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INDIA-EU WATER PARTNERSHIP

Protocol for Estimating Irrigation Performance in Small and Medium Irrigation Schemes in India, using Remote Sensing Data

Prepared under
the India-EU Water Partnership's Priority Area 5

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A. Introduction

Background

In March 2016, the EU and India reconfirmed their commitment to give new momentum to the bilateral relationship endorsing the EU-India Agenda for Action 2020 as a common roadmap to jointly guide and strengthen the India-EU Strategic Partnership in the next five years. Under the India-Europe Water Partnership (IEWP) the Indian Ministry of Water resources (MoWR) and the EU have agreed to work on nine Priority Areas. One of these priority areas (PR5) is “Water Use in Irrigation”.

In India, agriculture is of central importance to the national and regional economies, contributing 14.6 percent of GDP and over 55 per cent of employment. Along with food security, agriculture thus also provides livelihood for the majority of the population. In many regions due to inadequate rainfall, irrigation plays a key role in the drive to enabling and enhancing food production. To increase the agricultural productivity, the Government of India took various initiatives to ensure better Irrigation, including activities for Command Area Development (CAD) and Accelerated Irrigation Benefit Programme (AIBP). However, there still seem to be a gap between the command area developed, utilised and benefits achieved from the agricultural sector. To evaluate the effectiveness of efforts to improve performance of small and medium irrigation schemes, the MoWR requested support from the IEWP to develop a practical methodology to estimate water use efficiency. To ensure the replicability for all small and medium scale irrigation schemes in India it is important to use as much as possible readily available data and open source software. The MoWR selected three recently completed small/medium irrigation schemes to pilot the to-be-developed methodology with the longer term aim to roll it out to other small/medium schemes. The basic design of all three schemes is comparable, consisting of a dam and reservoir with one or two contour canals (Left Bank and Right Bank canals) supplying water by gravity to command areas ranging from 3840 to 9600 hectares.

Terms of Reference and expected outputs of this study

The study covers four main tasks:

1) Develop a concept note for Irrigation Efficiency Assessment for three projects identified by Ministry of Water Resources, River Development & Ganga Rejuvenation, India namely Mahuar in Madhya Pradesh, Lower Panjara in Maharashtra and Golavagu in Telangana. The concept note should clearly indicate the data required for the assessment, a draft methodology to be adopted, and a concise action plan to carry out the proposed assessment studies.
   The concept note was developed and submitted to IEWP late August 2018.

2) Field visit to India during 7 days (3-11 March 2019) to all three projects sites along with the representatives from the Ministry of Water Resources, River Development and Ganga Rejuvenation, India and IEWP/GIZ PMU. The main objective of the field visit is to evaluate the availability of field data and measurements and the feasibility of the proposed method to assess Conveyance efficiency, Field application efficiency and Irrigation uniformity.
   A field visit was organized in March 2019. A detailed field report including an updated methodology was submitted to IEWP May 2019.

3) Development of a Protocol for Irrigation Efficiency Assessment. After the mission to India a draft Protocol on Irrigation Efficiency Assessment is developed, which is easy to apply and takes into account the current data inventory. The Protocol will include a step-wise methodology which is applicable for all three irrigation projects and outlines next steps for implementation, including

addressing data gaps. After consultation and suggestions from MoWR and the IEWP/GiZ a revised version will be developed.
The protocol and its application to three medium/small schemes is described in this report.

4) During a second mission to India a workshop regarding the proposed protocol for Irrigation Efficiency Assessment will be undertaken to present the final Protocol to all relevant stakeholders (national and state representatives), highlight implementation implications, improvements in irrigation efficiency and possible challenges, and provide guidance so that relevant stakeholders will be able to implement the methodology outlined in the Protocol.
Due to COVID related travel restrictions this part of the work needs to be organized differently. An online meeting is planned mid-October 2020 with GiZ and the MoWR to discuss this protocol and further steps.

Outcomes from the field visit in March 2019

This report provides a description of the protocol based on the findings of the field visit to the three assigned irrigation schemes. After the visit in which the limitations of the using field data became clear, the methodology had to be thoroughly revised, as outlined in the paragraphs below.

In March 2019 the three irrigation systems were visited by a team consisting of representatives of the MoWR, CWC, local irrigation officials and representatives of farmer stakeholders. The main aim of the field visit was to assess the feasibility and suitability of the initially proposed methodology, a simplified method to estimate irrigation efficiency building on the existing CWC protocol. This method was successfully applied to 35 schemes as documented in a 2016 report[1]. However, the CWC protocol requires a substantial amount of field measurements and secondary data. The field visit to the three irrigation schemes in March 2019 revealed that the minimum data requirements to meaningfully estimate irrigation efficiency are not met; basic and reliable field data are lacking[2]. Some of the data could be measured for the purpose of assessing irrigation efficiency, but this would give a snapshot of the system performance (as opposed to the fuller and more reliable picture that would emerge from time series data covering several seasons and years). It would also require substantial human and financial resources and would not be easily replicable to other small/medium irrigation systems in India. Without detailed data on crops and water, measured over several seasons, an accurate and meaningful estimation of the conventional irrigation efficiency -defined as the amount of water beneficially used by crops as percentage of total water released- is not possible.

Furthermore, the use of land and water in the three visited schemes deviated from what was foreseen at the design stage and recorded in official documents. Using official data leads to two sources of inaccuracy. Firstly, reported cropping patterns in the three irrigation schemes do not account for the out-of-command land that is irrigated by pumping from the main canals. Secondly, water use estimated from canal discharge measurements underestimate the amount of water being applied to the field because it disregards the reuse of seepage through shallow groundwater wells. Both sources of inaccuracy potentially lead to an underestimation of irrigation efficiency and the area irrigated from the reservoir.

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[1] Summary Report On Water Use Efficiency Studies For 35 Irrigation Projects, CWC 2016.

[2] Assessing Water Use Efficiency in small and medium irrigation schemes in India, field report submitted to IEWP, April 2019.

B. Proposed protocol to estimate irrigation performance

Important considerations underlying the proposed protocol are:

- The protocol is applicable to small and medium irrigation schemes in India
- Data and software used in the protocol are freely available
- The irrigation performance indicators are widely used and described in literature
- The indicators can be used by season or year, and to assess trends over past five or six years

Indicators

The protocol uses 4 indicators that are widely used in irrigation performance. Annex A provides a list of literature describing the scientific foundation and application of the indicators.

1. Irrigated and cropped areas (seasonal trends over time 2015-2020).

   This indicator reveals how much of the command area is being used in Kharif (wet season from July-November) and Rabi (dry season from December – April). The time series analysis provides an insight in the trends over time, which can reveal the impact of interventions under the CAD or other measures. The indicator can also make visible the irrigation that takes place outside the command area. It is likely that the irrigation directly adjacent to the canal, use pumps to irrigate out-of-command areas.

2. Equity / uniformity (trends over time 2015-2020)

   This indicator provides insight in the equal distribution of water over the command and irrigated area. A low uniformity may point to distributional problems, such as irrigation water not reaching the canal tail-end or some farms receiving more water compared to other fields at other locations in the irrigation scheme.

3. Adequacy (trends over time 2015-2020)

   This indicator reveals to what extent *seasonal* crop water requirements are met. Low values of adequacy may point to insufficient water for crops leading to yield reduction or, in the worst case, crop failure. As a rule of thumb, the value of 0.7 (i.e. 70% of the crop water requirements met) is regarded as threshold below which yield reduction occurs.

4. Reliability (trends over time 2015-2020)

   This indicator reveals to what extent crop water requirements are met for each month during the growing season. Low reliability points to irregular water supply with sufficient water in one month and shortages in another month. Low levels of reliability adversely affect yields.

Data and software

Remote sensing data: The protocol uses remote sensing data that are freely available over the past 5 or 6 years (to allow for time series analysis) and have sufficient resolution for the application to medium/small irrigation schemes. The selected data are Sentinel 2 (MSI, level 2A) combined with Sentinel 1 (SAR GRD) for the years 2018, 2019, 2020 and Landsat 8 data for the years 2015-2020. Sentinel data has a resolution of 10m and Landsat 8 has a resolution of 30m. Further, the land classification step of the protocol uses the most recent Google Earth satellite images in 2020 in which land use types such as infrastructure (canals, reservoirs, roads), trees/forest and crop fields are clearly visible (resolution < 1 m).

Shape files: The MoWR provided the shapefiles delineating the command area and the canal layout as constructed by contractors according to the approved design.

