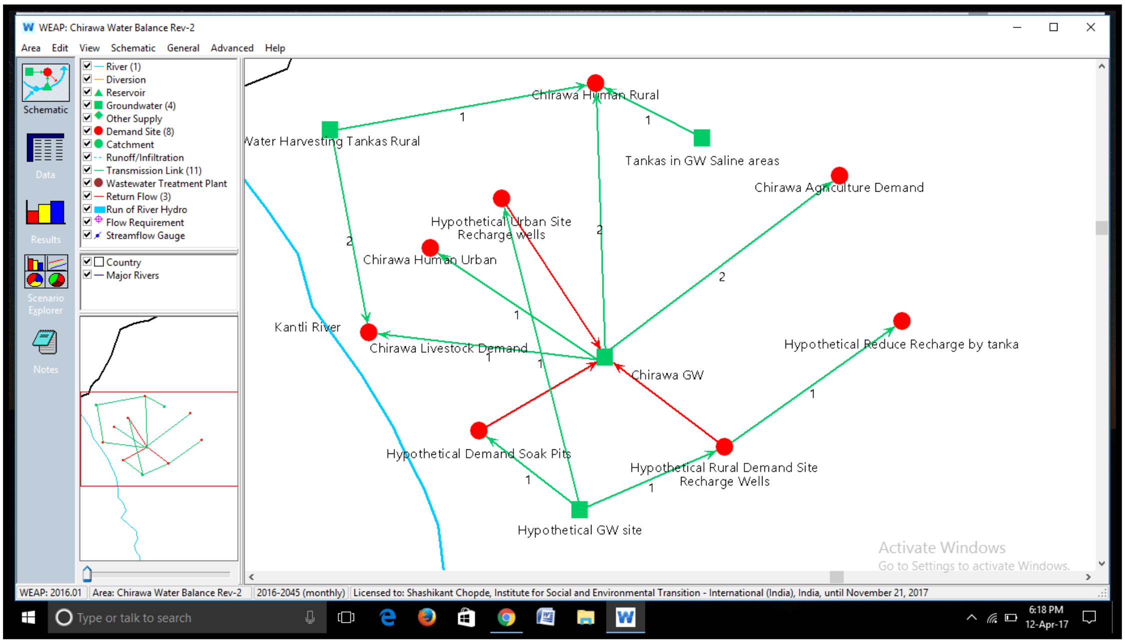
ADDRESSING CHALLENGES OF SEVERE GROUNDWATER DEGRADATION

Water Balance Modeling for Identifying Options for Chirawa Block, Jhunjhunu, Rajasthan



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Addressing Challenges of Severe Groundwater Degradation:

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The Project Summary

RJDSS has undertaken a project from the Department of Science and Technology, Government of India entitled *A Community Based Participatory Aquifer Management System for Providing Equity and Sustainability in Water Resource Management* in the villages of Chirawa block of Jhunjhunu District in semi-arid area of Rajasthan. Groundwater degradation is high and it is the only source for economy and livelihoods in the block. The project seeks to develop models of groundwater conservation and augmentation, enhance livelihoods by promoting improved water management and agriculture practices, and foster equitable access to drinking water in this water scarce block.

The water balance study is conducted to assess the current and future demand and supplies to identify and promote appropriate water management options in a timely manner.

Study approach and methodology

The study uses Water Evaluation And Planning (WEAP) tool developed by Stockholm Environment Institute (SEI, US) that has been applied to many important basins, internationally. Government of Rajasthan has also used WEAP for water resources planning of the state.

Results from the Geophysical study conducted under the project are used in combination with host of secondary data on parameters that influence water demand and supplies. Key data sets include long-term data on rainfall, population, cropping pattern and areas, scale of use of irrigation technologies, groundwater recharge and pumping. In addition, findings from assessments of various water harvesting and recharging technologies carried out by RJDSS are used. Lastly, consultations with farmers provided needed information on preferences of crops, water use rates and key assumptions used in the WEAP model.

Configuring WEAP model for Chirawa block

WEAP model is setup for 2015-45 for business-as-usual scenario and four other alternative water management scenarios:

- <u>The Integrated Crop and Water Management (ICWM) scenario</u>: it assumes replacing half the area under Wheat (the most water intensive crop) by Mustard, Gram and Horticulture. The scenario also assumes switching Horticulture fully to drip irrigation.
- <u>Reducing electricity hours of supply</u>: The model considers reducing the electricity supply for agriculture from current level of six hours to four hours per day.
- <u>Water Harvesting, Groundwater Recharge and Tankas</u>: It considers large-scale adoption of roof top rainwater harvesting tankas and artificial recharge tubewells. The artificial recharge tubewells are proposed in

both, rural areas of the block and Chirawa town. In addition, large-scale household levels soak pits for recharging are also considered.

- Combination scenario: Combines ICWM and Water Harvesting scenarios.

Key Results

- In business-as-usual or no-intervention scenario there will be (almost) no groundwater left by 2045;
- We assess the effectiveness of any scenario by the extent to which it bridges the demand-supply gap. Reducing electricity hours is the most effective option for water management, followed by, in descending order of effectiveness, combination scenario and subsequently the ICWM scenario;
- Water Harvesting, Groundwater Recharge and Tankas is the least effective scenario. However, it provides the much needed drinking water security especially where there are no potable drinking water sources;
- Chirawa town provides a critical and strategic opportunity for roof-water artificial recharge through recharge tubewell due to large-scale availability of roofs in contiguous patches. Investment in artificial recharge in the town yields higher returns than investments in artificial recharge through widely scattered recharge tubewells in rural areas of the block; and,
- Low cost household level soak pits are also found to be effective for recharge due to availability of household wastewater for recharging round the year.

Key Recommendations

- A model of community based agriculture power users' group need to be promoted on pilot basis in which the user group itself plans, operates, manages and monitors use of agriculture power and groundwater pumping. Simultaneously, IT-based smart solutions need to be developed to support the above;
- Growing Wheat for sale by farmers is highly unsustainable given the severe groundwater degradation in the block. Hence, appropriate policy and institutional mechanisms for discouraging wheat cultivation for sale/ procurement need to be promoted;
- To compensate the loss in income of farmers due to reduced production of wheat alternative non-farm livelihood options need to be promoted;
- Simultaneously, value-chain mechanisms in the promoted lower water use crops such as Mustard, Gram and Horticulture need to be developed. Specific capacity building, awareness and pilot implementation projects need to be developed and supported;
- Appropriate subsidy needs to be provided from government's flagship programmes for roof-water harvesting tankas especially in rural areas affected by groundwater quality problems of Chirawa block; and,
- Roof top rainwater harvesting for drinking and artificial recharge of groundwater needs to be made mandatory by Chirawa Municipality. Simultaneously, tax rebate can be provided by the Municipality to incentivize such initiative.

Addressing Challenges of Severe Groundwater Degradation:

Water Balance Modeling for Identifying Options for Chirawa Block, Jhunjhunu, Rajasthan

1. Introduction

Jhunjhunu district lies in the northeastern part of Rajasthan state and is divided into eight blocks namely, Chirawa, Surajgarh, Buhana, Khetri, Udaipurwati, Navalgarh, Jhunjhunu and Alsisar. This arid district covers an area of 5911 Sq.km. The study area comprising the entire Chirawa block that lies in the centre of the district covers a geographical area of 522 Sq.km. The average annual decadal growth rate of population of Chirawa block is 2.1 percent with increasing level of urbanization.

The block is characterized by highly erratic rainfall. The annual average rainfall during 1973-2016 is 455.69 mm that is marked with high inter-annual variability and an increasing trend (Figure 1).

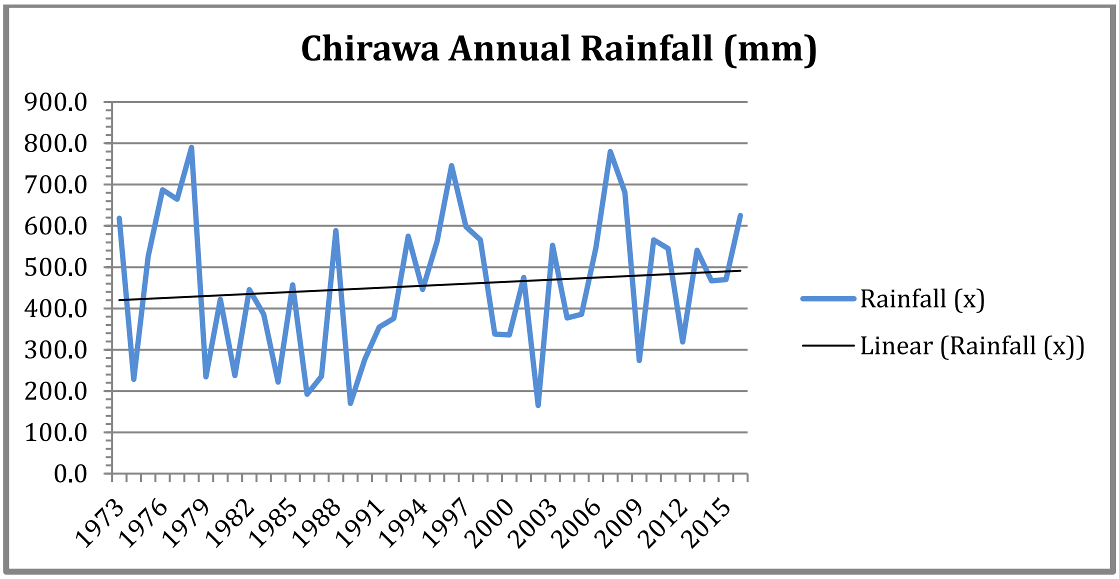


Figure 1: Chirawa annual rainfall and trend (1973-2016)

Chirawa is part of Kantli River Basin and there are no major surface water storages in the block. Hence the population is primarily dependent on groundwater for all the needs. Strikingly, about half(43.8 percent) of households own tubewell/ well while the rest depend on monsoon rains for agriculture. Further the poorer households have higher dependency on primary occupations namely, agriculture and livestock activities for their livelihoods. In contrast households in higher income categories tend to bank more on non-farm sources of income[1].

