Sustainable Irrigation for Cotton

Support from enhanced groundwater resource at semi-arid area of Gujarat state, India

Prepared by Team led by Dr. Dipankar Saha, National Advisor – WAPRO, Partners in Prosperity

Submitted by

PARTNERS IN PROSPERITY

B10/7002, Pocket 10, Sector B, Vasant Kunj, New Delhi 110070

Email: info@pnpindia.org.in | Web: www.pnpindia.in

Acknowledgement

The Document is prepared as a Policy Paper under WAPRO Project in India funded by Helvetas Swiss Intercooperation.

The support from the partners in WAPRO project has been very significant. Specifically, the support and insights from CSPC [Coastal Salinity Prevention Cell] staff at Ahmedabad and Talaja office, and colleagues in Partners in Prosperity are duly acknowledged. The farmers who enthusiastically participated in the focused group discussion at Mota Ghana village and their support during the field visit is thankfully acknowledged. The author would like to extend his gratefulness to his peers and PnP's field staff to make this effort into reality.

Dr. Dipankar Saha
National Policy Coordinator – WAPRO

Table of contents

List of Tables

List of Figures

List of Plates

1. Preamble

Besides paddy and wheat, cotton is another major crop in India. India got 1st place in the world in cotton acreage with 12.07 million hectares area under its cultivation i.e., around 36% of area of 333 Lakh Hectares (Directorate of Economics and Statistics 2021). Around 67% of India's cotton is grown on rain-fed areas and 33% with assured irrigation. In spite of India has on 38th rank in yield per acreage (510 kg/ha) it is the global leader in cotton production, with 26.44 MMT in 2021-22, 23% of world cotton production (Pathak H 2022). India is also the 2nd largest consumer of cotton in the world with estimated consumption of 5.75 MMT i.e., 22% of world cotton consumption. A large acreage under cotton cultivation in India face water stress and frequented by crop failures.

Cotton is the world's most significant fiber crop. Cotton in grown mainly in semi-arid areas in the country, especially in the central part with black cotton soils. The top cotton-producing states of India are *Gujarat, Maharashtra, Telangana, Andhra Pradesh, Madhya Pradesh, Karnataka, Haryana, Rajasthan, Punjab and Odisha.* Gujarat remains the highest cotton producing state in the country (COCPC 2022). In 2020-21 season, the state produced 90 lakhs of bales of cotton. The state stakes 25% of the total cotton production of India. Globally, India has the largest area under cotton cultivation, accounting 37% of the world's total area under cotton cultivation. Cotton in India is cultivated in Kharif season and most flourishing cultivation happen in region observing annual rainfall ranging from 400-600mm.

Since cotton is predominantly grown in semi-arid and arid regions, irrigation is vital to prevent crop failures during dry spells in Kharif season. In rainfed areas, it gets critical supplement irrigation from groundwater. On the other hand, mostly the rainfed areas are underlain by low-potential hard rock aquifers, which are already under stress and often overexploited (Bhanja, et al. 2016). Another issue is due to climate change, uncertainty in amount of rainfall and its diurnal distribution resulting in crop failure in cotton is an often-occurring phenomenon.

1.1. Cotton and irrigation issues

Even though cotton is a kharif crop, it needs critical supplement irrigation during the dry spells. For irrigation the cotton primarily depends on groundwater wells, both in the alluvial and hard rock areas. Because the cotton cultivated areas are mostly located in semi-arid and arid regions, the recharge from rainfall is limited and cannot cope up with the rising extraction for different societal uses. Moreover, if we consider the distribution of cotton cultivated areas, particularly in the front runner states of central and western India, they are underlined by low-hydraulic potential hard rock aquifers (Department of Drinking Water Supply 2004). These issues, i.e., low recharge to groundwater and less yielding aquifers, compound the problems of sustainability in irrigation for cotton crop. These issues are being addressed by promoting enhancing of water use efficiency in cotton growing regions.

Partners under WAPRO Project has flagged this issue and promoting a host of issues for better and quality outputs of cotton. One major intervention is enhancing irrigation efficiency. In Gujarat CSPC, a WAPRO partner intervenes through multiple themes of interventions, ranging from natural resource management, adoption to better irrigation technology, water saving farming practices, financial assistance, extension services to the farming community and policy interventions.

Two notable interventions by CSPC in Gujarat state are, promoting adaptation of drip irrigation and alternate furrow flooding method. However, the contentious issue is there should be adequate source water in the aquifer to irrigate. The Irrigation in the later part of cotton growing period, particularly faces crop failure if monsoon rains become erratic and inadequate. If recharge is less, the yield from the dug well also becomes inadequate.

The major intervention to counter the aquifer desaturation due to excessive extraction and provide assured irrigation is adoption of supply-side intervention like artificial recharge and rainwater harvesting. Commonly utilised methods are, check dams, construction of pond and desilting of ponds (Palanisami , Raviraj and Thirumurthi 2006). Artificial recharge is also adopted to enhance the depleted groundwater resources in the area.

2. Artificial Recharge to Aquifers and Groundwater Conservation through BBT

The challenge to recharge in the low potential aquifers, like in hard rock terrain, remains a challenge as the porosity and the specific yield of the aquifer is low, the efforts of recharging the aquifer remain futile to a great extent, as aquifer can absorb less water (Saha, Marwaha and Dwivedi, National Aquifer Mapping and Management Plan- A Step Towards Water Security in India- Water Governance: Challenges and Prospects 2019). Even if artificial recharge is adopted, often there is no significant enhancement of groundwater resource availability, which can commensurate the extraction of groundwater for irrigation (Saha, Marwaha and Mukharjee, Groundwater Resources and Sustainable Management Issues in India- Clean and Sustainable Groundwater in India 2017). The challenge is thus whether, is it possible to enhance the storage in the aquifer so that more water can be recharged for subsequent use to supplement water requirements of cultivated crops.