Spatial data processing software: All data processing steps and the computation of the indicators and time series, as described below, are implemented in Google Earth Engine (GEE) which uses Javascript (https://earthengine.google.com/). All necessary Sentinel and Landsat data can be accessed through GEE. Computations take place in the cloud, allowing the use of computers or laptops with a standard processor without the need for additional storage capacity. A reasonable internet connection is essential, though. QGIS, an open source GIS software, is used for the creation of a sample dataset for training and validation of the land cover classification and laying out the maps in this report. These tasks could also be done in GEE but QGIS is more convenient for this purpose.

Software to estimate evapotranspiration: Evapotranspiration is estimated with the METRIC algorithm and Landsat 8 data (30m). The Nebraska University provides an interface for the computation of this algorithm in GEE called EEFlux (https://eeflux-level1.appspot.com/)[4]. EEFlux is freely available.

Implementation

The protocol consists of three steps implemented in GEE. A link to the code in GEE for each step is provided in the annex. The steps are 1) create a land cover map using machine learning; 2) estimate the cropped and irrigated areas using NDVI; 3) compute uniformity, adequacy and reliability using evapotranspiration values derived from EEFlux.

Step 1: Create a landcover map with three broad classes (agriculture, trees, other)

The land cover map provides the basis for estimating cropped and irrigated areas. The map distinguishes between three broad land cover classes: agriculture, forest and other. The latter category includes water, infrastructure, houses and other built-up, roads, bare soil/rock). The land cover classification uses all cloud-free images of Sentinel 2 (with bands B2, B3, B4, B5, B6, B7, B8, B8A, B11 and B12) and Sentinel 1 (SAR) data available for the July 2019 - June 2020, covering Kharif followed by Rabi season. The land cover classification uses the machine learning algorithm Random Forest implemented in GEE. In the absence of field data, a sample set of training and validation data is constructed with the Google Earth base layer (resolution < 1m) in which water bodies, trees, agricultural fields, houses, roads and other infrastructure are clearly visible. The minimum number of sample points for training and validation for each class is 100. Accuracy indicators such as confusion matrix and producer accuracy are also computed. For the three broad classes of 'agriculture', 'trees' and 'other', the training set constructed from Google Earth satellite images is of sufficient detail and accuracy. However, without further field data on agricultural practices and cropping patterns, it is not possible to distinguish between crop types.

Step 2: Compute NDVI and estimate cropped and irrigated area.

The cropped and irrigated areas are estimated with the Normalized Difference Vegetation Index (NDVI). NDVI is a measure of greenness and health of vegetation and is computed as the normalized difference of the Red and Near Infrared NIR bands:

$$NDVI = (NIR - RED) / (NIR + RED)$$

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[4] For the computation of evapotranspiration there are several other algorithms such as SEBAL. We choose for EEFlux for the ease of implementation and less requirement of field data for validation.

By definition NDVI values range between -1 and 1. In areas with vegetation the NDVI is greater than 0. The NDVI values of water bodies is close to zero.

Making use of the land cover map developed in the previous step, the NDVI is computed for the agricultural area (pixels with land class ‘agriculture’) for the wet season Kharif (July – November) and dry season Rabi (December – April) for the years 2015 to 2020. For the period 2018-2020, Sentinel 2 data (resolution 10 m) are available during the Rabi season. For earlier years and for the cloudy months of the Kharif season for which no cloud-free images are available, a Landsat 8 based NDVI product is used with 30m resolution (refer to this link to the USGS for details).

During the Rabi season rainfall is insufficient to cover crop water requirements. Therefore, crops grown during the Rabi season are most likely irrigated. During the Kharif season the distinction between irrigated and rainfed crops is less straightforward because crops in the command area receive water from both rain and irrigation. Irrigated (Rabi) and irrigated/cropped (Kharif) areas are estimated by assuming a threshold value of NDVI. Where the NDVI value exceeds this threshold value, the pixel is assumed to be irrigated. The threshold value is estimated by taking the median value of all seasonal NDVI pixels (July-November for Kharif and December – April for Rabi). For the three case studies, the median value of the seasonal NDVI values ranges from 0.30-0.38, which compares well with the values reported in literature.

Step 3: Compute uniformity, adequacy and reliability with pixel values of evapotranspiration

Evapotranspiration is estimated with EEflux which uses the METRIC algorithm and Landsat 8 data (30m) to compute daily evapotranspiration (ET_a) for each available Landsat 8 image. On average there are 6 or 7 cloud-free images available during the Rabi season, and only one or two (or none at all) for the rainy Kharif season. Therefore, the evapotranspiration (ET_a) and related indicators (uniformity, adequacy and reliability) could only be computed for the Rabi season.

- Uniformity is computed as the coefficient of variation of seasonal $ET_a = CV(ET_a)$
  For the computation of seasonal values, the median value of available ET_a images during the Rabi season is multiplied by the number of days in the season/month. The coefficient of variation is computed as the standard deviation divided by the mean of all pixels.
- Adequacy is estimated as the Relative Evapotranspiration (RET).
  RET = seasonal ET_a divided by seasonal ET_{max}
  ET_{max} is the amount of water that crops could potentially evaporate without water limitations. In the absence of field data and agronomic information on crops and cropping patterns, in this protocol a statistical approach is taken to determine ET_{max}. ET_{max} is assumed as the 95 percentile of all ET_a pixels within the irrigated area.
  Overall adequacy = median value of all RET pixels within the irrigated area.
- Reliability is estimated as the coefficient of variation of the relative evapotranspiration over time. For each available image the RET is computed as ET_a/ET_{max}.
  Reliability = coefficient of variation of the time series pixels of RET. The overall reliability is taken as the median value of all CV(RET) pixels within the irrigated area.

C. Application of the protocol to three irrigation schemes

1. Gollavagu irrigation scheme

The Gollavagu Medium Irrigation Scheme, covering 3840 ha, has been finalized recently and actual irrigation of the fields started in 2018. The dam of about 15.5 meter can store 16 Mm^3 water at full capacity. The outlet from the reservoir feeds the contour main canal from which there are 38 offtakes supplying water to the secondary and field canals.

Step 1 – land cover map.

Figure 1 provides the Google Earth satellite image in GEE of the Gollavagu command area (greyish area) and canal network (black lines). The reservoir is visible in the upper left corner.

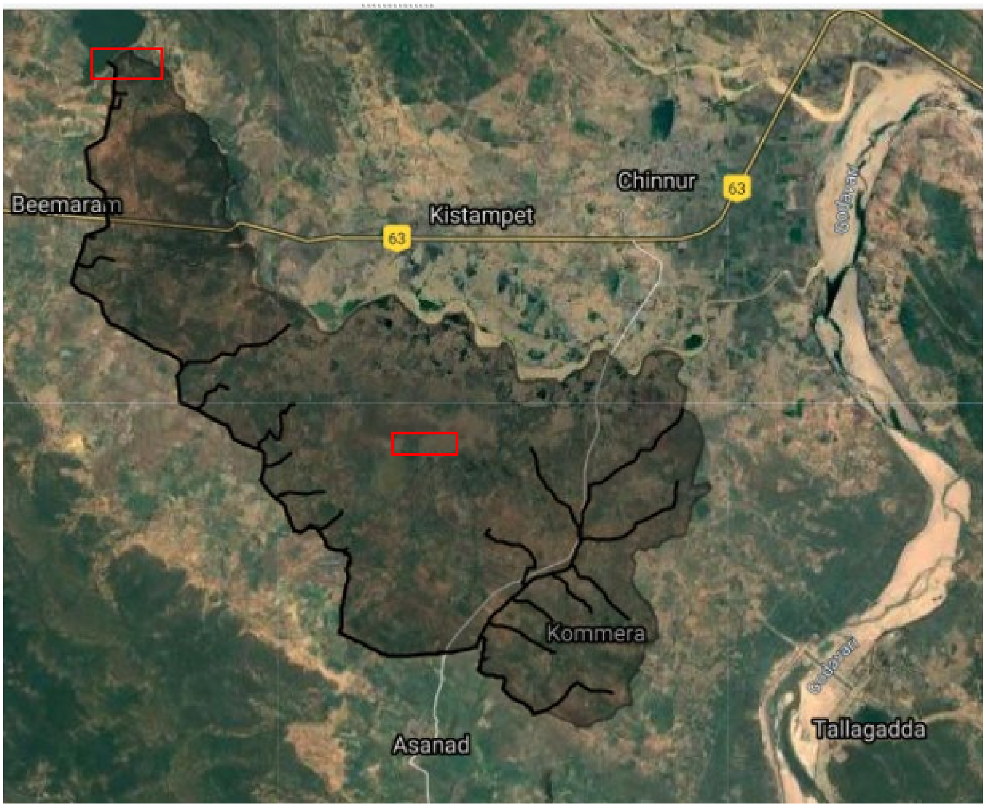


Figure 1. Gollavagu command area and canal network (the red squares indicated the zoomed-in areas in figure 2)

The Google Earth image is used to construct a sample set of 385 points, covering three classes: agriculture, trees, and other. Figure 2 illustrates how sample points are chosen that represents the different classes. The figure depicts two different areas in the command area as indicated by the red squares in figure 1. The blue dots in figure 2 represent the land cover class 'other' which includes water, houses and infrastructure. The yellow dots represent the land cover class 'agriculture'; the green dots 'trees'. As can be seen from the image around the reservoir, some overlap occurs between the classes 'agriculture' and 'trees' because it is difficult to distinguish between orchards (which fall under agriculture) and trees in the natural vegetation. However, since the area under orchards is very limited (concentrated around the reservoir) this confusion will not affect the overall results.