Crops are majorly grown in two seasons—Kharif and Rabi. The principal crops in Kharif are Bajra, Guwar, Pulses and Cotton while in Rabi farmers grow Wheat, Gram,

[1]Project Baseline Report, 2016, CEDSJ

Mustard and Barley. However increasing scarcity of water has forced few farmers to initiate agro-horticulture practices, though the scale is far less than desired. Low rainfall, increasing population, and high extraction of groundwater for irrigation due to inappropriate cropping practices for decades has led to overexploitation of groundwater. To counter the groundwater degradation CGWB has notified the block as 'Dark Zone' under Groundwater Regulation, in 2005. Despite that, continual and sustained increase in pumping has resulted in severe decline of groundwater levels and deterioration of quality. Consequently, the water has become unfit for drinking in some of the areas and the gap between who can access it for irrigation and who cannot has widened.

CEDSJ is providing technical support to RJDSS for implementing a project on community model for groundwater governance and management in Chirawa. The project is supported by Department of Science and Technology (Government of India). Under the project two studies have been carried out on baseline conditions of groundwater availability and use, and geophysical survey for identifying prospective locations of groundwater recharge. The current water balance study aims to assess current and future water demand and supplies to promote appropriate water management options in a timely manner study. It uses findings of the above studies apart from secondary sources of data and information.

2. The Water Evaluation and Planning Model

WEAP, the Water Evaluation and Planning, is a decision-support model developed by Stockholm Environment Institute (SEI, USA). It is an user-friendly tool that considers an integrated approach to water resources planning. It provides a framework for assessing water resources and planning that has been used to understand current water resource conditions and explore a range of demand and supply management options to balance the need between environment and development. At the same time, WEAP has ability to model scenarios of socio-economic and technological developments, and understand their implications on water resources demands and supplies. One of its strong features is transparency in data that has been used to promote multi-stakeholder negotiations. It has been successfully used worldwide in various river basins such as Yellow River (China), Nile and Niger rivers (Africa), River Basins of Peru (South America), Connecticut River Basin (USA). Further, Government of Rajasthan has used WEAP for meso-scale modeling of water resources of the state.

Specifically in the context of the study, WEAP is used to simulate: water supplies through groundwater; and, water demand driven by increasing population, urbanization, agriculture, and associated water management technologies in the block. The block's water resources is modelled for 2015-45 in business-as-usual or reference base case and future scenarios of socio-economic developments and water management options. The scenario development is further described below.

3. Setting up WEAP for Chirawa block

For modeling the reference base case using which all the future scenarios are developed, the base account for the year 2015 was setup using the data and parameters of that year with following considerations:

- The level of demographic and agriculture development;
- The nature and extent of proliferation of irrigation saving technologies; and,
- The level of local groundwater supplies.

The business-as-usual or reference base case was developed for 2015-45 using the projected growth rates and trends of population, urbanization, agriculture, and water resources development and management. The model was run for monthly time step starting from June of every year, which is the first month of monsoon.

Further, rainfall data for 1973-2016 is analysed to project future rainfall for 2016-2045. As the rainfall data is skewed it is normalized using the normal distribution function. The normal distribution values for various years are grouped into five equal class-intervals with average rainfall value computed for each interval. Table shows range of class-intervals in terms of Standard Deviations (SDs) from the mean.

Table 1: Range of annual rainfall magnitudes by water year type

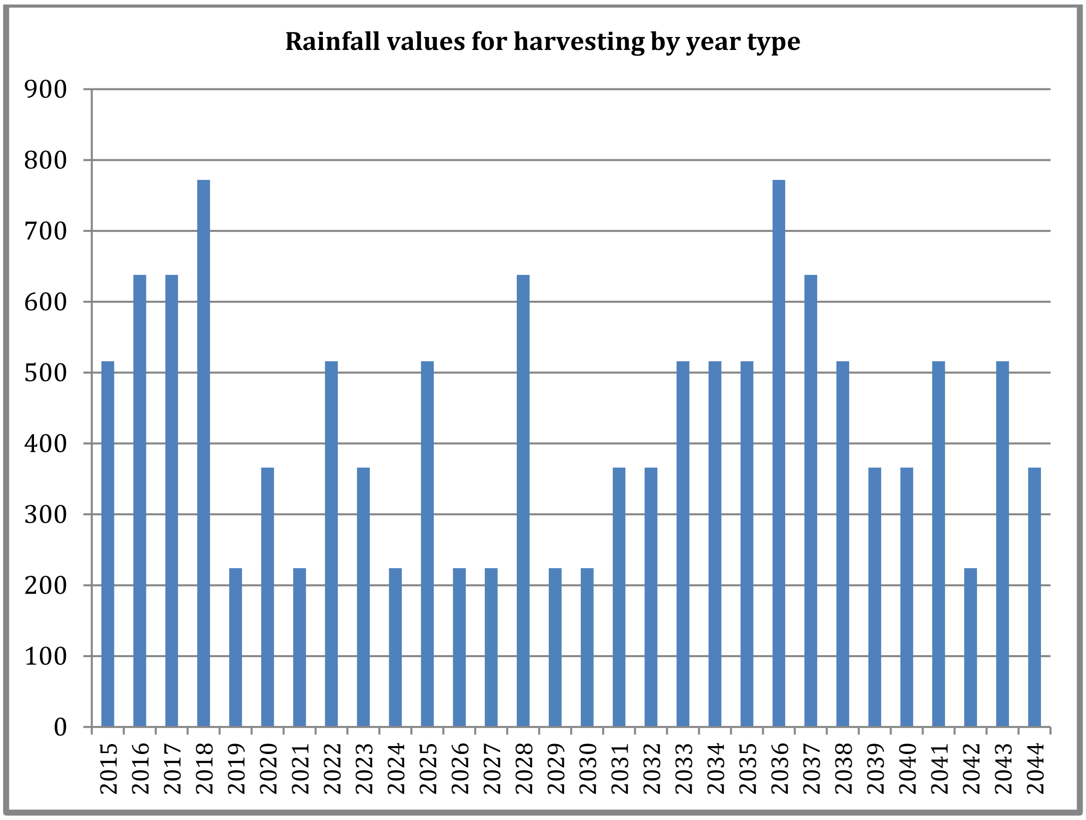
Class-interval (deviation from mean as multiplier of SD)	Year Type	Annual average rainfall value for the class-interval (mm)	Average number of rainy days	Number of years
-1.69578301701027 to -0.895783017010269	Very Dry	224	16	10
-0.895783017010269 to -0.0957830170102687	Dry	366	24	9
-0.0957830170102687 to 0.704216982989731	Normal	516	30	15
0.704216982989732 to 1.50421698298973	Wet	638	30	7
1.50421698298973 to 2.30421698298973	Very Wet	772	31	3
Average/ Total		455.69	25.51	44

Note: The extreme high rainfall values are relatively far away from mean than the extreme low values denoting that the rainfall values are skewed right (positively skewed).

Corresponding lower and upper limits of rainfall values for each class-interval are computed to assign specific water year type (dry, wet etc.) for each of 44 years for which historical annual rainfall is available. Finally, historical sequence of water year type for consecutive 30 years is replicated to develop the sequence of water year types for 2016-2045.

Ninety percent of the above average annual rainfall values for each water year type are fed into the WEAP model for computing potential volume of water available per unit area of roof for artificial recharge wells and roof water harvesting tankas (Figure 2).

