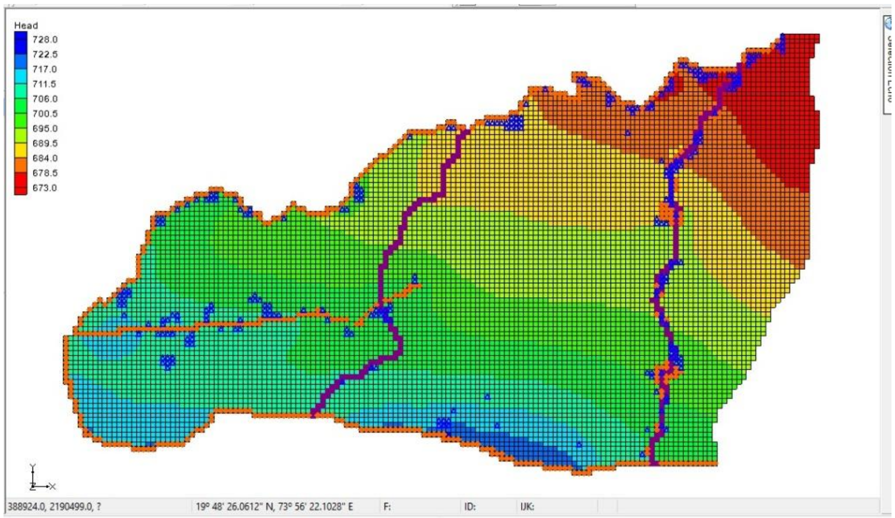


Figure 5.11: Heads output

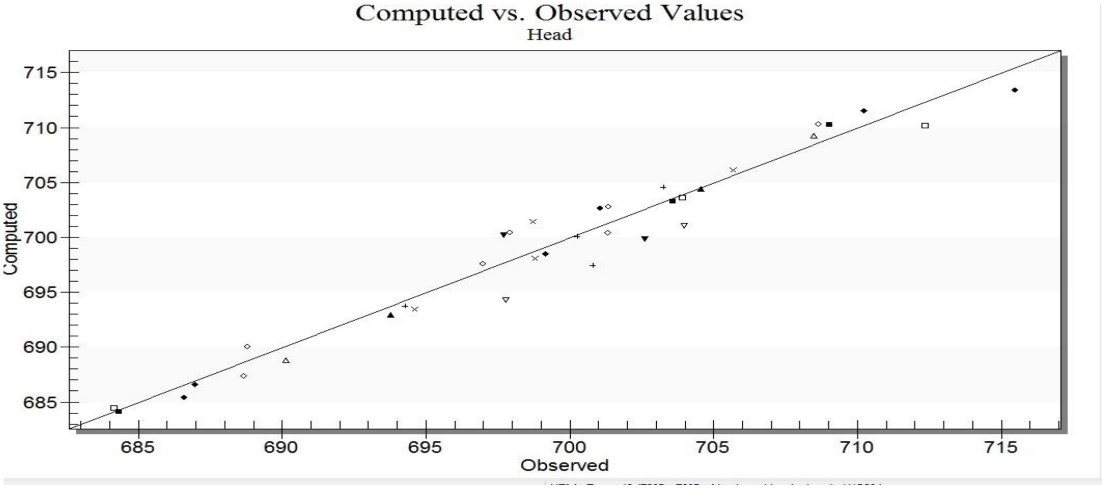


Figure 5.12: Calibration plot

To quantify the flow in the region, flow budget is computed by classifying various zones for canal, hill, Dubere region. **(**Appendix B**)**

Table 5-4: Zone budget

All units in TCM/day	ZONE 1	ZONE 2	ZONE 3	ZONE 4
Region	Canal-River	Canal	Hill side	Dubere area
	IN	IN	IN	IN

CONSTANT HEAD	1.57	2.94	3.52	1.81
FROM ZONE 1	0.00	0.05	0.00	0.09
FROM ZONE 2	1.02	0.00	0.23	0.12
FROM ZONE 3	0.00	0.40	0.00	0.90
FROM ZONE 4	0.09	0.15	0.41	0.00
Total IN	2.69	3.55	4.15	2.93
	OUT	OUT	OUT	OUT
CONSTANT HEAD	1.16	0.72	0.78	0.43
DRAINS	0.00	0.41	0.25	0.86
ET	1.38	1.03	1.82	0.97
TO ZONE 1	0.00	1.02	0.00	0.10
TO ZONE 2	0.06	0.00	0.40	0.02
TO ZONE 3	0.00	0.23	0.00	0.41
TO ZONE 4	0.09	0.13	0.90	0.00
Total OUT	2.70	3.50	4.16	2.93