Figure 3 depicts all sample points used for training and validation of the land cover classification.

Figure 2: Google Earth satellite images depicting land classification sample points in Gollavagu scheme

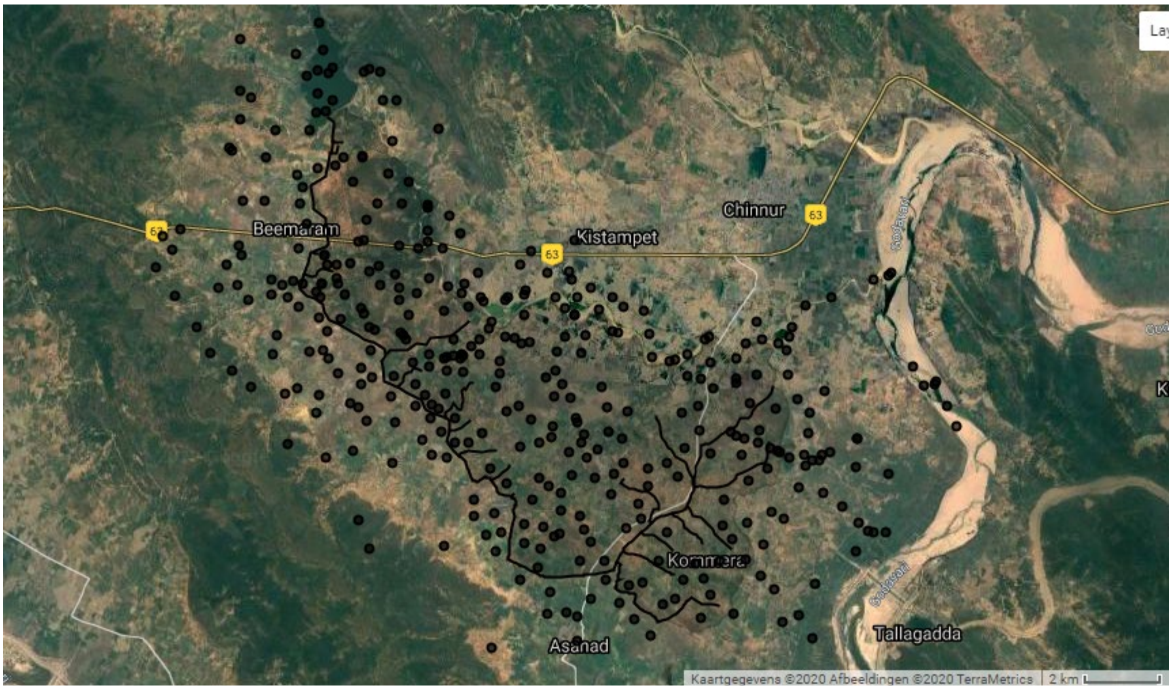


Figure 3: Google Earth satellite images depicting sample points used in the land cover classification in the Gollavagu scheme.

The 385 sample points were randomly assigned to two purposes: 70% of the sample points for training and 30% for validation purposes.

For Gollavagu scheme cloud-free Sentinel 2 data are available for the months December 2019 and January through May 2020. Sentinel 1 (SAR) data are available for the months July 2019 through June 2020. The land cover classification uses the machine learning algorithm Random Forest and the spectral time series data of the Sentinel 2 bands (B2, B3, B4, B5, B6, B7, B8, B8A, B11 and B12) and the Sentinel 1 band (VH).

The resulting land cover map is shown in figure 4. The gross area covered by the command area is 6350 hectares. The area of class 'agriculture' (green pixels) is 6250 hectares.

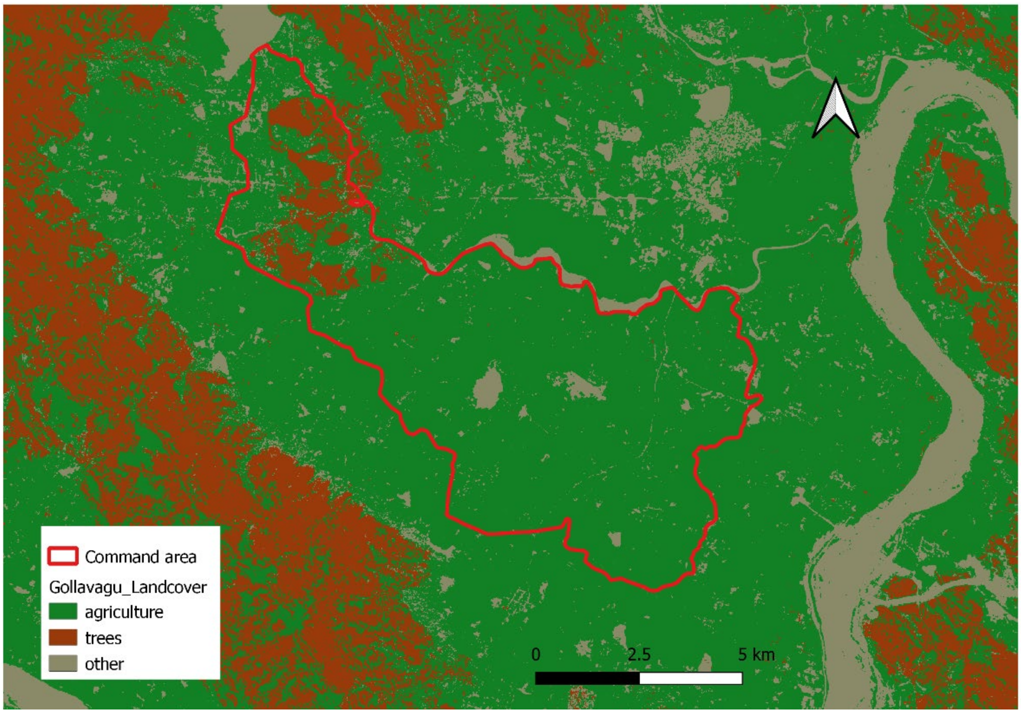


Figure 4. Land cover map of Gollavagu scheme (derived from 2019/20 data)

The overall accuracy of the classification is 84%. The producer accuracy of class 'agriculture' is 93%, for 'trees' 64% and 'other' 63%. The overall accuracy is good.

Step 2: NDVI and irrigated areas

First, the NDVI for the Rabi and Kharif 2019/20 season is calculated with the normalized difference formula in Javascript in GEE, based on Sentinel 2 data with 10m resolution. For the Kharif 2019/20 only one cloud free images is available (in July 2019). For the Rabi season 2019/20 there are 6 cloud free images. The seasonal NDVI is estimated as the median value over the 6 images. Secondly, the threshold value is estimated by taking the median value of the NDVI over the pixels classified as 'agriculture' falling within the command area. For Gollavagu during Kharif 2018/19 this 0.38 (based on one image); during Rabi 2019/20 this is 0.35, based on 6 images. Figure 9 shows the frequency histogram of NDVI pixel values. To enable a visual inspection, the pixels with NDVI > threshold are coloured red. Lastly, the total area of the red pixels is computed. The results for Kharif 2019/20 are depicted in figures 5 and 6.