Figure 2: Rainfall magnitudes for harvesting



Note: Ninety percent of above values considered as available for roof water harvesting

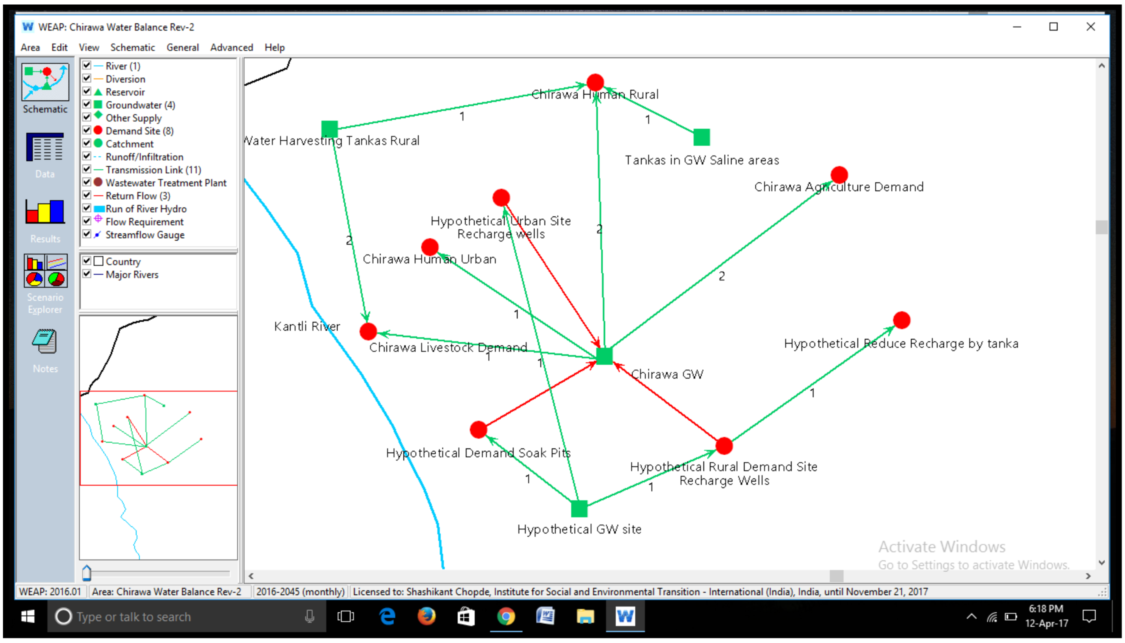
The core approach was to consider both types of demand sites—agriculture and domestic, drawing water from groundwater reservoir. The water allocation priorities across domestic, agriculture and industrial uses was set in descending order as per the national and state water policy. This approach enabled to model:

- Changes in rural and urban domestic water demands in the block;
- Changes in agriculture demand;
- Assess level of competition for the resource as socio-economic transition occurs; and,
- Assess impact of increased demand due to population growth, urbanization and agriculture development on specifically, the already over-exploited groundwater resources.

4. Data for WEAP model

The water demand and supply system is modeled under all the scenarios for 2015-2045. The startup year, 2015, was selected to initialize the model due to availability of data on population, cropped areas under various crops by seasons, and groundwater supplies. The WEAP schematic for the Chirawa block is shown in Figure 3.

Figure 3: WEAP schematic for Chirawa block



4.1. Demand sites

As mentioned in the foregoing, there are multiple demands on groundwater in the Chirawa block. There is a striking variation in level of socio-economic development between the largest urban center (Chirawa town) and rest of the rural areas of the block having implications for water use that needs to be accounted for. Further, diversity of extent of irrigation for each crop type by season needs to be considered. Due to this, any modeling attempt to assess fragility of supplies must include all known uses in the contiguous geographical area of the block. The following sites were accounted for in the model:

Domestic demand sites: The sites for this demand need to account for population both, human and livestock population. For this Census 2011 and Livestock Census 2012 data is used to compute populations for 2015 by applying the growth rates.

Agriculture Demand: One demand site for modeling agriculture water demand.

Linking Demand and Supplies: All the demand sites were linked to supply nodes (data sources and setup described below) through transmission links.

4.2. Data for demand drivers

Population for each Demand node: Population data of Census 2011. Further, the population was split into rural and urban for domestic demand node as per the share mentioned in Census 2011.

The livestock population was taken from Livestock Census of 2012.

Growth rate of human and livestock population: For total (rural and urban) human population it is computed based on observed decadal growth rates over last five Censuses. The proportion of urban to total population is increased to 40% by 2045 in line with anticipated general level of urbanization in India. Growth rate for livestock population is calculated based on Livestock Census of 2007 and 2012. (Figure 4 and Figure 5).

Figure 4: Projected urban and rural population

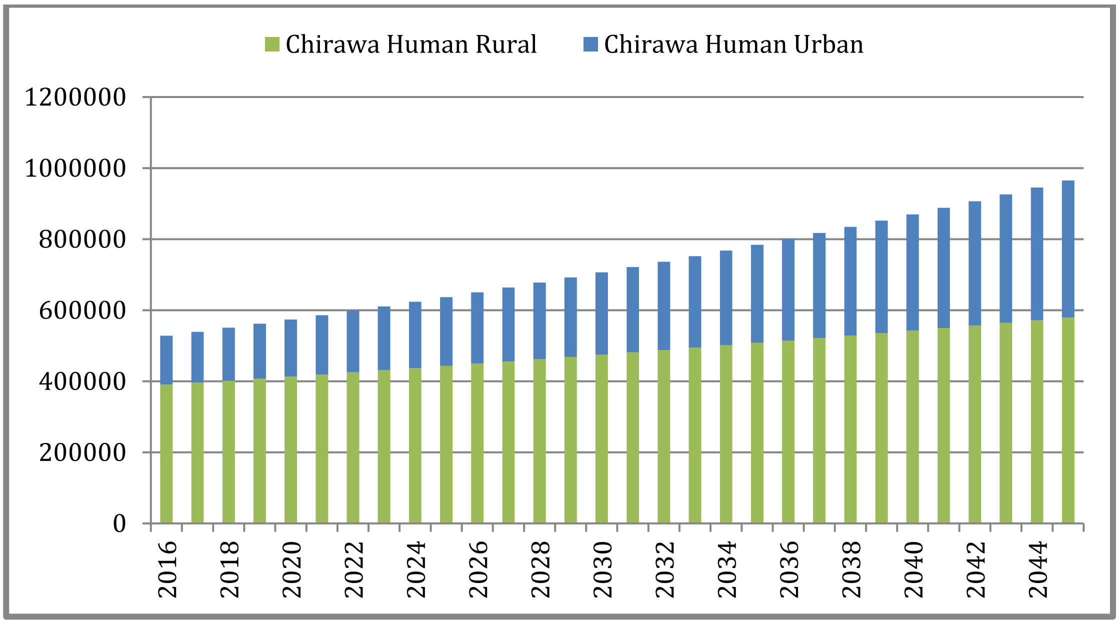
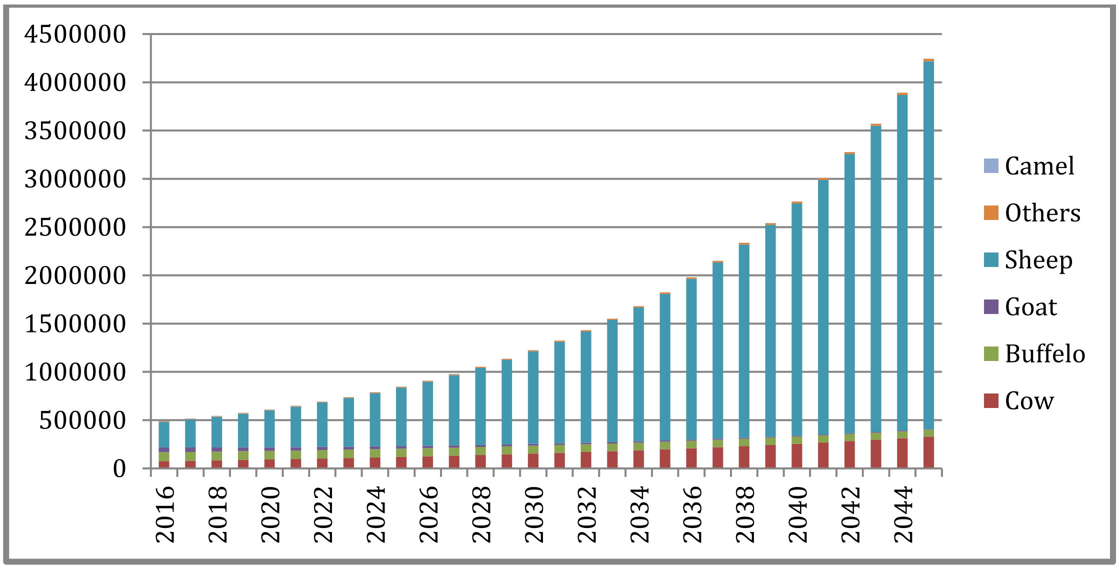


Figure 5: Projected livestock population



Cropped area and level of irrigation for agriculture demand node: Only two cropping seasons, Kharif and Rabi, are considered. The major Kharif crops include Bajra, Guwar, Pulses, Cotton and Other Kharif[2] while Rabi crops comprises Wheat, Barley, Mustard, Gram, Horticulture and Other Rabi[3]. The area under various crops by season and irrigated/ un-irrigated category is taken from agriculture tehsil level records at Chirawa for 2015-16. Along with we used the Jhunjhunu district level data on cropped area under various crops by season available for 2004-05 to 2012-13. The block level area under various crops, specific to each year during 2016-45 is calculated by multiplying the corresponding crop areas at block level for 2015 by a fluctuation coefficient. The fluctuation coefficients for each major crop for each water year type in future[4]are calculated as ratio of crop area for that water year type and crop area in normal year recorded during 2004-05 to 2012-13 at the district level. It is to be noted that 2015 was a normal rainfall year as per our classification mentioned above.