Source: MODFLOW

Total flow in and out of the system is 9.856 TCM. From the table, water entering from hill side is 3.52 TCM of which most of the water is lost because of ET loads and rest is either entering zone 4 or leaving system by constant head. Zone 2 with canal has an inflow of 2.94 TCM from constant head and with inflow from Zone 3 restricted to areas where canal being inactive. Outflow in Zone 2 is 1.03 TCM and 0.72 TCM by constant head. Effective water entering because of canal is 2.24 TCM.

Recalling the values form table 4, water percolation rate in the canal is 24lps amounting to 2.07 TCM /day which is nearly same as that of modelled value. Now Zone 1 gets 1.03TCM of water from canal area which explains the better cropping intensity in this zone 1(65% of Zone 1 geographical area is cropped).

Table 5-5: ET loads comparison

ET zones	MODFLOW ET load (mm)	Actual ET (mm)	Difference (mm)	Calculated drop for 21 days (m)	Obs. Drop (m)
Zone 1	1.3	2.51	1.21	1.01	0.4
Zone 2	1	2.59	1.59	1.34	2.3
Zone 3	0.8	2.13	1.32	1.2	1.8
Zone 4	0	2.31	2.31	1.94	1.3
Zone 5	0.3	1.52	1.22	1.02	1.2
Zone 6	0.6	2.30	1.70	1.43	1.6

Comparing the true ET loads acting on the zones and MODFLOW ET load applied to calibrate the wells on these zones, drop in water table over period of 21 days is calculated using equation 9. Later calculated drop is compared with actual drop recorded. The difference in drops between calculated and observed values for various regions are in the range of 0.1 to 0.9, this may be attributed to well reading and model parameter errors.

Scenario 2: Here to simulate the model without canal it is assumed that farmers change the cropping area to observe the same calibration well levels as that of scenario 1. This will give the amount of cropping area reduction required to observe the same well level as scenario 1, in other words to determine the amount of cropping area which will give similar well levels as the one recorded with presence of functional canal but with no canal flow .

Then the model is simulated under same condition as that of scenario 1. MODFLOW ET loads are iterated to match calibration value of that scenario 1.