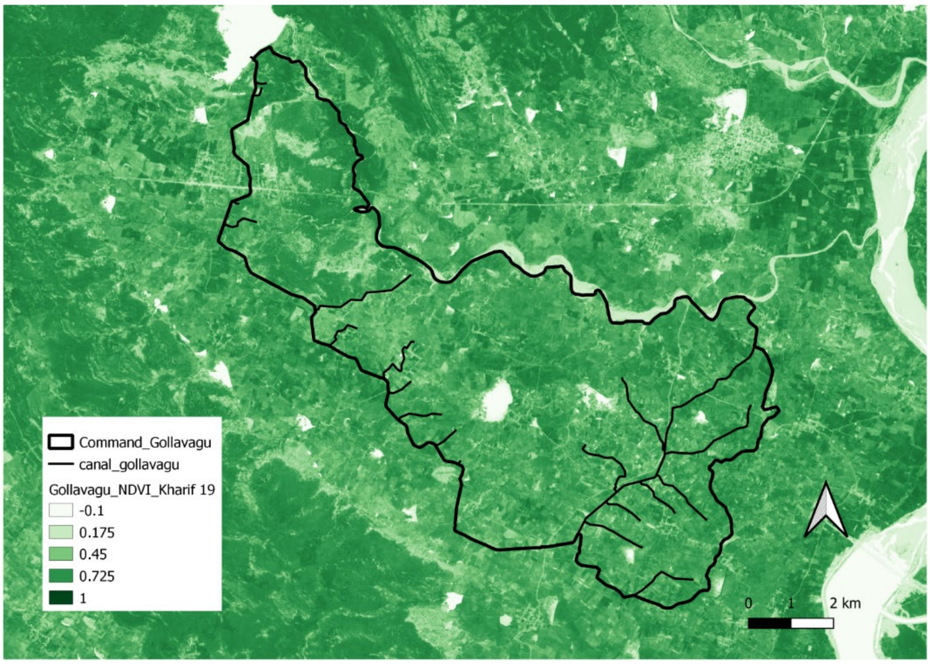


Figure 5. The NDVI of the Gollavagu scheme and surroundings during Kharif 2019/20.

The black lines depict the canals and command area. The white areas are water bodies (reservoirs, tanks and rivers). The dark green shows high NDVI values, where vegetation and crops are lushest.

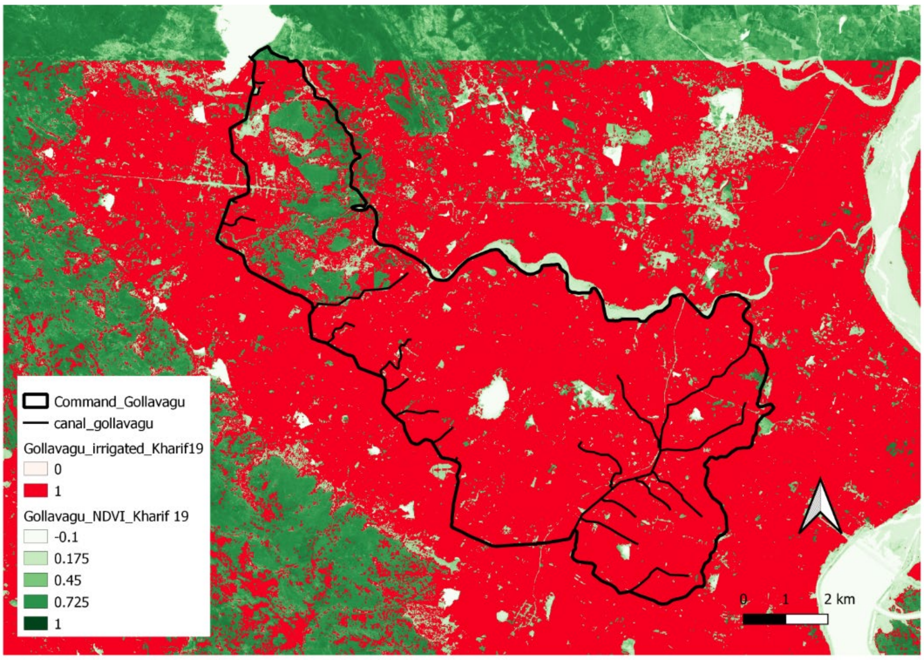


Figure 6. All pixels classified as 'agriculture' with NDVI > 0.38 are coloured red. The green pixels in the lower left of the map and in the upstream reach of the command area depict forested areas. The small patches green pixels in command area are trees/shrubs (this was verified with Google Earth image).

The total area of red pixels (i.e. the irrigated/cropped area) is 6067 hectares, indicating that 97% of the command area during the Kharif 2019/20 was cropped.

The NDVI and estimated irrigated areas during the dry season Rabi 2019/20 are depicted in figures 7 an 8.

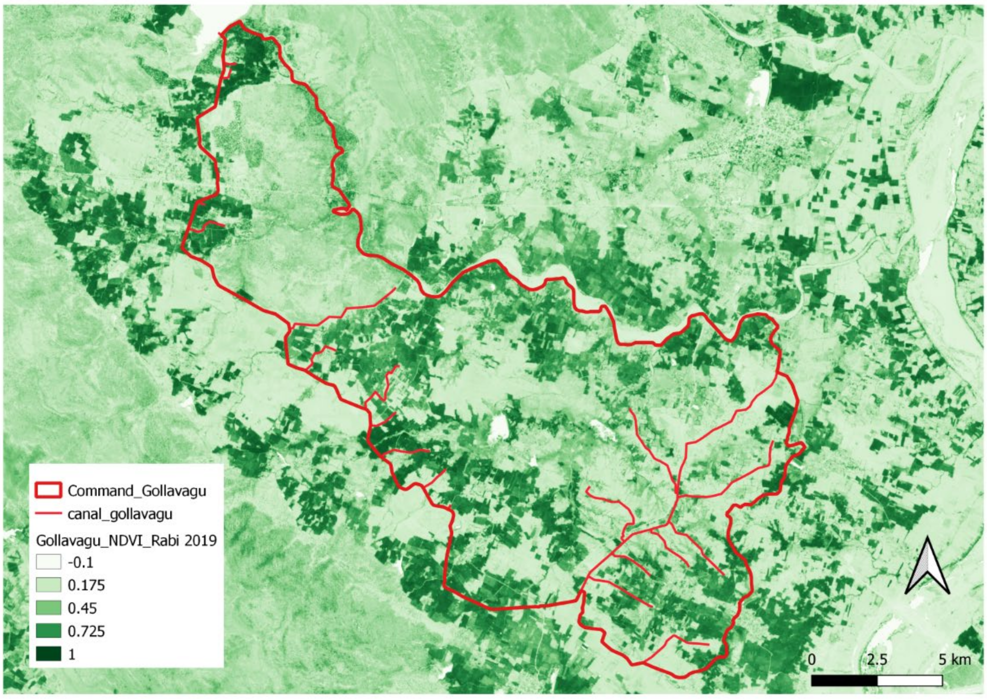


Figure 7. NDVI of the Gollavagu scheme and surroundings during Rabi 2019/20. The areas in dark green show areas with healthy lush vegetation or crops.

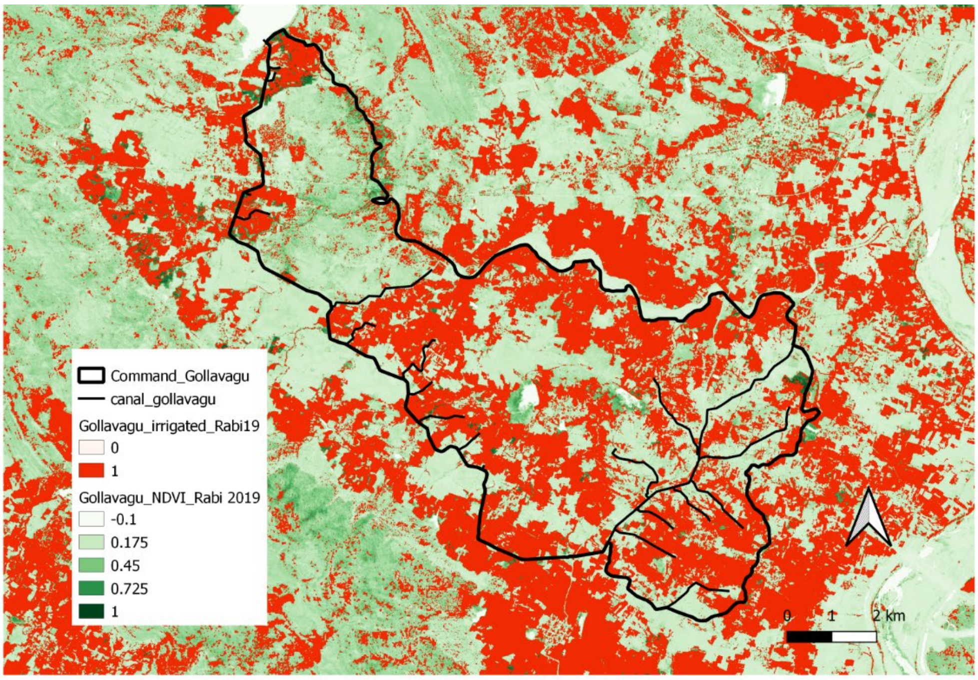


Figure 8. All pixels classified as 'agriculture' with NDVI > 0.35 are coloured red.