Annual water use rates: The model considered Government of Rajasthan norms for water supply for municipalities (80 lpcd) and rural areas (40 lpcd).

The per-day water requirement by various livestock types such as cow, buffalo, sheep, goat and all others are considered based on our own field survey.

There is no flood irrigation in the entire block. The crop water requirements for various crops are taken based on actual field measurements carried out by RJDSS for sprinklers and drip.

Priority: WEAP allows flexibility to assign different supply side and demand side priorities. As per the State Water Policy the domestic and irrigation demand sectors are assigned priorities 1 and 2, respectively for supply. In addition, the model is setup for sourcing water from various sources at varying priorities: Domestic water supply priority for water harvesting tankas and groundwater are assigned as 1 and 2, respectively.

4.3. Data for Supply nodes

Groundwater: Groundwater resource data for the block is derived from the Rajasthan District wise Groundwater Resource Availability, Utilisation and Stage of Development (2011) by apportioning the replenishable annual recharge from rainfall for Jhunjhunu district by percentage of areas of Chirawa block to Jhunjhunu district.

Natural Recharge by water year types: As more than 80 percent of annual precipitation takes place in the months of July-October, we divided annual recharge (as computed above) across four months, August-November in the proportion of 10, 35, 35 and 20 percent, respectively. The one-month lag was considered to account for time between rainfall and aquifer infiltration. In addition, natural recharge is considered differently across the five water-year-

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[2] All the remaining Kharif crops are clubbed into Other Kharif category

[3] All the remaining Rabi crops are clubbed into Other Rabi category

[4]Refer "Section 3: Setting up WEAP for Chirawa block" to know future sequence of water year types

types, namely very dry, dry, normal, wet and very wet at 10, 20, 100, 110 and 120 percent, respectively of the average annual replenishable figure computed, as above, for the block.

Storage Capacity: Geophysical resistivity survey has been undertaken for almost 50% of the total area of Chirawa block as part of the current project. It provides information for 110 VES points on thickness of impermeable top layer, unsaturated thickness, depth to water level, and depth to bed hard rock along with depth of bed hard rock to measured depth. In addition, it maps the diverse geological formations at each VES point. Considering the range of porosities of different formations provided by Freeze and Cherry (1979), and the data on above mentioned depths, the storage capacity and initial storage of the groundwater for the Chirawa block are calculated and fed into the model.

5. Developing future scenarios

As mentioned in the foregoing, all the scenarios including the reference base case were run for the period 2016-45. Scenarios for various water conservation schemes on demand management and supply augmentation were created. The scenarios are based on principles mentioned in the State Water Policy of 2010, and also that certain policies would be implemented simultaneously.

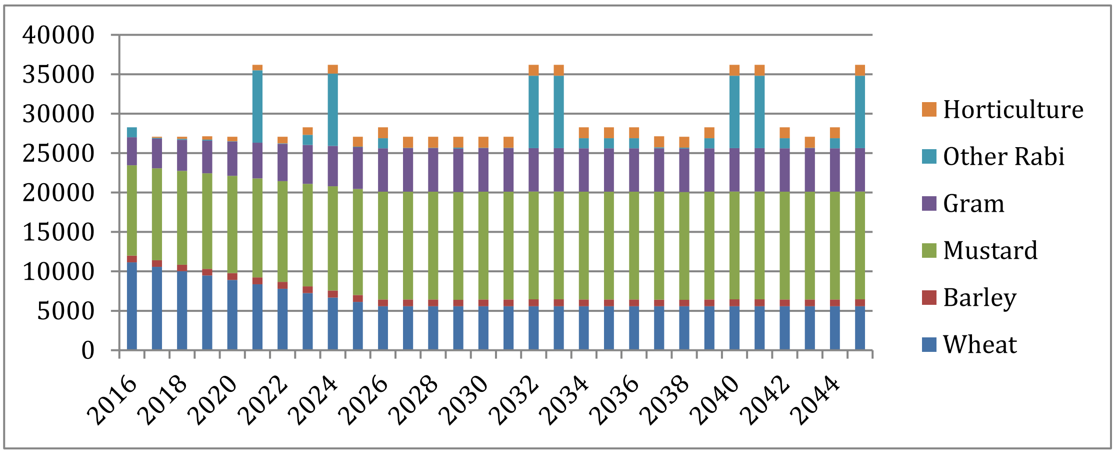
Firstly, the *Reference Base Case* scenario is developed. It assumes that no demand side management or supply side augmentation measures are taken. Primarily, it is a business-as-usual scenario. Overall human population growth, crop pattern and associated cropped areas, irrigation water technologies, and consequent water demand continues to grow/ vary at current patterns and trends; the composition of urban to total population increases to 40 percent by 2045, thereby reducing the share of rural population accordingly (Figure 4); livestock population by various types of livestock continue to grow at current rate (Figure 5); and, current level of domestic water use (lpcd) in Chirawa town and rural areas of the block continue at the same level. On groundwater supplies, annual natural recharge is considered at varying levels by water-year-types as mentioned earlier.

Demand Side Management (DSM) scenarios

a) Integrated Crop and Water Management Scenario (ICWM) scenario: This scenario targets Rabi crops by curtailing the area under Wheat that is most water intensive while accordingly increasing area under Mustard and Gram which are less water intensive crops. It assumes the current area under Wheat would reduce linearly to half in ten years. The reduced Wheat area is used to augment areas of Mustard (40%), Gram (35%) and Horticulture (25%) (refer

Figure 6). RJDSS has already initiated piloting this shift in crop pattern and achieved fair degree of success. In addition, full area under horticulture crop would be shifted linearly to drip irrigation from sprinkler in ten years.

Figure 6: Area under various Rabi crops in ICWM scenario (ha)



b) Reducing Electricity Supply for groundwater irrigation pumping from 6 to 4 hours per day

Currently farmers are supplied electricity for six hours that is charged at a flat rate depending on pump HP. Hence, farmers try to maximize returns from high investments in wells/ tubewells and spending on electricity charges by maximizing pumping for irrigating the crops. One way to control groundwater pumping is through direct control by Electricity Board by reducing supply hours. We believe if farmer is assured of current income from farm and additionally created non-farm sources, this strategy might work. Hence, this scenario assumes reduction in supply from 6 to 4 hrs per day. The quantum of water pumped can be directly correlated to hours of electricity supply. In other words with 33 percent reduction in electricity supply the groundwater pumping would reduce by the same percent.

Supply Augmentation (SA) scenario:

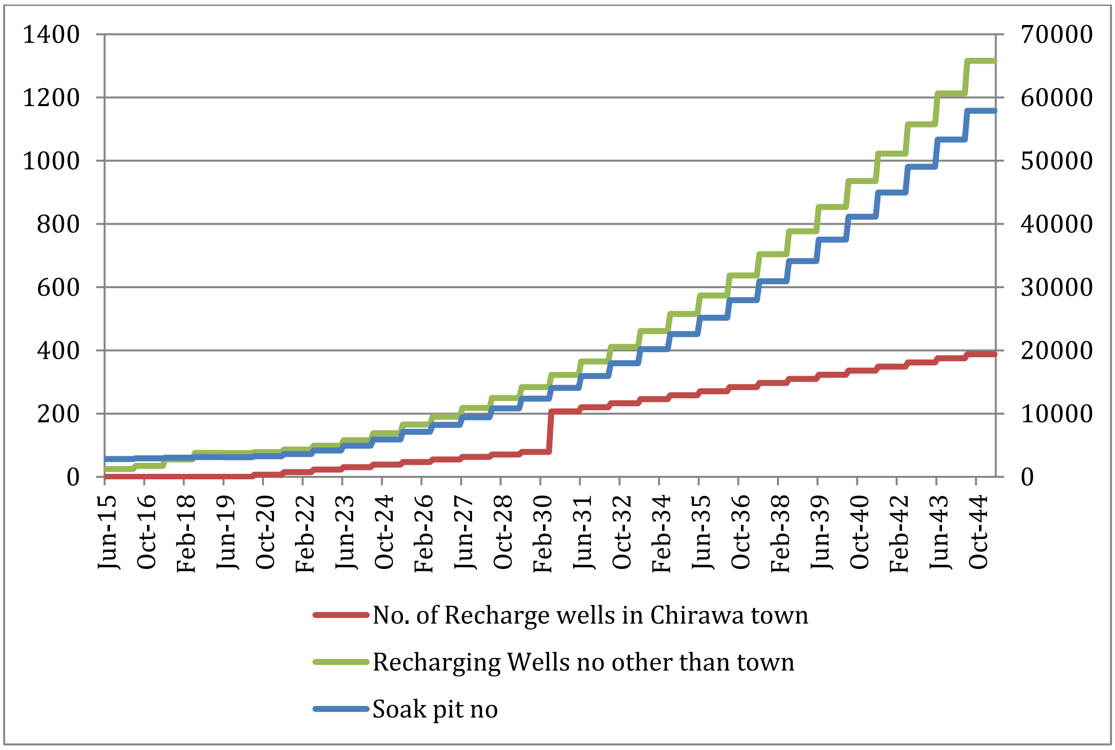
Drinking water security and groundwater sustainability are key concerns in the block. Large-scale decline in groundwater levels has turned it unfit for human consumption due to high salinity, nitrates and fluorides in about 30-50% of the area of the block. Hence, supplies are augmented through rainwater harvesting tankas (for drinking water security) and groundwater recharging through soak pits and artificial recharge tubewells. RJDSS has pilot tested many soak pits and few models of artificial recharge through tubewells that use surplus roof-top rainwater after harvesting in tankas. Based on the analysis of such experiments the model is fed with data on volume of each tanka and average (roof-top) area per recharge tubewell. The model uses design of such pilot-tested proven experiments and in this scenario we propose the following scale of various supply augmentation measures during 2016-45:

- It is assumed that 20 percent HHs in the rural areas of block will install rainwater harvesting tankas by 2026(in ten years) and tanka coverage will reach to 50 percent HHs by 2045. In addition, the surplus rainwater after capture in tankas from 50% area of the block where groundwater is still good will be used for groundwater recharge through artificial recharge tubewell;

- By 2026 (in ten years) 20 percent HHs will install soak pits and the coverage will reach to 50 percent by 2045;
- The current area of Chirawa Municipality is approximately in Sq.kms that is expected to grown to 2.5 times by 2031 as per the Chirawa Master Plan document. About 35 percent of it can be safely considered as roof-top area in the town. Artificial recharge tubewells harvesting roof-top rainwater are proposed even in the Municipality area. It is assumed that 10 and 20 percent of the total available roof-area will be covered for artificial recharging by 2030 and 2045, respectively.

Figure 7 shows assumed scale of soak pits and artificial recharge tubewells over 2016-45.

Figure 7: Soak pits and artificial recharge tubewells in SA scheme



Note: Soak pit numbers on secondary Y-axis (right side vertical axis)

Combined ICWM and Water Harvesting Scenario: The scenario considers combination of ICWM and Supply Augmentation scenarios.

6. Results

The water demand setup in WEAP includes domestic and agriculture demands. Hence, the demand nodes include: two human domestic demand nodes representing urban and rural human uses; one livestock demand node; and, one agriculture demand node with two sub-branches, Kharif and Rabi. Each agriculture sub-branch is further divided into sub-branches each representing a major crop.

In addition, a supply node for groundwater is configured.

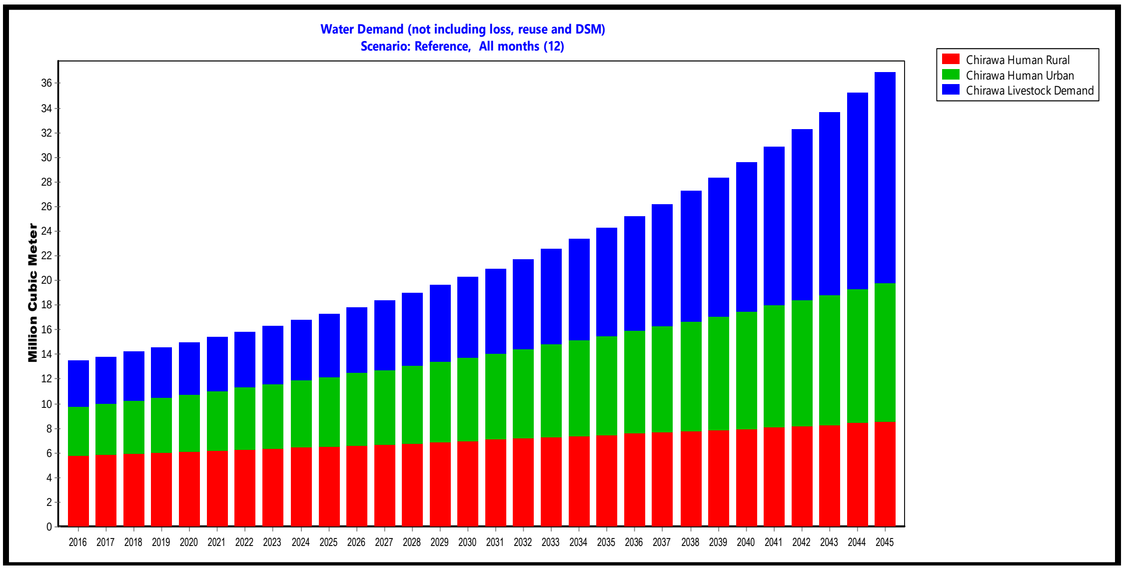
First, the results of Reference Base Case or business-as-usual scenario are presented on magnitudes and scales of demands across domestic and agriculture sectors, and its consequent impact on groundwater supplies. Subsequently, we draw conclusions from the demand management and supply augmentation scenarios as mentioned earlier.

6.1. Reference Base Case

Domestic Water Demand

In this section we present the scale of domestic water demand in Chirawa block. As mentioned earlier groundwater is only source for all the needs. While rural domestic demand would grow marginally, the urban and livestock demands are expected to grow significantly. The total annual domestic demand would increase to 36 MCM by 2045 (see Figure 8).

Figure 8: Domestic demand in Reference Base Case

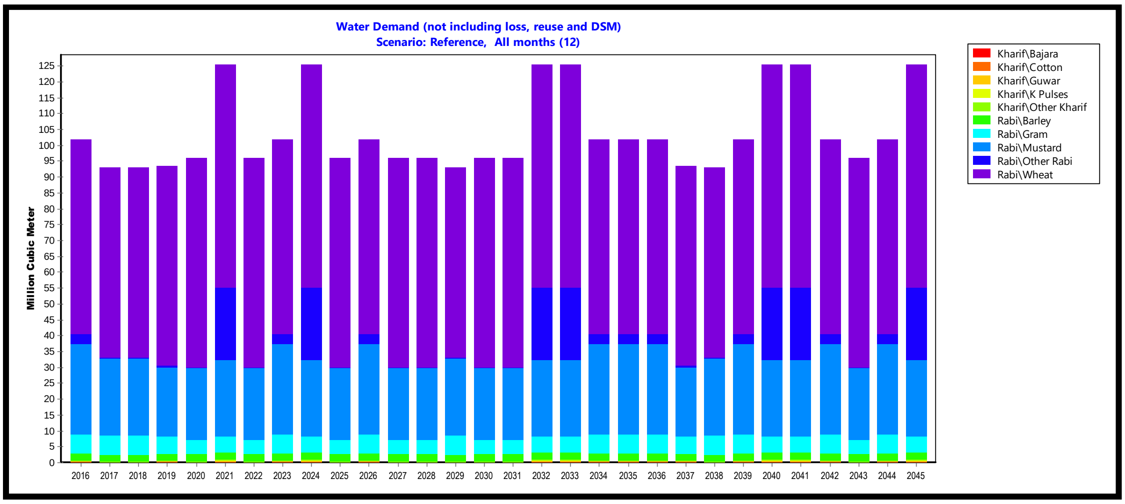


Agriculture Water Demand

Significant proportion of irrigation water is used by Rabi crops while water use by Kharif crops is an extremely small component of total agriculture demand. Wheat is the highest water consuming crop followed by Mustard in the block. The total annual agriculture demand fluctuates between 90 and 130 MCM depending on cropped area under various crops that depends on the water year type (

Figure 9).