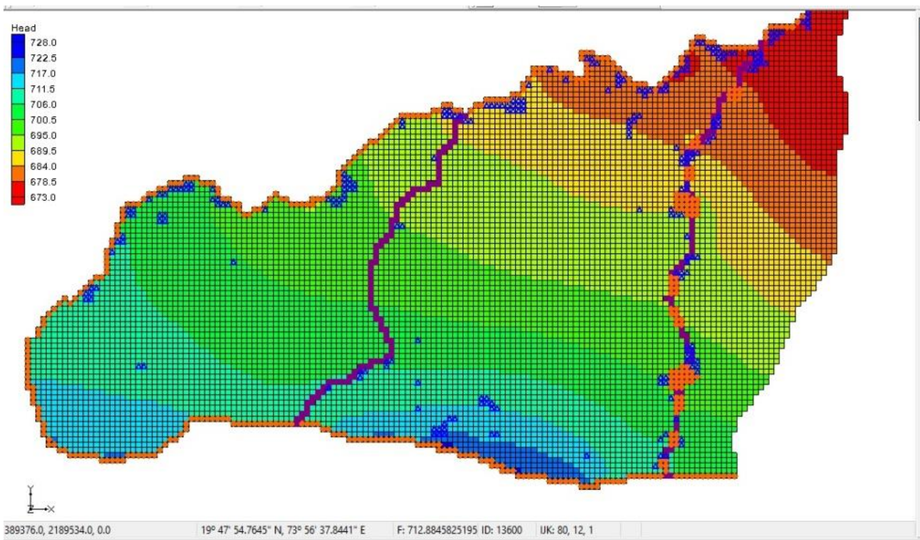


Figure 5.13: Output heads

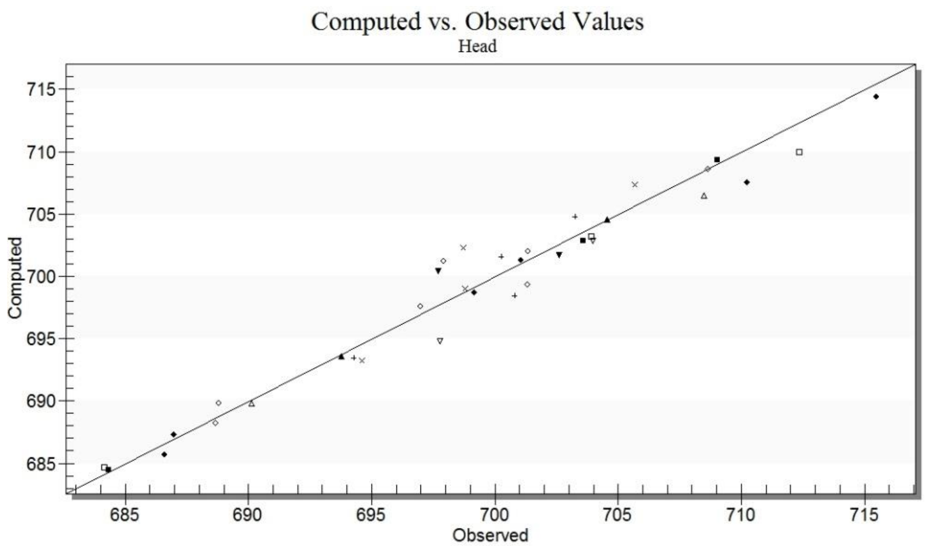


Figure 5.14: Calibration plot for Scenario 2

Zone budget for this scenario is given in the following page.

Table 5-6: Flow budget for Scenario 2

All units in TCM/day	ZONE 1	ZONE 2	ZONE 3
	IN	IN	IN
Regions	River side	Hill Side	Dubere side
CONSTANT HEAD	1.92	3.82	1.74
FROM ZONE 1	0.00	0.19	0.24
FROM ZONE 2	1.00	0.00	0.48
FROM ZONE 3	0.28	0.13	0.00
Total IN	3.20	4.15	2.40
	OUT	OUT	OUT
CONSTANT HEAD	1.68	1.02	0.58
DRAINS	0.22	0.12	0.53
ET	0.85	1.51	0.96
TO ZONE 1	0.00	1.00	0.29
TO ZONE 2	0.19	0.00	0.13
TO ZONE 3	0.24	0.48	0.00
Total OUT	3.20	4.15	2.48

Source: MODFLOW

In the flow budget without canal, most of the GW flows are from the hill side. Off the 2.8 TCM water from Zone 2, 1 TCM enters the zone 1. This shows that the zone 1 will have better GW availability even in the absence of canal when compared with other zones but not enough to sustain old cropping pattern i.e. cropping pattern with canal.

Table 5-7: ET load comparison of scenario 1 and scenario 2

ET zones	MODFLOW ET load (mm) Scenario 1	MODFLOW ET load (mm) Scenario 2	Actual ET (mm)	Difference in ET loads (mm)	New actual ET load (mm)
Zone 1	1.3	0.3	2.51	1	1.47
Zone 2	1	0.3	2.59	0.7	1.89
Zone 3	0.8	0.8	2.13	0	2.13
Zone 4	0	0	2.31	0	2.31
Zone 5	0.3	0.3	1.52	0	1.52
Zone 6	0.6	0.6	2.30	0	2.30

Source: MODFLOW and calculation

5.3.3 Analysis

From table 5.7 it can be seen that there is drop in MODFLOW ET load in the zones 1 and 2 of magnitude 1 and 0.7 mm while other zones are not affected when the canal is not active. In other words it means that without the canal ET load has to drop by 1 and 0.7mm in zones 1 and 2 to sustain the observed well level. Also the canal command area which is between the canal and river (zone 1) is obviously affected by the absence of canal. Interesting aspect is the effect of canal on zone 2 which is not a part of command area as it is upstream/ upper region of the canal. It is seen that in the absence of the canal, this zone is affected adversely. This clearly indicates the ‘blocking’ of groundwater flows from the upper regions by the canal resulting creation of ‘water banks’ for the upper regions.