The total area of red pixels during Rabi 2019/20, considered as irrigated area is 3293 hectares, corresponding with 53% of the command area.

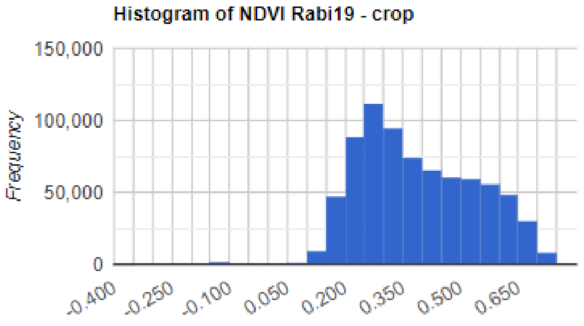


Figure 9. Frequency histogram of the NDVI of pixels falling within the Gollavagu command area. The median value of NDVI is 0.35.

Zooming in to the upper reach of the main canal just below the reservoir (Figure 10) shows irrigated fields adjacent to the canal but falling outside the command area. During the field visit in March 2019 we saw farmers raising the water level and (illegally) pumping water from the main canal to irrigate their fields outside the command area. The NDVI map clearly shows this practice.

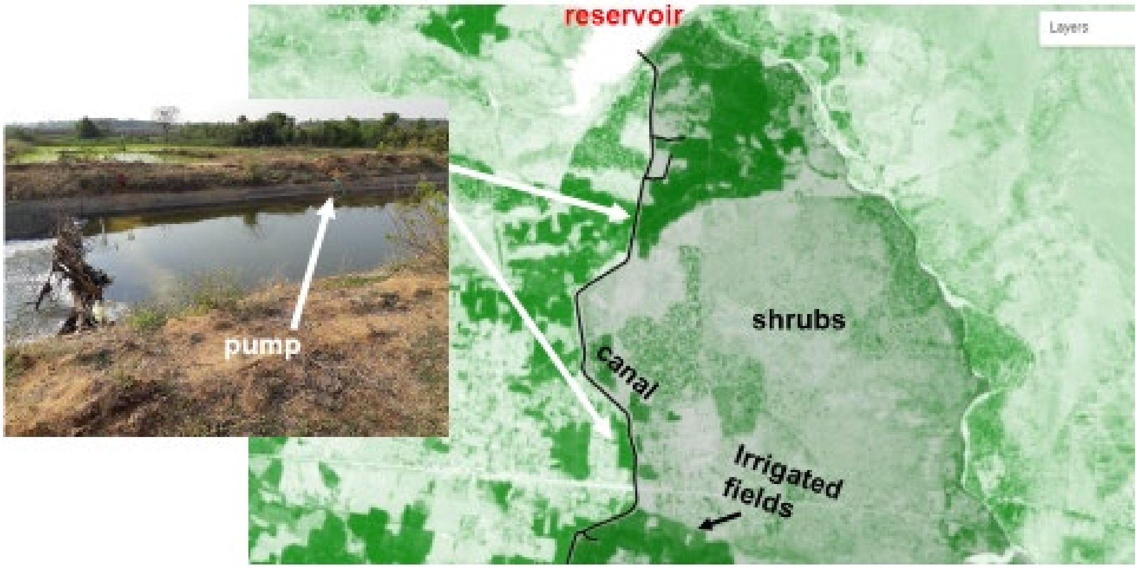
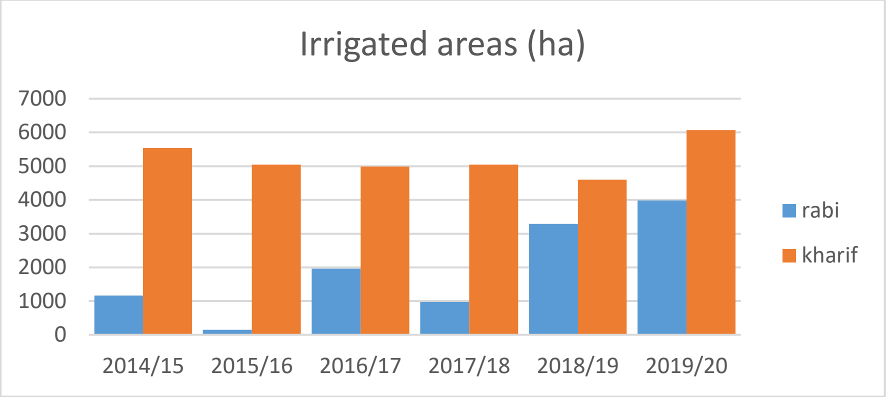


Figure 10. Pumping from the main canal to irrigate out-of-command area in the upper part of the Gollavagu irrigation scheme.

Following the procedure as described in the paragraphs above, the cropped/irrigated areas during the Kharif and Rabi seasons are determined for the years 2014 to 2020. The results are depicted in figure 11.



	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
% of command area cropped during Kharif	89%	81%	80%	81%	74%	97%
% of command area irrigated during Rabi	19%	2%	31%	16%	53%	64%

Figure 11. Time series data of irrigated area within the Gollavagu command area.

The time series data of irrigated area during the Rabi season exhibit an increasing trend, in particular after 2018, the year that the scheme was commissioned. In 2019/20 nearly the entire command area was cultivated during Kharif, while nearly two third of the command area was irrigated during the dry season Rabi.

Step 3: ETa based indicators uniformity, adequacy and reliability

The ET_a values are estimated using Landsat 8 data (30m) and the METRIC algorithm with the EEFlux software integrated in GEE. For the Gollavagu scheme & surroundings 34 cloud-free images are available during the Rabi months of the years 2014/15 till 2019/20, corresponding to 6 or 7 images per season per year. For each image the daily ETa is computed. The image for the 7th of April 2019 is shown in figure 12.

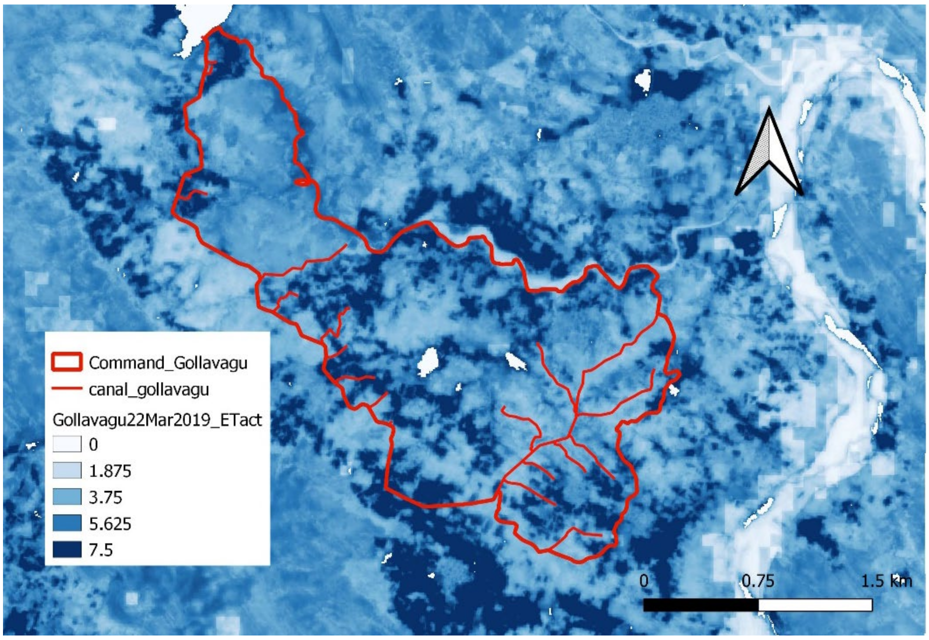


Figure 12. Daily ET_a values derived from the Landsat 8 image of 22 March 2019

The ET_a values range from 0 to 7.5 mm (darkest blue). The ET_{max}, estimated as the 95 percentile value of all ET_a pixels of the cropped area falling in the Gollavagu command area, is 7.3 mm for the Rabi 2018/19. The daily values are aggregated to seasonal values by multiplying by the number of days.