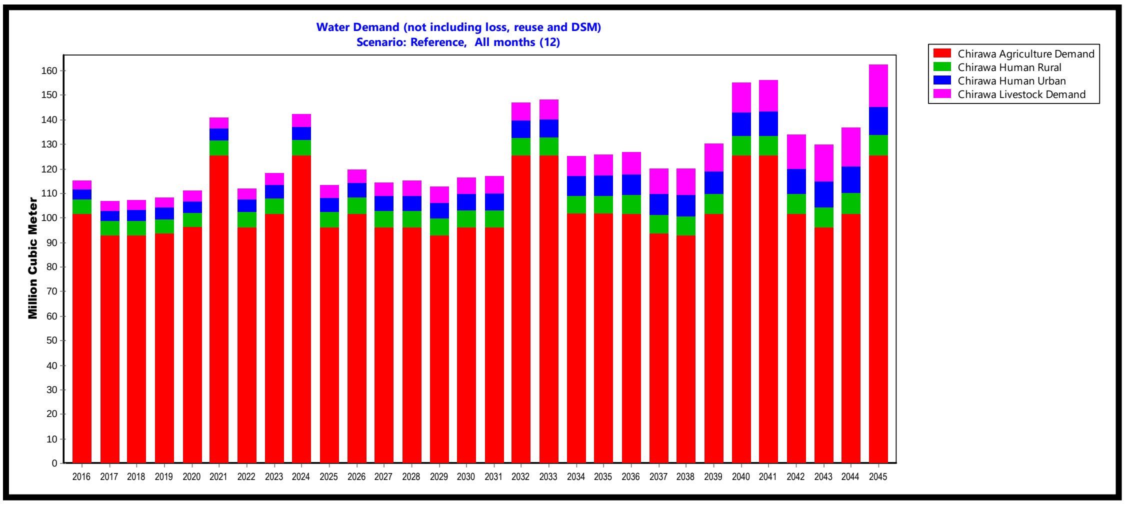
Figure 9: Agriculture water demand in Reference Base Case



Total Water Demand

Agriculture sector consumes the largest followed by urban domestic and livestock uses. The total annual demand of Chirawa block is expected to rise to ~160 MCM by 2045 (Figure 10).

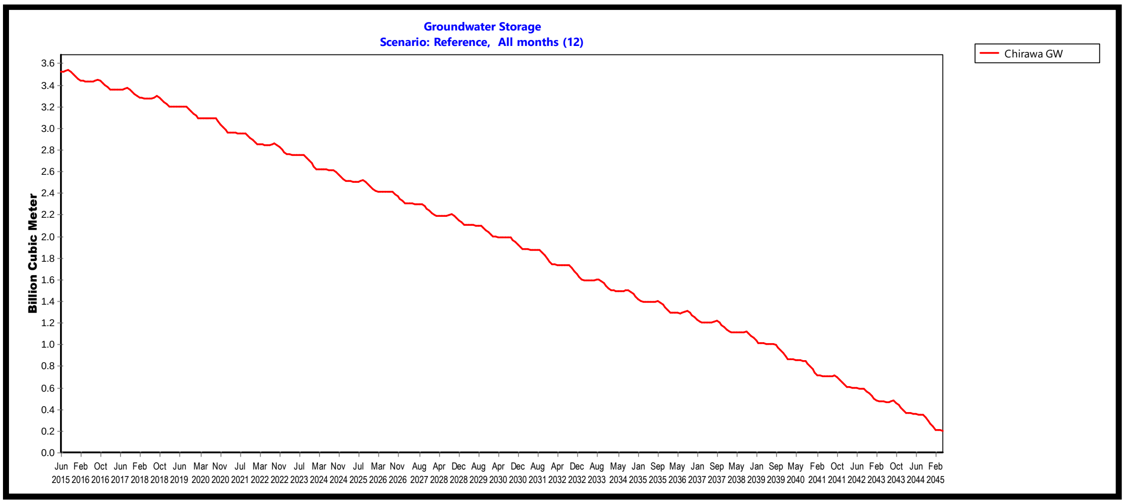
Figure 10: Total demand in Reference Base Case



Now we present the change in groundwater supplies for meeting the above demand.

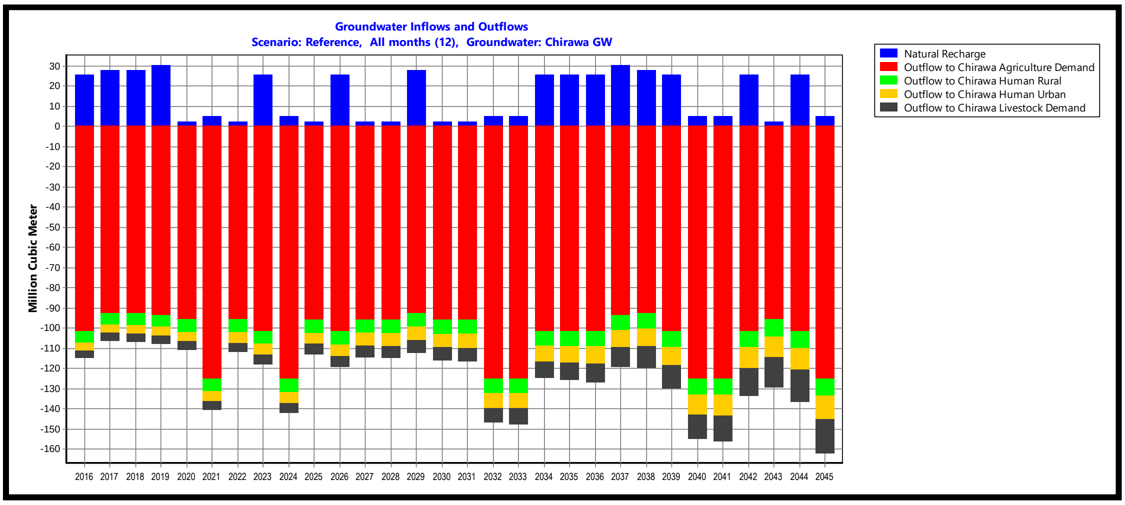
Figure 11 shows groundwater storages over the period 2016-45. There is a secular decline of groundwater storage to the extent that by 2045 almost all of the groundwater would be fully exploited. This will have large-scale impacts on drinking water security and agriculture that would no longer be feasible. Also such massive decline will have profound impact on groundwater quality as evidenced even today in almost 30-50% of the area of the block.

Figure 11: Groundwater storage in Reference Base Case



The precarious state of groundwater by 2045 can be explained by looking at magnitudes of natural recharge and extraction as shown in Figure 12. It shows that the annual extraction varies approximately from 3.5 to 50 times the annual natural recharge across normal water year and very dry water year type.

Figure 12: Groundwater recharge and extraction in Reference Base Case



6.2. Demand Management Scenarios

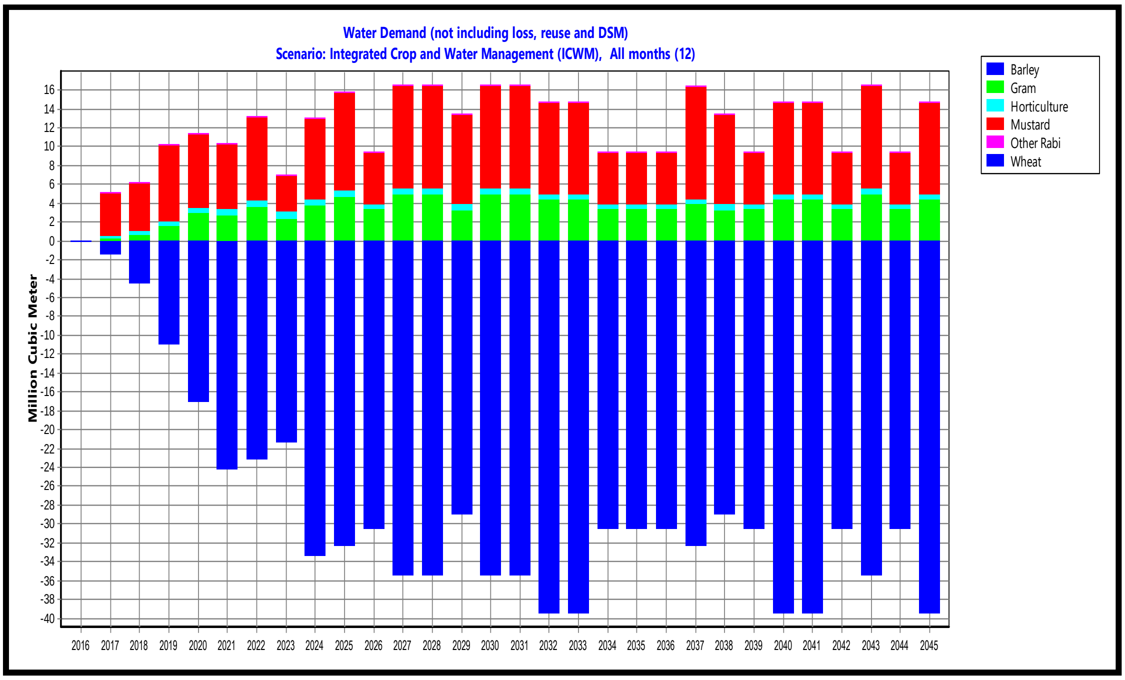
Two demand management scenarios have been modelled: The Integrated Crop and Water Management (ICWM) scenario; and, reducing electricity supply in agriculture sector.

Under the ICWM scenario the area of most water intensive crop--wheat, is reduced to 50 percent by 2026 (next ten years) with the reduction compensated by augmenting areas under Mustard (40%), Gram (35%) and Horticulture (25%). In addition, it is assumed that 100 percent of Horticulture cropped area will be brought under drip irrigation in the same period (by 2026) (see

Figure 6).