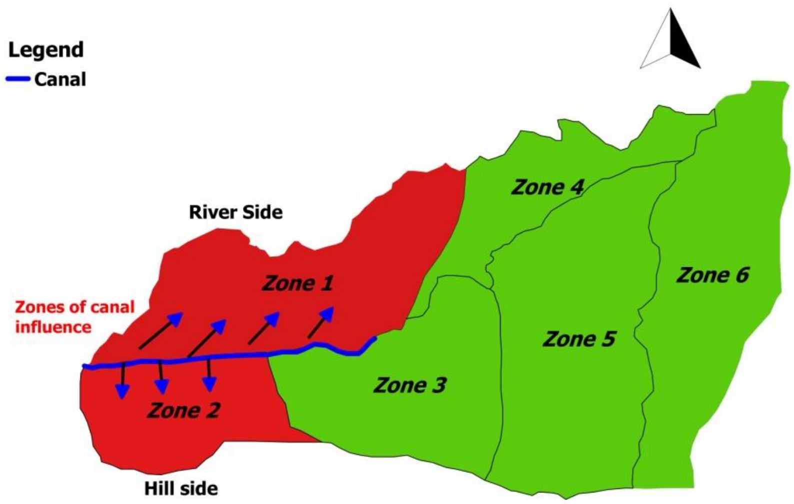


Figure 5.15: Zones of canal influence

The influence of canal on the upper region of the study area is shown through the cross section view of the GW table in the figures below

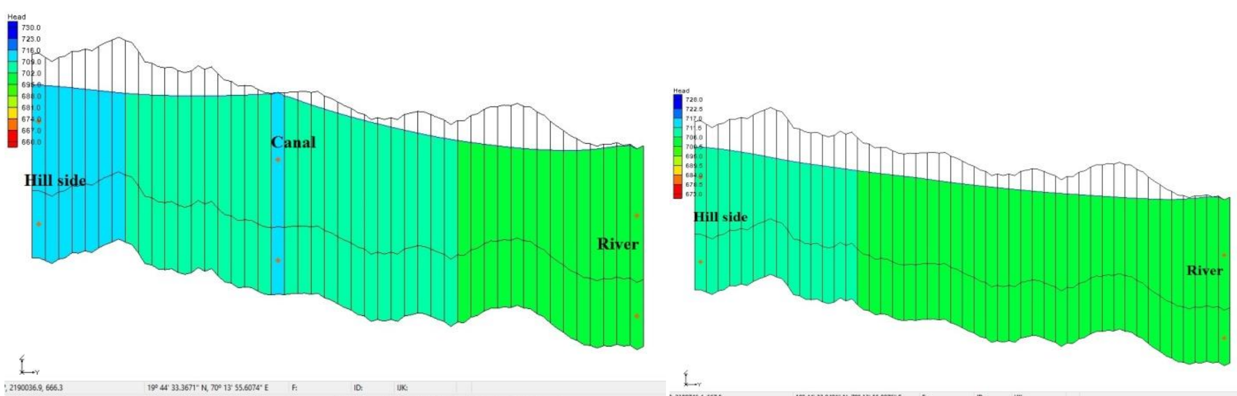


Figure 5.16: Water table with and without canal

In simulation between flow and no flow scenarios of canal the change in actual ET load observed are 1.51 and 1.89mm. The corresponding change in cropping area in the zone 1 and zone 2 are given in the table below.

Table 5-8: Cropping area with and without canal

	Scenarios	Area (ha)	Cropping area (ha)	Cropping percent	ET load (mm)
Zone1	With Canal	160	104	65	2.5
	Without canal	160	63	39	1.5
Zone2	With Canal	85	58	68	2.59
	Without canal	85	44	51	1.89

Note: Zone 4 is also influenced by the canal as the canal extends up to the end of zone 4 but the scenario for which the MODFLOW model was simulated, canal was active only till end of zone 1. Hence the canal influenced could not be captured on zone 4.