Uniformity (or equity) = coefficient of variation of evapotranspiration = CV (ET_a).

Uniformity can be computed over the cropped or irrigated area. Lower values of the coefficient of variation mean a higher uniformity and hence better performance. Values below 0.10 point to good performance. For the Gollavagu scheme this value computed over the irrigated pixels fluctuates between 0.14 and 0.17 for the year 2015-2019, with no clear trend over time. The value computed over the command area pixels fluctuates between 0.22 and 0.32. This seems to indicate that there is substantial variation in water supply to different fields of the command area. This was confirmed during the field visit where we observed that some areas, in particular at the canal tail ends, did not receive water during Rabi. The water is reasonably well distributed over the areas that do receive water and are irrigated during Rabi.

Adequacy = relative evapotranspiration (RET) = seasonal ET_a/ seasonal ET_{max}

Values above 0.70 are regarded as good performance; values below 0.70 point to sub-optimal performance which may lead to yield reduction or crop loss. For the Gollavagu scheme values during the Rabi seasons between the years 2015 – 2019 fluctuate between 0.78 and 0.84 (measured over the irrigated pixels), indicating that seasonal crop water requirements of irrigated crops are generally met.

Reliability = coefficient of relative evapotranspiration over time = CV (monthly RET) = CV (ETa/ ETmax).

Higher values of the coefficient of variation mean more variation over time of relative ET (which is a measure of the extent to which crop needs are met). Values < 0.10 point to good performance. For the Gollavagu system, reliability values fluctuate from 0.05 to 0.09 during the Rabi seasons of 2015-2019, indicating good performance. Figure 13 shows the adequacy values (ET_a/ET_{max}) over the months. While there is variation over the months it is within acceptable limits.

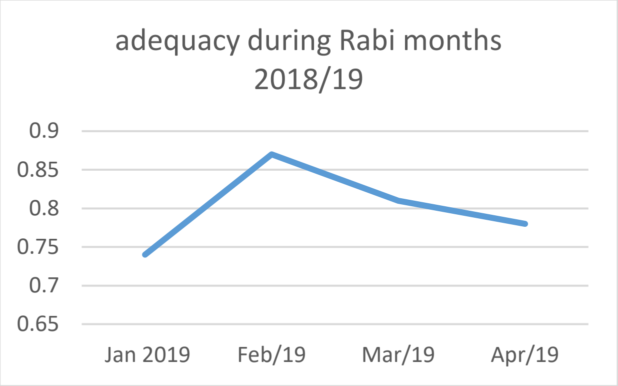


Figure 13. Adequacy values over the months of the 2018/19 Rabi season in the Gollavagu irrigation scheme.

The table below provides an overview of the time-series values of the ET based indicators.

	Uniformity command	Uniformity irri area	Adequacy	Reliabity
Rabi 2014/15	0.24	0.14	0.80	0.07
Rabi 2015/16	0.25	0.14	0.79	0.08
Rabi 2016/17	0.27	0.16	0.84	0.07
Rabi 2017/18	0.32	0.14	0.84	0.05
Rabi 2018/19	0.26	0.17	0.78	0.09
Rabi 2019/20	0.22	0.16	0.83	0.06

Table 1. Time-series values of the ET based indicators, Gollavagu scheme

Summarizing irrigation performance indicators for the Gollavagu scheme

- Irrigated areas are increasing over time, in particular during the Rabi seasons 2018/19 and 2019/20.
- The uniformity/equity performance is low, indicating an uneven distribution of irrigation water over the command area. This is in line with observations during the field visit where we observed that canal tail-ends did not receive water during the Rabi season.
- The seasonal adequacy of the irrigated area is well above 0.70 indicating good irrigation performance.
- Reliability values are within the acceptable range, indicating that monthly fluctuations are limited.
- While the protocol gives a good overview of performance over time, the analysis is only as good as the data and assumptions being used. No recent field data on agricultural practices and cropping patterns were available; the analysis depends on remote sensing data exclusively. Ground truth information would render this analysis more reliable.

2. Lower Panjara irrigation scheme

The Lower Panjara Irrigation scheme consists of a reservoir with a maximum of 89 MCM live storage which provides water by gravity to a command area of 7585 ha through two contour canals: Right Bank Canal and Left Bank Canal. Further, the reservoir provides water to the city of Dhule and industry. The construction of the system was recently finalized. The layout of canal and the command area incorporates several small tanks that were already in use before the Lower Panjara irrigation system was implemented. In 2017 there was some 5000 ha irrigated. Releases from the reservoir occurred on demand by farmer groups. In 2018, however, due to water shortage no releases from the reservoir for irrigation were foreseen. At the time of the field visit (March 2019) water delivery for irrigation had not yet started for the new season. It was foreseen that the first irrigation in the command area from the main and secondary canals would start in July 2019. During the first quarter of 2019, the Right Bank Main canal conveyed water on several occasions, primarily for delivering water for domestic purposes on the demand of the city of Dhule and for filling several of the small tanks in the command area.

Step 1 – land cover map.

Figure 1 provides the Google Earth satellite image in GEE of the Lower Panjar command area (greyish area) showing the training training and validation points. In total 440 points were selected, roughly equally distributed over the three classes ‘agriculture’, ‘trees/forest’ and ‘other’.

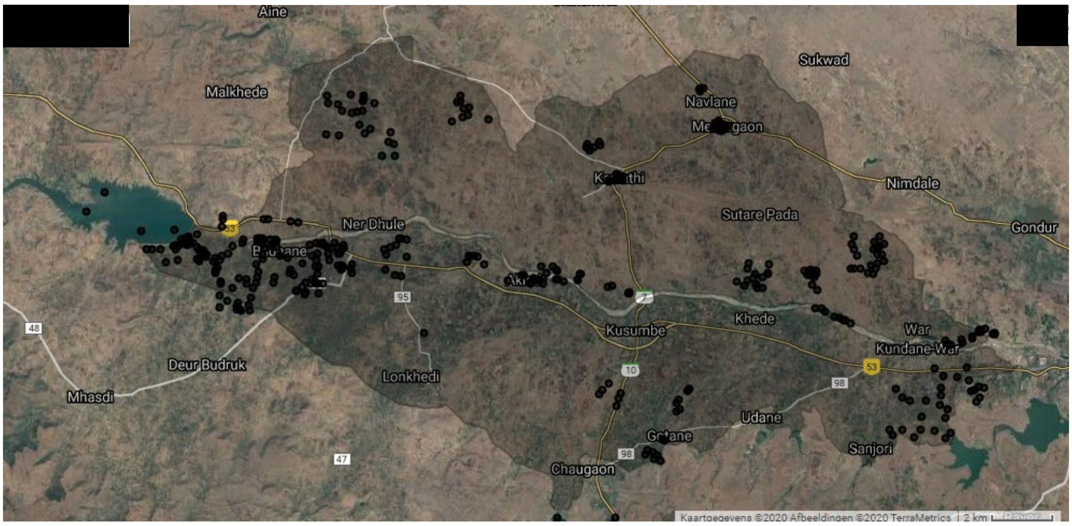


Figure 14: Google Earth satellite image showing the Lower Panjara scheme and surroundings

Using Sentinel 1 and 2 data for the year 2019/20 and the machine learning algorithm Random Forest, a land cover map was constructed as shown in figure 15, where the green pixels are agricultural fields, brown are trees/forest and grey depicts the class ‘other’ (water, infrastructure, houses, roads, bare soil etc.). The overall accuracy of the classification is 91%. The producer accuracy of class ‘agriculture’ is 94%, for ‘trees’ 88% and ‘other’ 80%. The overall accuracy is very good.

The command area covers 17,280 hectares.