Bore Blast Technique (BBT) is used to create additional storage within the low potential hard rock areas. In this technique a blasting is done at a depth/depths in a number of closely spaced bore wells around the mother well (production well) or without the mother well. The simultaneous blasting creates a cumulative impact and rocks are crushed underground to create additional fractures. Such fractures or secondary porosities created additional storage space as well as create conduits to flow water into the wells (Dhiman 2019).

3. Experiment Site

WAPRO partner in India, CSPC has done an experiment in Talaja taluka in Bhavnagar Dist. of Gujarat. Cotton is the major crop grown in this area during kharif season. The area is underlain by low-potential basaltic aquifer with an annual rainfall of about 600mm. The CSPC intervenes with the cotton farmer in multiple themes, ranging from natural resource management, adoption to better irrigation technology and agronomic practices, financial assistance etc. The interventions have made substantial impact in water resource management, sustainable agricultural practices and socio-economic gains for farming community.

A special intervention is taken on artificial recharge and groundwater conservation by BBT at several locations on experimental basis in five villages (which will be referred as Talaja cluster of CSPC intervention area) viz., Jalvadar, Juni Chhapri, Navi Chhapri, Mota Ghana and Hajipar. Out of these, Jalandhar, Juni Chhapri, and Navi Chhapri villages fall within on Talaji River catchment while Mota Ghana and Hajipar villages are located in Navli River catchment **(Fig. 1)**.

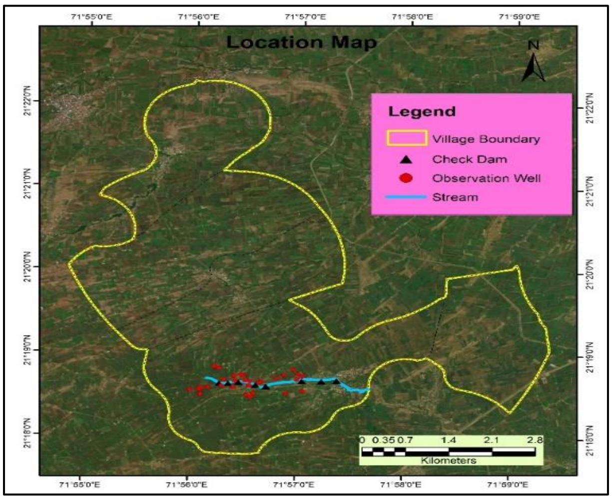


Figure 1: Location map of CSPC intervention area

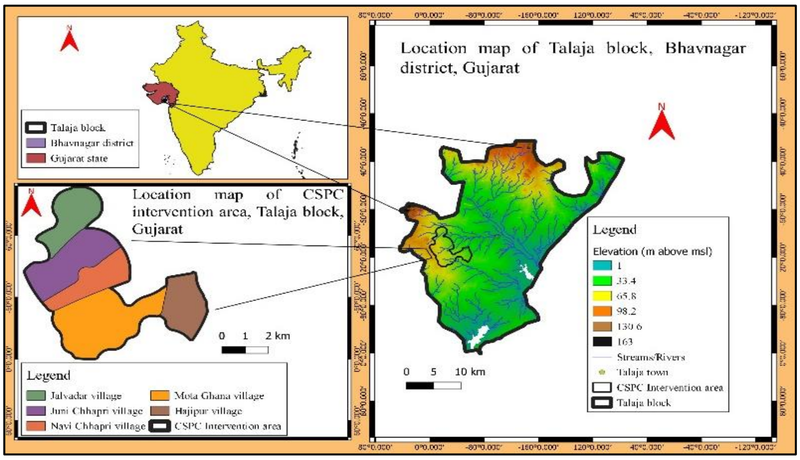


Figure 2: Location map of the study area

In Figure 2, five cluster villages are shown. The BBT sites are between the check dams created on the stream in Motta Ghana village**.**

3.1. CSPC Activities in Talaja cluster of CSPC Intervention area

CSPC is engaged in a host of activities with the farmers centering on sustainable cotton cultivation in the area. Their wide array of activities include:

a) **Soil and Water conservation,**
They are adapting land treatment, desilting of existing check dams, creating additional check dams and repairing of existing structure, pond deepening, bunding of farms to retain overland flow and to recharge to existing wells. All are intervention are aimed at water and soil moisture availability.