The ground water stock variation in the study area over the period of time obtained from the well readings is shown in the graph below

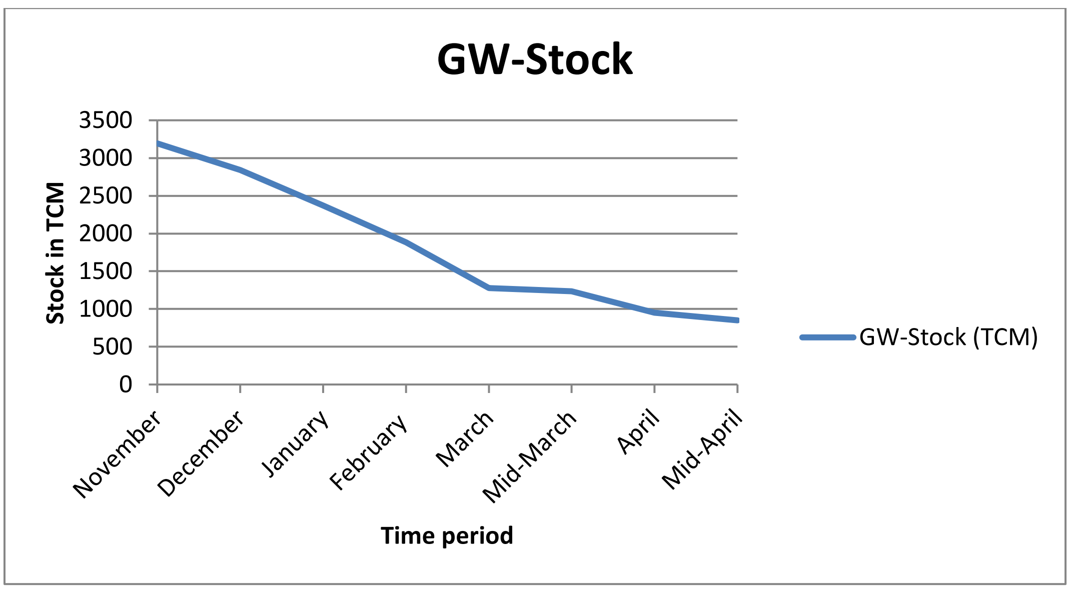


Figure 5.17:Variation of groundwater stock over the period of time

The drop in the GW stock is linear till the month of March and after that the drop becomes more gradual as the GW stock is kept for drinking water security and protective irrigation.

Finding:

- The percentage decrease in cropping area in zone 1 without canal is 39%
- Percentage decrease in cropping area in zone 2 without canal is 24%
- Overall decrease in the total cropping area of 425ha without canal is 14%
- Amount of water added by canal to the system is 2.24 TCM/day.

6. Conclusion

- The benefit of canal (DBI) is substantial as the impact of canal is not restricted to the command area but also to the non command area. As the canal 'blocks' the flow of water from the upstream side /hill side there by providing water to the non command area.
- Zone budget shows that the amount of water entering from hill side during canal flow is 5.27 TCM/day and without canals its 2.8 TCM/day. Hence presence of canal increases water flow in the hill side.
- The cropping pattern in directly dependent on canal water in the canal influence zones. While zones like Dubere area and areas near the base of the hill are outside the ambit of Canal Zone of influence.
- The change in total cropping area due to absence of canal is 14% while that in command area is 40% and uphill region (zone 2) is 24%.
- Cost of infrastructure per hectare for rejuvenation of a DBI system is approximately Rs.55000/ha.
- Rejuvenation of DBI is an feasible option and better than conventional canal irrigation system.

6.1 Scope for future works

- To run the transient condition model of the village by developing the complete watershed groundwater model to determine the changing boundary flows.
- Understandings inter-well water transfer acting in the area and transfer of water from one zone to another.

7. References

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Appendix A: Farmer survey questionnaire

Well code - ____________ **Zone -** ___

Farmer name - ____________________________ **Survey no.-**_____

Well and pump data

Well dia. – _____
Soil type – ________
Soil thickness – _____
Hard rock start – _____

Pump capacity – _____
Pump age – _______
Pump type – __________
Distance of pump to field – _____

Cropping Data

Crop	Duration of crop (months)	Area			Drip (y/n)	Number of waterings	Number of pumping hours for one watering				
		K	R	Tot			Kharif	Sep	Nov	Jan	Mar

Well water transfer –

From / To	Survey no.	distance (m)	start date	frequency (days)	pumping hours/day	for which crop?

Recovery Information

	Sep	Nov	Jan	Mar
Pump operation hours per day				
Dip in water level below ground level in feet/m				
Recovery time				

Drip irrigation details

Crop	Area	Plants/acre	Discharge at plant roots (lpm)	Pump operating days			Operating hours		
				Kh	Rb	Su	Kh	Rb	Su

Appendix B: Water budget zones