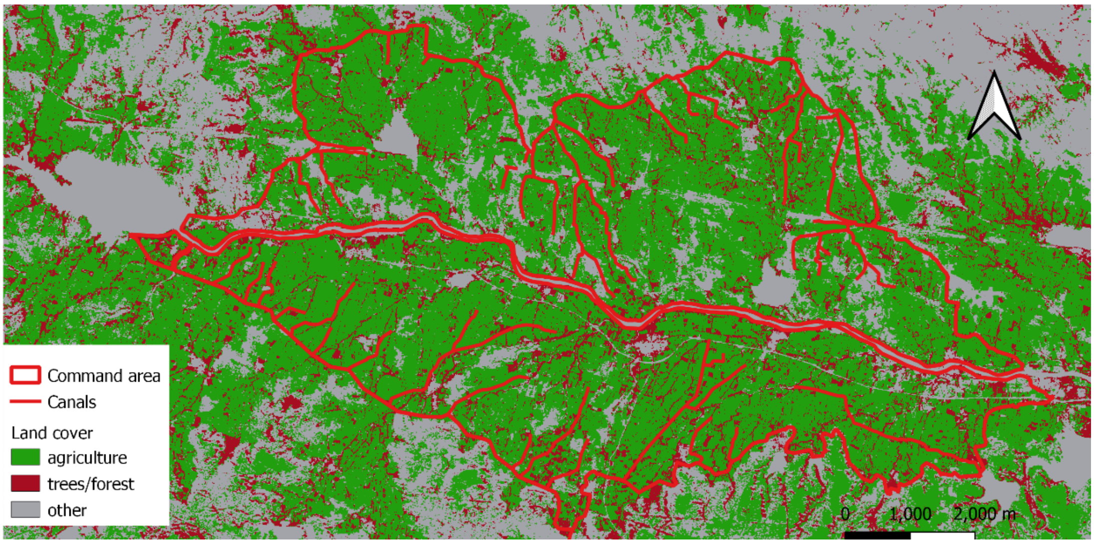


Figure 15. Lower Panjara land cover map

Step 2: NDVI and irrigated areas

First, the NDVI for the Rabi and Kharif 2019/20 season is calculated with the normalized difference formula in Javascript in GEE, based on Sentinel 2 data with 10m resolution. For the Kharif 2019/20 only two cloud free images are available; for the Rabi season 2019/20 there are 7 cloud free images. The seasonal NDVI for Rabi 2019/20 is estimated as the median value over the 7 images. Secondly, the threshold value is estimated by taking the median value of the NDVI over the pixels classified as 'agriculture' falling within the command area. During Rabi 2019/20 this is 0.33. To enable a visual inspection, the pixels with NDVI > threshold are coloured red. To estimate the irrigated area, the total area of the red pixels is computed. The results are depicted in figures 16, 17 and 18 below.