b) **Promoting Efficient irrigation system**
   i) *Alternate Furrow flooding Irrigation*: The most widely used method to increase water use efficiency in cotton (**Plate 1**). It is found to be the most suitable and adaptable. It saves 50 to 60percent of water in comparison to compete flooding method of irrigation.
   ii) *Drip Irrigation:* Gujarat Green Revolution Company provides subsidy of 50-60 % of the cost incurred for drip installation. CSPC provides further 5% incentives on the adaptation of drip irrigation particularly for cotton. However, the farming community is at times reluctant to adopt drip irrigation primarily because of cumbersome laying and removal of the pipes before sawing and after harvesting the crop. The interconnected system of pipes face various functional issues at different periods of crop growth. About 70 percent water saving is achieved in comparison to flood irrigation **(Plate 2)**.
   iii) *Sprinkler and Laser irrigation*: are used for groundnut and Onion. GGRC provide about 10 % support for Sprinkler and about 25-30 % for laser irrigation. CSPC provide another 5 % support incentive. By these two about 50-60 % water savings **(Plate 3)**.
   iv) *In addition to promotion of efficient irrigation technology, CSPC is also promoting and introducing methods to preserve soil moisture. Plastic mulching **(Plate 2)** and other farm preparation techniques are among the techniques promoted.*

c) **Capacity Building**: The emphasis is given to sustainable resource use in cotton cultivation, intercropping, selection of seeds, fertilisers to be used, promotion of efficient irrigation technology, disease and pest control and others. The issue of child labour, enhancing cotton production, health precaution during various spraying of pesticides and others. Trainings are given at different levels, like group discussion, demonstration and training at the Talaja office, yearly workshops, and exposure visits.

4. Overview of the area of Intervention

The area, Talaja Cluster village, falls in Gujarat Plain of Central Highlands (Malwa) Agro Ecological region (ICAR), with an average elevation of 30m above msl. The region receives an average annual rainfall of 510 to 520mm, of which> 95 % occurs during South West Monsoon season (June – September). The month-wise normal rainfall is given in **Fig. 3.** The driest month is February. While with an average of 210 mm, July is the rainiest month. In Bhavnagar, the average annual temperature is 27.7 °C.

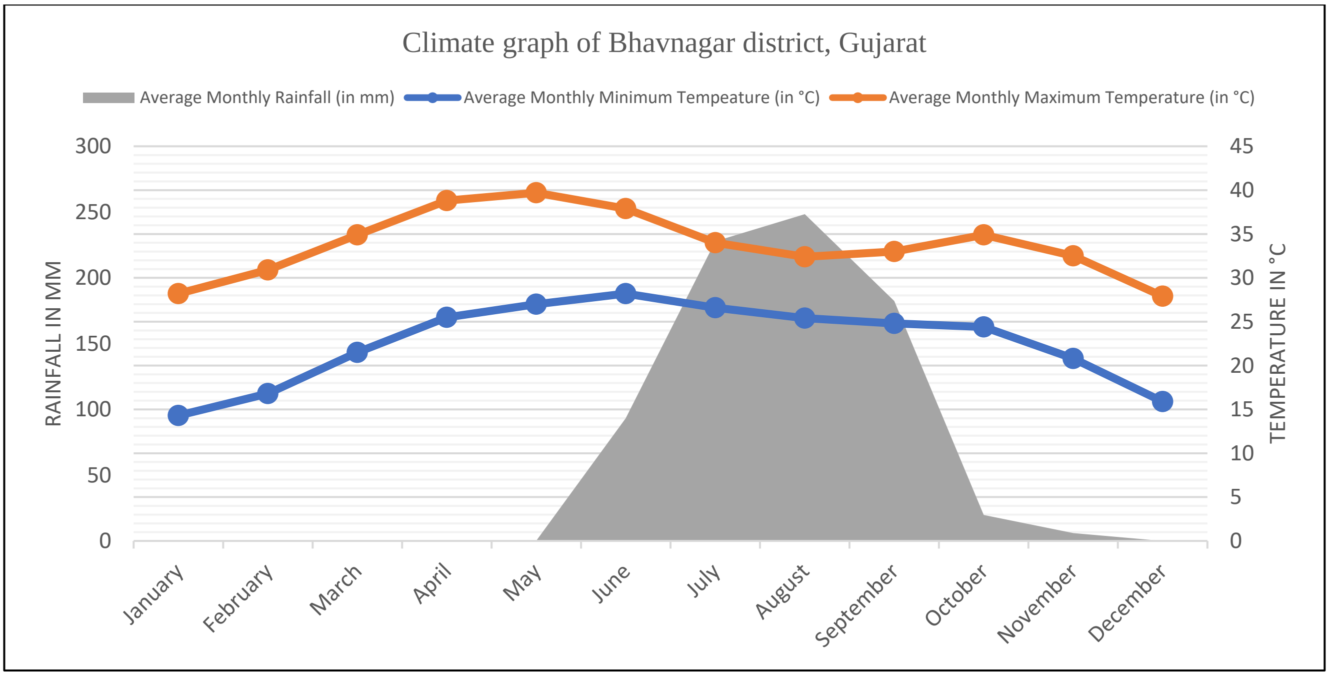


Figure 3: Climate graph of Bhavnagar district, Gujarat

The general slope of the area is towards the south-east, towards the Gulf of Khambhat. The terrain is marked by flat to gently undulating topography. The Altitude varies from the sea level along the Gulf of Khambat to 163 m above msl in the north western and north eastern parts. In the intervention villages the altitude generally varies from 30 to 60 m above msl. The area is underlain by multiple flow of basalt rocks (Deccan Trap). The geomorphology is predominantly marked by denudational origin pediment pediplain complex **(Fig. 4)**. Gujarat has predominantly a non food crop economy with preponderance of cotton, groundnut and tobacco. In the recent decades, commercial orientation is more associated with oilseeds, sugarcane, vegetables, spices etc. and the area under cereals such as rice, bajra and jowar has decreased. Gujarat has predominantly a non food crop economy with preponderance of cotton, groundnut and tobacco. In the recent decades, commercial orientation is more associated with oilseeds, sugarcane, vegetables, spices etc. and the area under cereals such as rice, bajra and jowar has decreased.