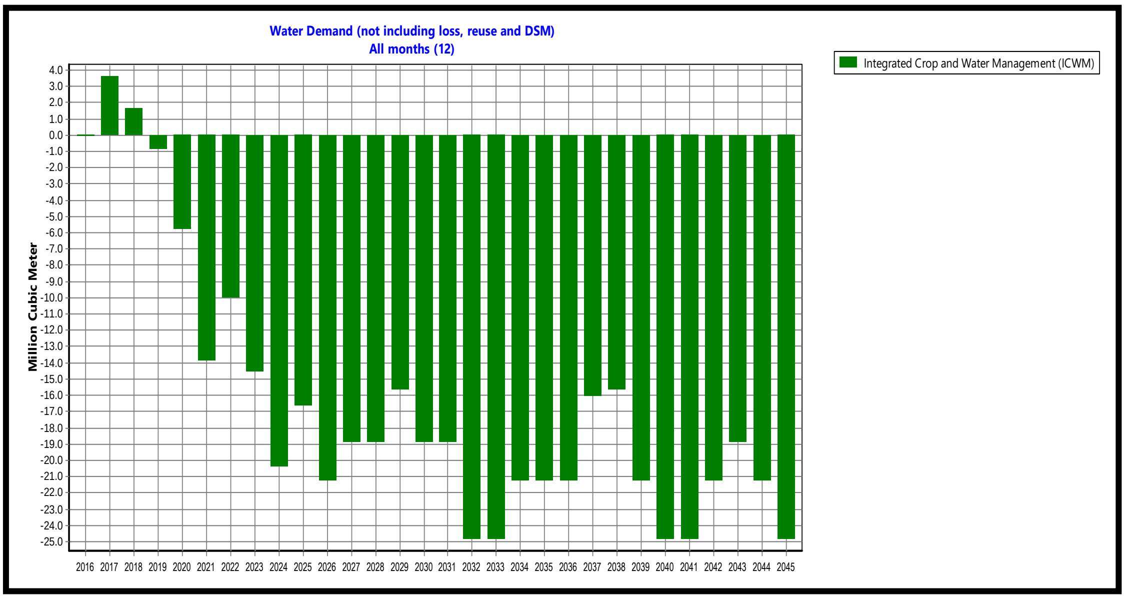
The saving in water use for Wheat is many times higher than additional consumption of water in the three crops promoted–Mustard, Gram and Horticulture (Figure 13).

Figure 13: Irrigation water use across various crops in ICWM scenario relative to Reference Base Case



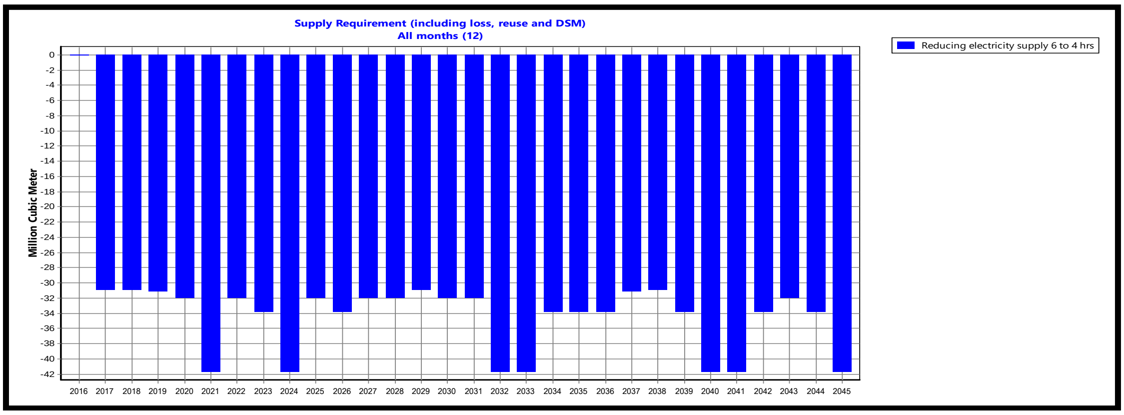
The overall demand of water is substantially reduced as evident in Figure 14.

Figure 14: Overall reduction in water demand in ICWM scenario relative to Reference Base Case



Reducing electricity supply scenario: The electricity supply in agriculture sector is reduced from six hours currently to four hours per day. The overall demand reduces even much more (Figure 15).

Figure 15: Water Demand in Reduced Electricity Supply Scenario relative to Reference Base Case



6.3. Supply Augmentation (SA) Scenario

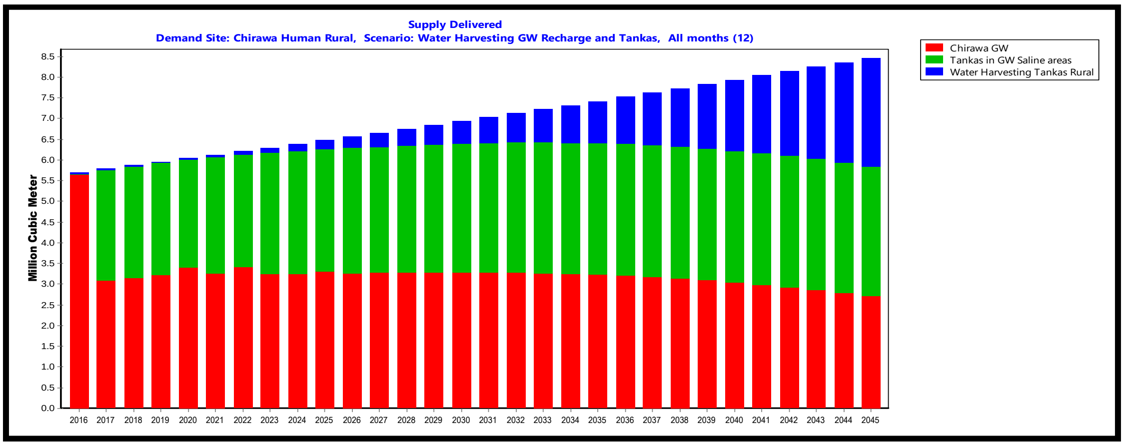
The supplies are augmented to enhance drinking water security and groundwater recharge. For drinking water security roof-top rainwater harvesting tankas are proposed while groundwater recharging is aimed to be achieved by artificial recharge tubewells and soak pits. For further details on scales of the proposed measures please refer to “Supply Augmentation Scenario” under “Section 5: Developing Future Scenarios”. With such enormous investments in water harvesting and recharge we investigated:

- Proportion of domestic water demand sourced from tankas and groundwater;
- Magnitudes of groundwater recharge by soak pits and artificial recharge tubewells; and,
- Implications of above on overall groundwater recharge vis-à-vis extraction.

The tankas are the only reliable source in areas where groundwater has become saline. In other non-saline areas of the block tankas still are preferred option especially for drinking water needs. The tankas meet more than 50 percent of the total domestic demand as evident from

Figure 16.

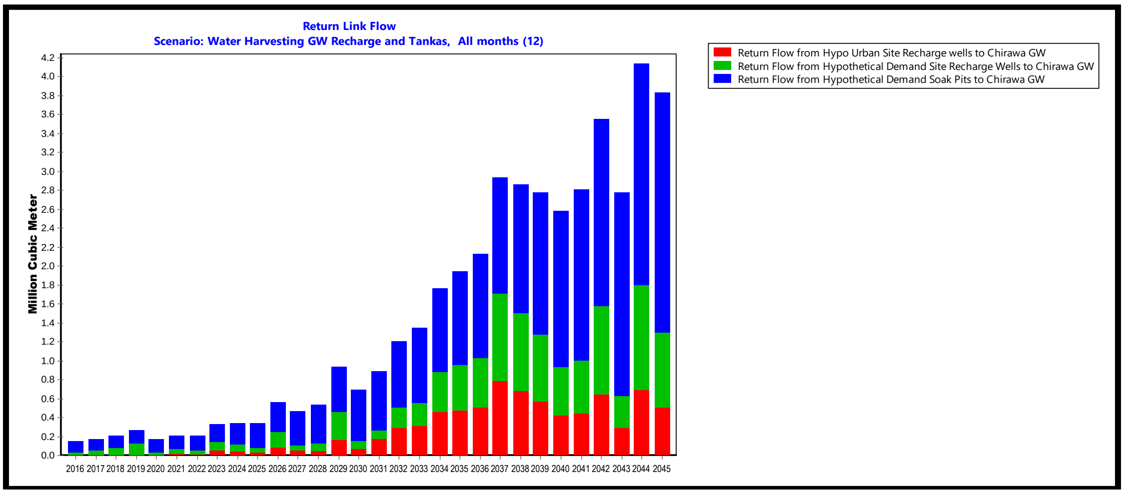
Figure 16: Domestic water demand from various supplies under Water Harvesting Groundwater Recharge and Tankas Scenario



Now let us see the scale of groundwater recharge by investments in artificial recharge tubewells (in rural areas and Chirawa town) and soak pits.