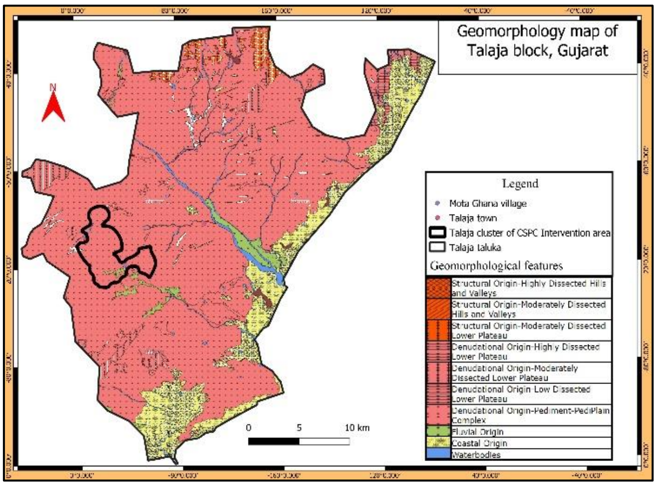


Figure 4: Geomorphology map of the Talaja Block

The Talaja block as well as the intervention area is primarily an agriculture-dominated area, where the largest share of land is under cultivation **(Fig. 5)**. Agriculture and allied activities employ the largest share of population. The agricultural sector has seen tremendous transformation in the recent decades. Sustainability of agriculture is the most important issue before policy makers in order to attain food security, livelihood security and as well as ecological conservation.

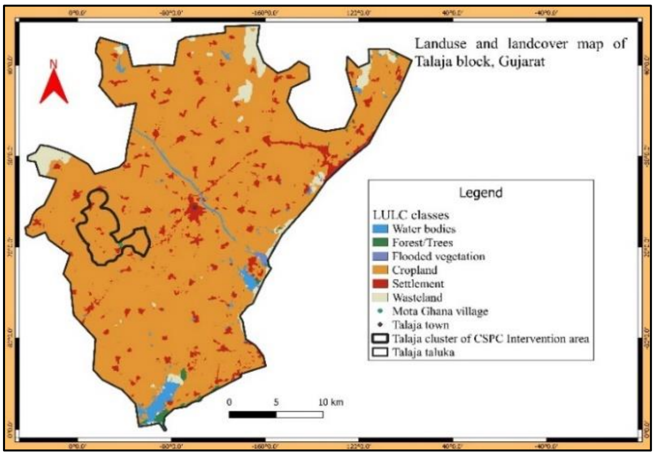


Figure 5: Land use of Talaja Block

In the area cotton and groundnut are the predominant kharif crops **(Fig. 6)**. The other major crops cultivated are bajra, sesame, jowar, onion, etc. As we can see from the cropping data of Bhavnagar district between 1966-67 and 2016-17, the area under the cotton has significantly increased over last five decades. Area under less water guzzling crops and drought resistant crops viz. coarse grain, minor millets and pulses seem to have reduced significantly over the same period of time. Though, cultivation of vegetables (especially onion) and fruits have picked up pace and contribute significantly to the total cultivated area. However, cotton seems to have become the most dominant crop account for more than 70% of the area under Kharif season cultivation.

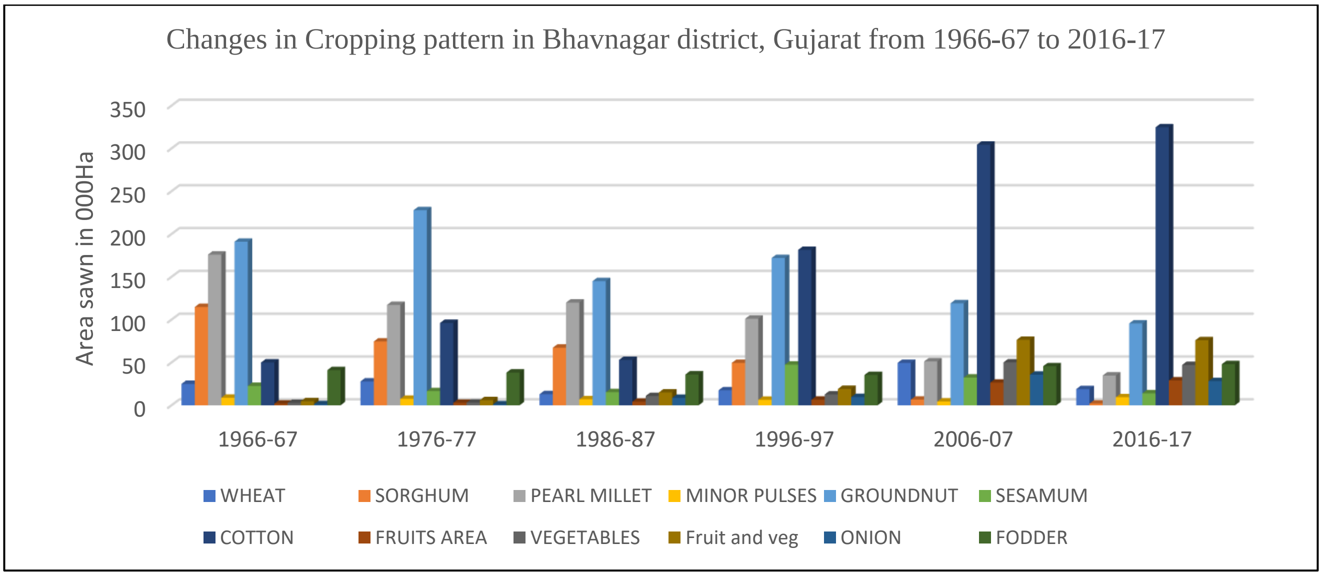


Figure 6: Changes in cropping pattern in Bhavnagar district, Gujarat (1966-67 and 2016-17)

The area of Talaja cluster of CSPC intervention is over 550 hectares, spanning across five villages mentioned earlier. The area is drained by Navali River (southwardly flow) and Talaji River (south-easterly and later southwardly flow) **(Fig. 1)**. The major crops cultivated in the region are cotton and groundnut covering 75% and 25% of the net sown area respectively in Kharif season. In Rabi season Onion, Wheat and Chickpea covering 40%, 40-50%, and, 10-20% of the net sown area. In summer season, Bajra, fodder crop and summer ground nut are cultivated covering merely 20-30% of the Area collectively. The average land holding size in the area is one to two hectares. Most farmers are small and marginal farmers.

As in the Bhavnagar district, the intervention area also has observed changes in cropping pattern and cotton accounts for maximum increase in acreage. Agricultural practices have also observed transformation in terms of mechanisation of agriculture, development of water resource, especially ground water, irrigation technology and changes in input-output linkages (use of pesticides, artificial plant nutrition, HYV seeds and others). The agrarian economy has experienced shifts towards monopolisation of cotton cultivation and loss of crop diversity.

The cotton predominant agricultural economy has been recently facing increasing incidences of water stress and scarcity of water resources especially for supplement irrigation in cotton cultivation in Kharif and significantly demand for irrigation in Rabi-Summer season cultivation.

4.1. Dependence on groundwater for irrigation

The Irrigation in the Bhavnagar district is heavily dependent on groundwater extracted primarily through dug wells and also tube wells. The net irrigated area has increased from 54.9 to 237.2 thousand ha, from 1966-67 to 2016-17 and almost the entire increase is by using groundwater **(Table 1)**. The Narmada canal water is brought into through pipelines but for drinking use only. The Kharif crop is mainly rainfed. However, the area belong to semi-arid climate and as reported uncertainty in rainfall distribution is impacted because of climate change. That's why, the dry spells in Monsoon season critically depend upon groundwater resources.

The Rabi and summer irrigation is entirely dependent upon open wells.

Table 1: Area under various type of sources of irrigation in Bhavnagar district, Gujarat (area in 1000 Ha)

Year	Canals	Tanks	Tube wells	Open Wells	Other sources	Net Irrigated Area	Gross area irrigated
1966-67	10.6	0	0	44.3	0	54.9	54.9
1976-77	30.5	1.7	0	49.8	0	82	82.9
1986-87	9.7	4.3	0	82	0	96	107.5
1996-97	22.82	0	0	143.05	0	165.9	203.4
2006-07	27.9	3.2	0.8	224.6	5.8	262.3	377.5
2016-17	61.9	3.95	4.16	151.2	15.8	237.24	317.22

In the CSPC Intervention area, the entire irrigation is based on open wells/dug well. The depth varies from 20m to 30m with diameters of 3.5 m to 5 m. Motors of 5 to &7.5 HP is lowered at 25 m to 28m and produces a discharge of 25 to 32m^3 /hr). The discharge sustains for 5 to 6 hours. On an average, the area is 5 to 15 bigha in general per well. Sometimes water is shared to the adjoining land plots. The average cost of construction of a well is INR 0.4 to 0.7 million depending upon the formations encountered. Presently the water level remains between 30 to 35m. As per the reporting of the villagers, the water level has gone down by 15 to 20m in last three decades **(Table 2)**.

Table 2: Changes in water table in Taleja cluster of CSPC intervention area from 1970-71 to 2020-21

Villages	Water table (in m bgl) from 1970-71 to 2020-21					
	1970-71	1980-81	1990-91	2000-01	2010-11	2020-21
Mota Ghana	10.7	12.2	13.7	18.3	24.4	27.4
Juni Chhapari	9.1	10.7	12.2	16.8	18.3	22.9
Navi Chhapari	10.7	12.2	13.7	16.8	18.3	22.9
Jalvadar	12.2	13.7	15.2	19.8	25.9	29.0
Hajipar	9.1	12.2	15.2	18.3	21.3	22.9

Flood irrigation was the most common method of irrigation (for more than 90% of the area) and continues to be so followed by drip irrigation and laser irrigation. Owing to higher operational and management costs associated with sprinkler, drip and laser irrigation, despite various incentives and schemes, farmers have shown less interest towards adoption of these methods. Now, in 2022, majority of the farmers apply alternate furrow method rather than drip irrigation for cotton.

The major water use efficiency measures adopted for cotton irrigation are:

a) Alternate Furrow flooding Irrigation (cotton mainly): The most widely used method than enhances increase water use efficiency. Saves 50-60% of water.

b) Drip Irrigation (groundnut, Sugarcane, cotton): GGRC provides subsidy of 50-60 % of the cost incurred. Additionally, the WAPRO partner extend 5% incentive support, besides constant extension services. It is reported that, about 70 percent water saving is achieved in comparison to flood irrigation.

c) Sprinkler and also Laser irrigation (recently introduced) are used for groundnut and Onion. GGRC provide about 10 % support for Sprinkler and about 25-30 percent for laser irrigation. CSPC provide another 5 % support incentive. About 50-60percent water is saved in laser and sprinkler system in comparison to complete flooding method.