Even with much lower unit cost of soak pits they seem to be recharging the maximum primarily for the reason that they run on all the days of year against recharge tubewells which function only during the four-month monsoon season (Figure 17). The figure also clearly shows that concentrated groundwater recharging in Chirawa town can fare equally with artificial recharge tubewells in the remaining rural areas of the block. This is perhaps an opportunity not to be missed that is created due to increasing urbanization.

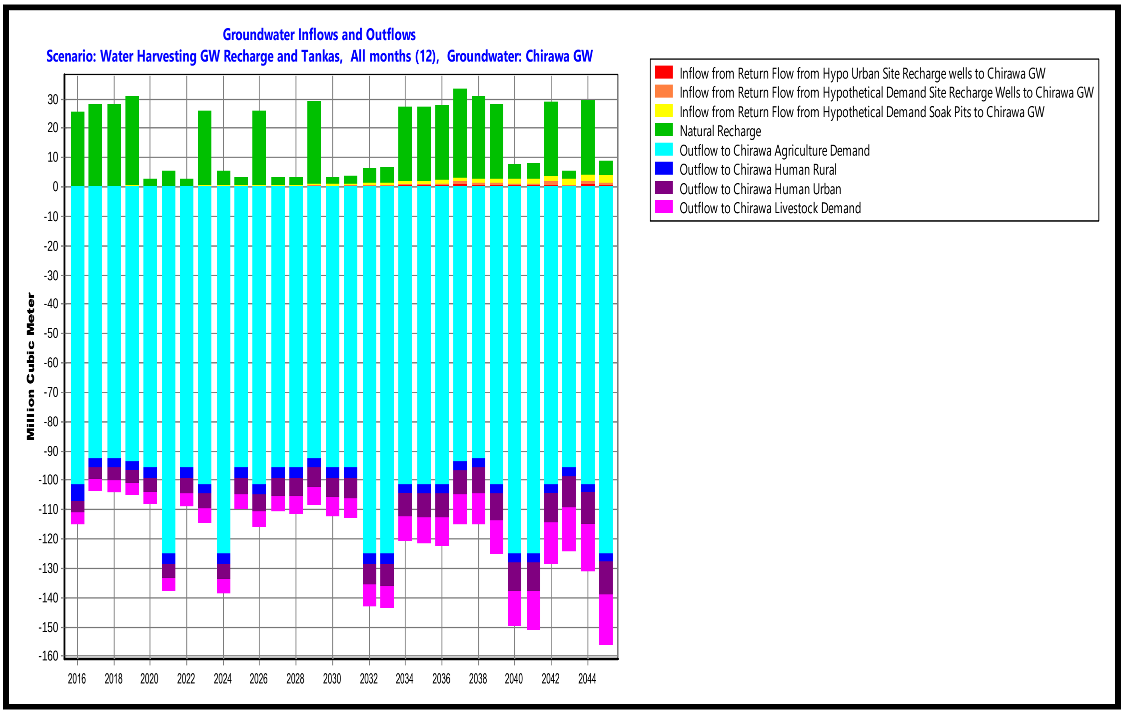
Figure 17: Groundwater recharge through recharge tubewells and soak pits in Water Harvesting Groundwater Recharge and Tankas Scenario



However, total recharge due to above large-scale water harvesting efforts is very insignificant when we consider the picture of overall supplies and demand. The yellow and red colour small columns in
Figure 18 evidences the insignificant contribution of recharge measures. However, it is to be noted that the water harvesting tankas proposed under this

scenario play a significant role in ensuring drinking water security especially in arid areas where groundwater is highly degraded.

Figure 18: Groundwater recharge and extraction in Water Harvesting Groundwater Recharge and Tankas Scenario



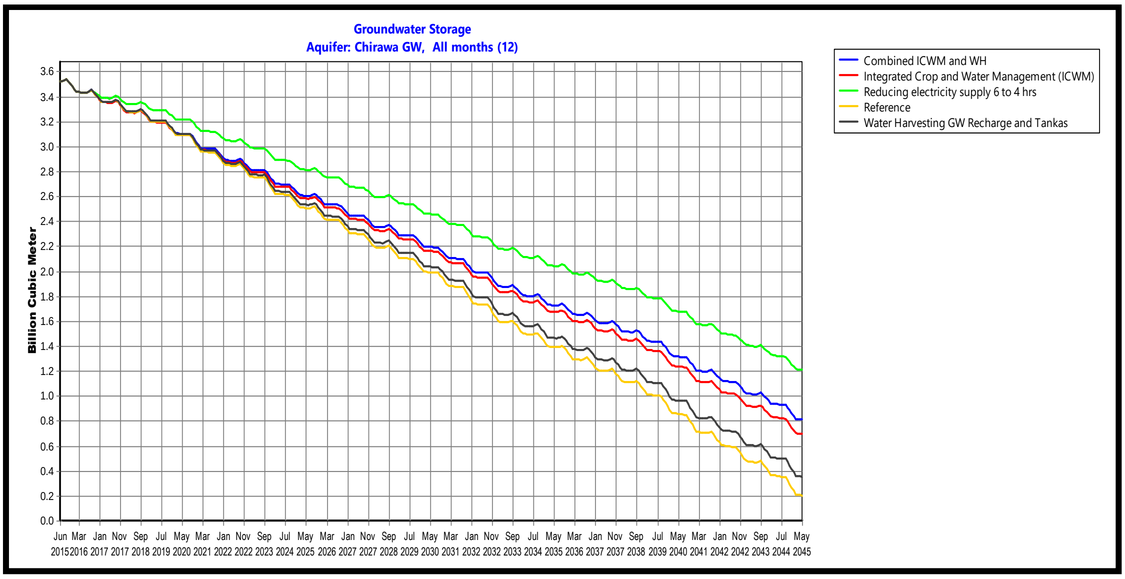
6.4. Combined DSM and SA Scenario

The combined effect of ICWM scenario and Water Harvesting Groundwater Recharge and Tankas is reflected in changes in groundwater storages and it is presented in the next section.

6.5. Groundwater Storages across Scenarios

The aim of water balance modeling is to find ways in which the needs of drinking water security, livelihoods and groundwater conservation can be best met. In this section we focus on groundwater declines across scenarios. As can be seen from Figure 19, Reducing Electricity Supply seems to be most effective in slowing the pace of groundwater decline; followed by Combined ICWM and Water Harvesting scenario, ICWM scenario, and the least effective is Water Harvesting and Groundwater Recharge Scenario. As mentioned, in this section we are focusing just on the issue of groundwater sustainability and not on returns in form of drinking water security that is achieved at high level as in the least effective scenario. The figure also clearly brings out that groundwater would be fully exhausted even in the best scenario of Reducing Electricity Supply though it will prolong the availability for approximately 8-10 years beyond the modeling period. Hence, it is opportune time now to find and promote transformative ways to address the triple-challenge of drinking water security, livelihoods and groundwater sustainability.

Figure 19: Groundwater Storages across Scenarios



7. Conclusions and Recommendations

The analysis of water balance of Chirawa block shows that in Reference Base Case or business-as-usual scenario groundwater would be almost fully exhausted by 2045. Four alternative water balance scenarios are developed and their effectiveness to bridge the gap between demand and supply is assessed. These scenarios are: Integrated Crop and Water Management (ICLM); Reducing Electricity Supply hours; Water Harvesting Groundwater Recharge and Tankas; and, combination of ICLM and the Water Harvesting scenarios. It is found that reducing electricity hours is most effective followed by, in decreasing order of effectiveness, the combination scenario, ICLM scenario, and last on the measure of effectiveness, the Water Harvesting scenario. However, the Water Harvesting scenario provides the needed drinking water security in the region especially where groundwater quality has deteriorated in large tracts making it unfit for human consumption. Based on the findings of the modeling we recommend the following on priority basis:

- Community based power user groups need to be promoted at distribution line level to restrict the electricity consumption to pre-agreed number of hours per day. Simultaneously, IT based innovative tools need to be developed to monitor electricity consumption and water pumping by users;
- Groundwater abstraction can be reduced significantly by reducing to at least the current area under Wheat and compensating the same by augmenting areas under Mustard (40%), Gram (35%) and Horticulture (25%). For this strategy to work value-chains for the above three crops need to be developed, the fund for which can be sourced under current

programmes of Agriculture Department and NABARD. Needless to say it will require concerted effort of extension, capacity building and community mobilisation;

- Given the availability of roof-tops on large scale in a contiguous and concentrated area of Chirawa town, artificial recharge through recharge tubewells should be promoted in the town. Advocacy effort will be needed to get this in building by-laws of the Municipality. At the same time large-scale awareness and capacity building programmes will need to be conducted to create the needed demand for adoption;
- Roof top Rainwater Harvesting Tankas need to scaled-up in entire belt of groundwater salinity in the block. Advocacy will be needed to ensure that appropriate subsidy is provided to households through relevant and flagship government programmes; and,
- Soak pits need to be promoted by sourcing subsidy under various potential programmes of the government.

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