GGRC does not provide the subsidy on the laser irrigation. CSPC provides the 25-30 % support on adoption of laser irrigation.

5. Bore Blasting Technique: Methodology and location

Though not in a wider scale BBT is being adopted sporadically since a decade to enhance the storage capacity of ground water, recharge and availability. In hard rock areas, particularly where the fractures/joints and other secondary porosities are limited, BBT is used to artificially create cracks in the rock bed which hold additional water. In addition to that, since the blasting takes place at different depth simultaneously, the newly created cracks or opening of existing fractures help in creating additional path of recharge from the surface and from the weathered zone at top.

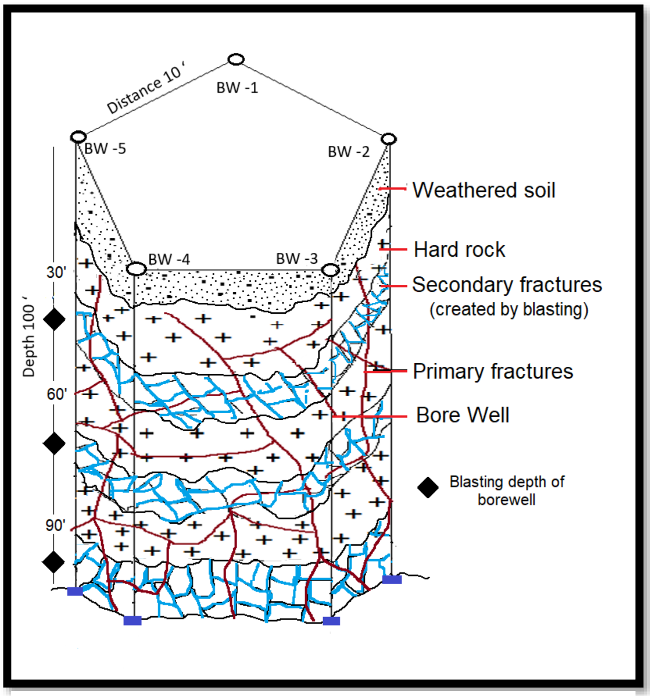


Figure 7: 3-D schematic diagram of the secondary fracture created through BBT

Additionally, the newly developed cracks, extend the conduits so that the groundwater flows laterally and vertically connecting the existing fractures/joints thus impacting wider areas.

In the intervention area, in Mota Ghana village, BBT was firstly taken up in 33 clusters on the Navali River, in between 10 check dams constructed on the stream. A typical BBT site where BBT has been done (between Check dam 4&5 is shown in **Plate 4**. The number of BBT clusters between the check-dams are given in **Table 3**.

The weathered zone is maximum 5 to 7 meter thick. In the each of clusters, five bore wells with 100 ft depth were dug at 10 ft distance, placed as a pentagon (Plate 5). The explosives were placed at three different levels at 30 ft, 60ft and 90ft in each bore-well (Fig 7). The explosives are thus placed against the hard rock and blasted simultaneously, so that a resonance is created which results in pulverization of the rocks and created secondary porosities at three depth level.

Table 3: Number and location BBT clusters in between check dams, Mota Ghana village

Check-dams	Number of BBT clusters	Year of construction
Between CD 1&2	2	2022
Between CD 2&3	2	2022
Between CD 3&4	2	2022
Between CD 4&5	3	2022
Between CD 5&6	2	2022

Check-dams	Number of BBT clusters	Year of construction
Between CD 6&7	10	2022
Between CD 7&8	4	2019
Between CD 8&9	4	2019
Beyond CD 9	4	2019

6. Assessment of Impact

In order to assess the impact created by BBT of groundwater resource, water levels are monitored. Thirty dug wells are being monitored on both sides of the streams where nine check dams (**Plate 6**) are constructed and in between them BBT carried out. The observation wells vary in depth from 25m to 30m and are located within 400 meters on both sides of the streams. The location of the observation well can be seen in **Fig 8.**

The water level was measured during pre and post BBT period which is effectively also pre- and post-monsoon period also, as the BBT was carried out in summer months. Depth to water level map (in m bgl) and water table contour maps (in m above msl) are prepared to understand the built up of resource and change in groundwater flow regime (**Fig. 8,9,10,11**). It can be clearly seen from **Fig 8** and **Fig 10** that there is a rise in water level of about 8 to 10 meter in general. In the central part around well numbers 26-6-2-1-7 (close to the stream and BBT site), the rise is quite high even to the tune of 12 to 14 meters or even more. The water level contour maps **(Fig 9 and Fig 11)** reveal that during preconstruction, the water level flow direction was divergent, mainly controlled by the extent of groundwater extraction at different wells located at different places. Whereas, during post construction, many a place, it is found that, groundwater flow is diverging from the stream alignment (where the BBT sites are located), thus indicating significant recharge, and formation of groundwater mounds.

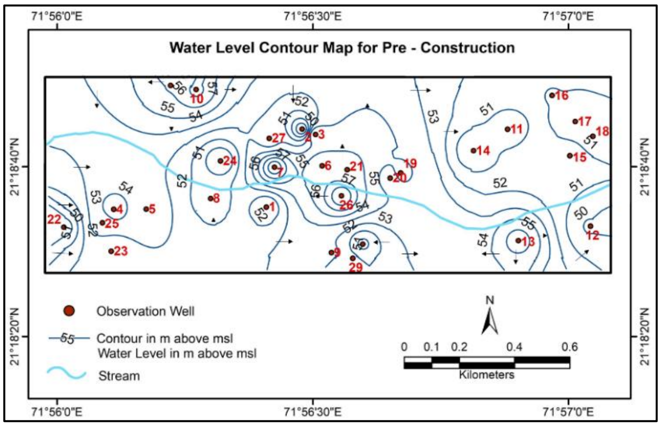
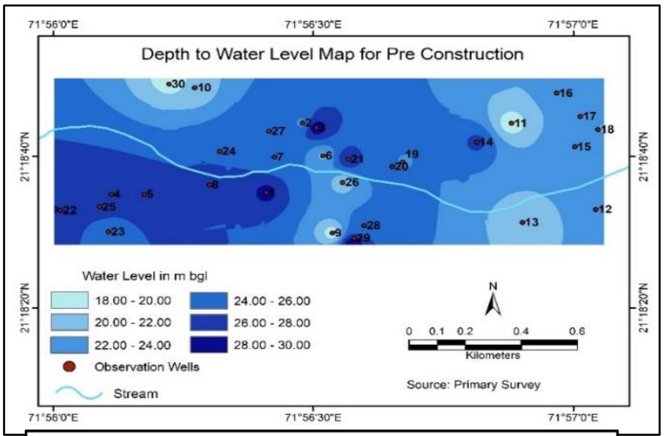


Figure 9: Water table contour map (m above msl), pre BBT



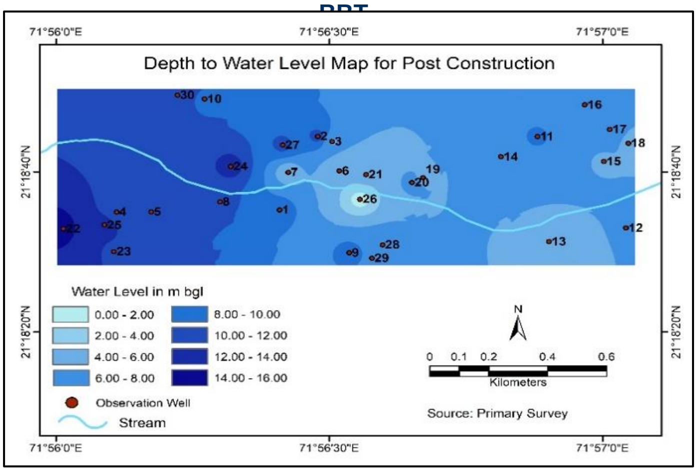


Figure 10: Depth to water level map for post-BBT

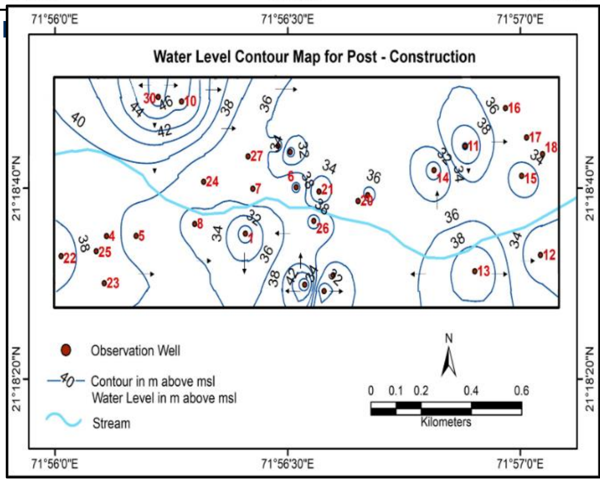


Figure 8: Water table contour map), post-BBT

7. Community Interaction

A focused group discussion was held at Ghana village on 19.9.22 with the CSPC staff and the villagers, especially those who cultivate cotton around the intervention area **(Plate 7)**. During the Kharif season, 75 percent of the Net Sawn Area is under cotton, 25 percent is under groundnut, Onion is a major Rabi Crop covering 20 to 30 percent area, Wheat covering 25 percent of the Net sawn area and the remaining area under gram, pulses and fodder. In the summer season, 20 percent of the cultivable land is cultivated and the major crops are summer groundnut and fodder. Out of total area under cotton, 80 percent of the area is under alternate furrow method, 5 to 10 under drip and laser method and the remaining under complete flooding method.

The farming community seems to be aware of the water stress situation and the need to sustain the water use in agriculture. They seem to be aware of the intervention, particularly the BBT made by CSPC. Prior to BBT the wells remained dried during summer months, but after the intervention, presently a water column of 3 to 8m remains in the wells. One such dug well visited was on the field of Samatbhai Bhamar (**Plate 8**) having 32meters depth, and water level on 19th September 2022 was 10.6meters irrigating around 7bigha of land. Previously during non-monsoon season, about 3.5 meter water use to remain. After BBT, the water column improved to about 7 meters in the months.

Seeing the positive impact created by BBT, the farming community is also ready to partially invest for further BBT intervention, to the extent of 20 to 30% of the cost**.** The farmers reported to be getting additional production through assured irrigation. This has resulted in additional 30% rise in production in cotton and 20-30% rise in groundnut production also. The trend is sustained by 10-20% rise in crop area in Rabi season.

The impact can clearly be noted in sociological and perception space of farming community. Dug well/open well (depth 30 to 35m).They are very interested to explore the concept of water resource management through technological intervention, newer methods to save water and accept water as a perishable and extremely vulnerable natural resource. They seem to have built a common understanding and are ready to take community level steps towards sustainable use of water resource while sustaining growth in agricultural practices. Farming community is increasingly participating in water budgeting and water security committee proceedings in their respective villages.

8. Conclusion

The study area represents a part of the coastal Gujarat region, known for cotton cultivation. The terrain is almost flat to gently undulating, marked with black cotton soil and underlain by low-potential hard rock aquifer made up of basalt flows. With the rising aspiration, the farming community is looking toward for assured irrigation and groundwater is being increasingly developed widely to coup up the demand for irrigation. It can be seen that in Bhavnagar district the net area is under irrigation has increased from 54,000Ha to 237,000Ha from 2006-07 to 2016-17. The increase in irrigated area is catered from groundwater. In the five villages under intervention by CSPC the water level has declined significantly in last few decades with increasing extraction of groundwater. The farmers are deepening dig wells but prefers dug well rather than bore well also indicates low yielding capacity of aquifers. Lately a lot of emphasis has been given to rainwater harvesting and artificial recharge to enhance water availability in aquifers. At the same time, farming community is persuaded to adopt efficient irrigation practices so that less ground water is consumed. The efforts taken to enhance groundwater resources availability remains partially achieved as the aquifer capacity to absorb recharged water is low because of low porosity and specific yield.

The efforts taken by CSPC to adopt BBT has immensely helped in increasing the ground water storage in the aquifers. This is amply proven by the depth to water table maps and water contour maps prepared for pre and post BBT construction prepared from the data collected from thirty monitoring wells.

9. Recommendation and way forward

The study of the area and related literatures/maps/data, analysis of the data related to BBT, hydrogeological field visit, interacting with the communities can be synthesize into the following recommendation:

a) BBT is an excellent technique to create additional fractures and joints by artificially pulverising the rock bed in the hard rock aquifers.
b) BBT creates significant enhancement of groundwater storage in low potential hard rock aquifers, thus more water can be stored below ground for subsequent irrigation.
c) BBT also creates fractures/joints which connects the existing fractures thus impact wider area and also enhance the rate of recharge to the aquifers.
d) Further scientific study like SLUG test in pre and post BBT needs to be carried out to quantify the exact dimensions of benefit.
e) Focus group discussion with community reveals their will to contribute to the cost of BBT. Government should formulate such schemes with proper planning while involving communities.
f) The perennial, low order streams are most suitable for BBT, as they benefit of stream flow (source water) for recharging the newly created secondary porosities.
g) Villagers should be encouraged and trained for monitoring the water levels and also the conductivity of ground water, particularly in such area where saline water occurs at shallow depth. This is required for impact study
h) BBT is a very suitable groundwater recharge and water conservation methods in arid and semi-arid regions of the country thus it will provide much required substantive irrigation for cotton during kharif season.

Plates

 Picture 1: Drip Irrigation and plastic mulching in a cotton field	 Picture 2: Alternate furrow flooding in a cotton field
 Picture 3: De-silted pond and BBT site between Check dam 4&5	 Picture 4: Laser Irrigation in a field in Mota Ghana
 Picture 5: BBT bore wells in a cluster before explosion	 Picture 6: Check dam (CD1) on Navali River
 Picture 7: Meeting with Farming community and CSPC staff	 Picture 8: Dug well near BBT site and check dam (CD1)

10. References

Bhanja, Soumendra N., Abhijit Mukherjee, Dipankar Saha, Isabella Velicogna, and James S. Famiglietti. "Validation of GRACE based groundwater storage anomaly using in-situ groundwater level measurements in India." *JOURNAL OF HYDROLOGY*, 2016.

COCPC. *Area, production and productivity of cotton in India from 1947-48 onwards.* Navi Mumbai, Maharashtra: Meeting of Committee on Cotton Production and Consumption, The Cotton Corporation of India Ltd., 2022.

Department of Drinking Water Supply, Ministry of Water Resources, Government of India. *Technical Document on Water Harvesting and Artificial Recharge.* New Delhi: Ministry of Water Resources, Government of India, 2004.

Dhiman, S. C. "Rejuvenation of aquifers, In Water Governance: Challenges and Prospects." *Springer Nature*, 2019.

Directorate of Economics and Statistics, Govt. of India. "Agricultural Sitiation In India, Directorate of Economics and Statistics, Department of Agriculture & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India." January 2021.

Palanisami , K, J Raviraj, and S Thirumurthi. "Artificial Recharge in Hard Rock Areas of Coimbatore District –A Case Study." International conference on Groundwater sustainable Development problems, perspectives and challenges, 2006.

Pathak H, Mishra JP and Mohapatra T. "Indian Agriculture after Independence, Indian Council of Agricultural Research, New Delhi." 2022.

Saha, Dipankar, Sanjay Marwaha, and Arunangshu Mukharjee. "Groundwater Resources and Sustainable Management Issues in India- Clean and Sustainable Groundwater in India." *Springer*, 2017.

Saha, Dipankar, Sanjay Marwaha, and S N Dwivedi. "National Aquifer Mapping and Management Plan- A Step Towards Water Security in India- Water Governance: Challenges and Prospects." Edited by Dipankar Saha & Sh A C Tyagi Amarjit Singh. *Springer*, 2019.