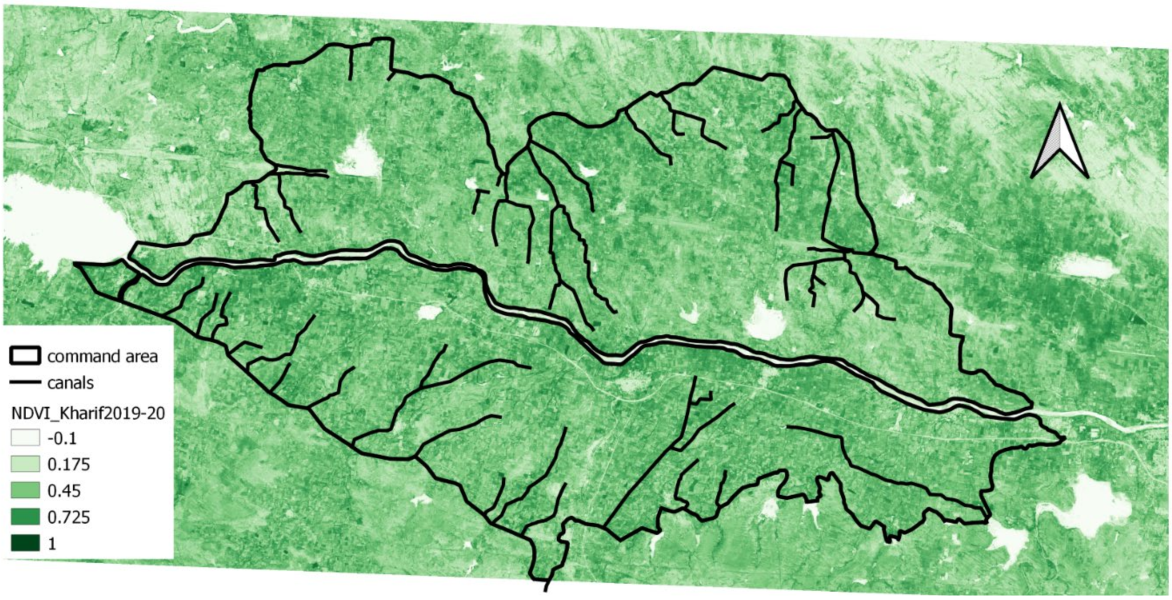


Figure 16. NDVI for the Lower Panjara scheme, Kharif 2019/20

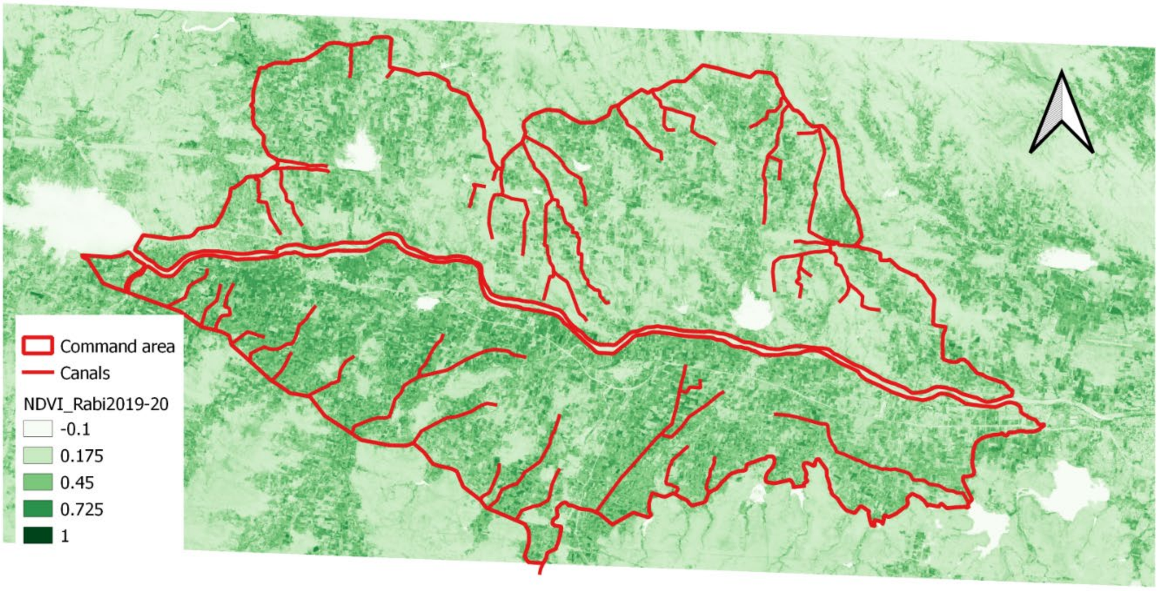


Figure 17. NDVI for the Lower Panjara scheme, Rabi 2019/20

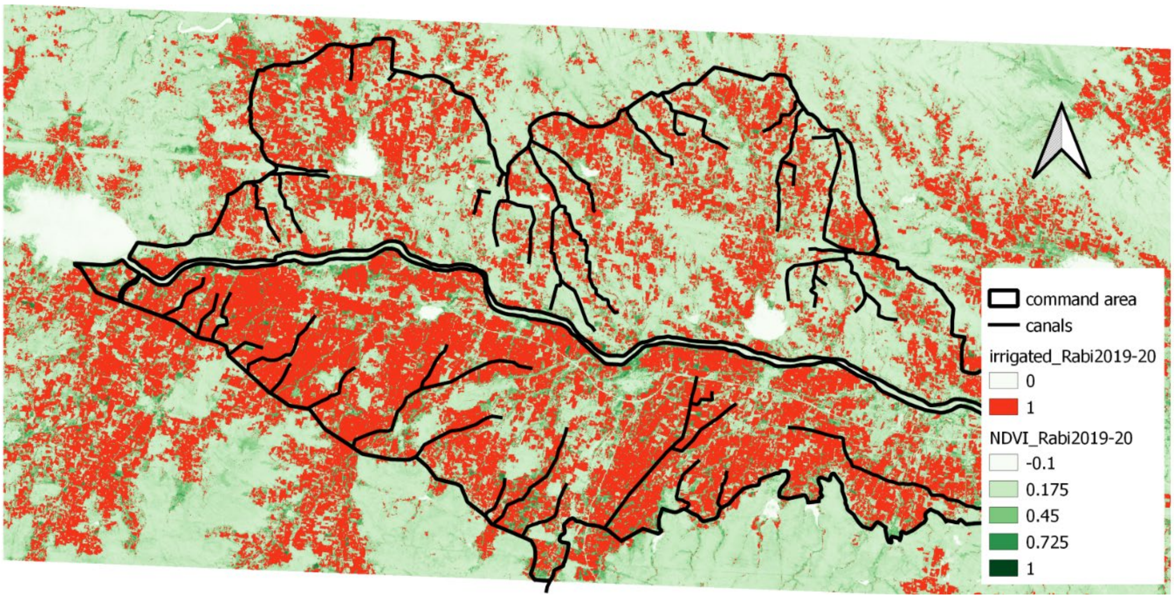
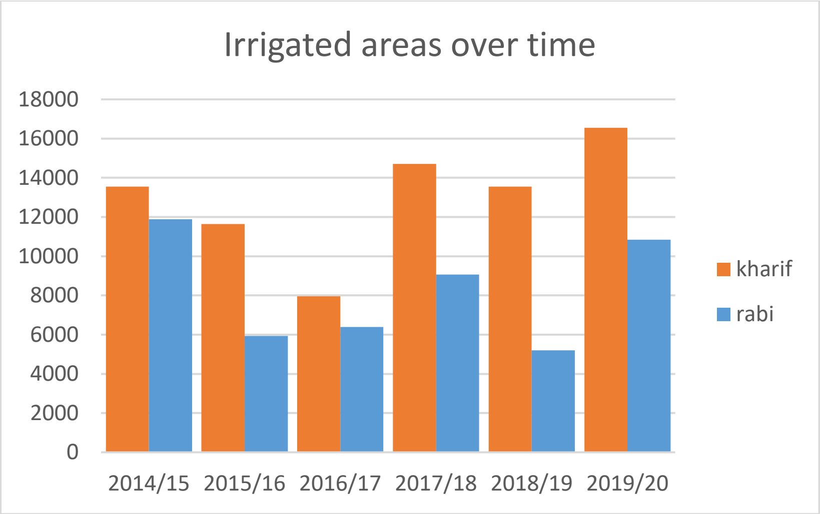


Figure 18. Lower Panjara scheme NDVI Rabi 2019/20. All pixels classified as 'agriculture' with NDVI > 0.33 are coloured red.

The total area of red pixels during Rabi 2019/20, considered as irrigated area is 10,836 hectares, corresponding with 63% of the command area.

Following the procedure as described above, the cropped/irrigated areas during the Kharif and Rabi seasons are determined for the years 2014 to 2020. The results are depicted in figure 19.



	2014/15	*2015/16*	*2016/17*	*2017/18*	*2018/19*	*2019/20*
% of command area cropped during Kharif	78%	67%	46%	85%	78%	96%
% of command area irrigated during Rabi	69%	34%	37%	52%	30%	63%

Figure 19. Time series data of irrigated areas in the Lower Panjara command area

In particular, during the Kharif season the area exhibit a rising trend over the past few years.

Step 3: ETa based indicators uniformity, adequacy and reliability

The Eta values are estimated using Landsat 8 data (30m) and the METRIC algorithm with the EEFlux software integrated in GEE. For the Lower Panjara scheme & surroundings 39 cloud free images are available during the Rabi months of the years 2014/15 till 2019/20, corresponding to 6 to 8 images per season per year. For each image the daily ETa is computed. The image for the 3rd of April 2019 is shown in figure 20.

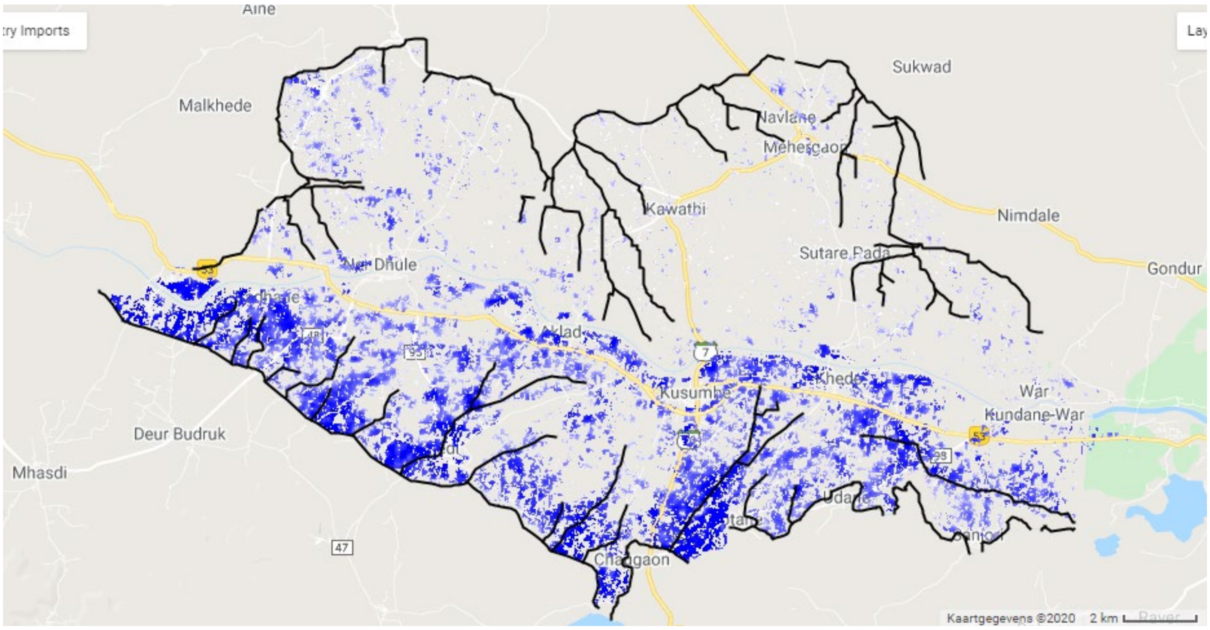


Figure 20. Daily ET$_a$ values derived from the Landsat 8 image of 3rd of April 2019, clipped to the Lower Panjara command area and land cover class 'agriculture'. The ET$_a$ value range from 0 to 8 mm.

The indicators uniformity, adequacy and reliability are computed as explained earlier in this report. The results are provided in the table below:

	Uniformity command	Uniformity irri area	Adequacy	Reliabity
Rabi 2014/15	0.44	0.36	0.64	0.22
Rabi 2015/16	0.58	0.36	0.65	0.23
Rabi 2016/17	0.58	0.40	0.64	0.34
Rabi 2017/18	0.55	0.35	0.65	0.19
Rabi 2018/19	0.62	0.43	0.58	0.24
Rabi 2019/20	0.40	0.31	0.72	0.20

Table 2. Time-series values of the ET based indicators, Lower Panjara

Summarizing irrigation performance indicators for the Lower Panjara scheme

- During the Kharif season most of the command area is cultivated; during Rabi relatively small part is irrigated.
- The seasonal adequacy is below the acceptable value of 0.70, except for Rabi 2020 season, indicating that fields receive insufficient water to meet crop water requirements.
- Reliability values are low, indicating large fluctuations over the months.
- Uniformity/equity performance is very low, indicating an uneven distribution of irrigation water over the command area and irrigated area.
- While the protocol gives a good overview of performance over time, the analysis is only as good as the data and assumptions being used. No recent field data on agricultural practices and cropping patterns were available; the analysis depends on remote sensing data exclusively. Ground truth information would render this analysis more reliable.

3. Mahuar irrigation scheme

The Mahuar irrigation in the Sivpuri district consists of a reservoir feeding two contour canals (Left and Right Bank main canal). The command area according to the design documents is about 9600 hectares. The construction of the Mahuar irrigation system was recently finalized and irrigation started a few years ago. The CAD foresees lining of the some field canals (about 30m / ha) but not all have not been constructed yet, some of the CAD works were still ongoing at the time of the field visit. Pumping from drains and shallow groundwater in the command area is very common. Farmers claimed that there are more than 1000 wells in the command area, of which many are located in the downstream part of the command area. The water retention capacity of the (rocky) soil is low and there is a rapid runoff to drainage canals and seepage to groundwater. Farmers in the downstream part of the scheme depend to a large extend on shallow groundwater and pumping from drains to bridge the long irrigation intervals. Some farmers use shallow wells and pumping from drains to irrigate out-of-command area, though the extent is unknown.

Step 1 – land cover map.

Figure 21 provides the Google Earth satellite image in GEE of the Lower Panjar command area (greyish area) showing the training training and validation points. In total 540 points were selected, roughly equally distributed over the three classes ‘agriculture’, ‘trees/forest’ and ‘other’.

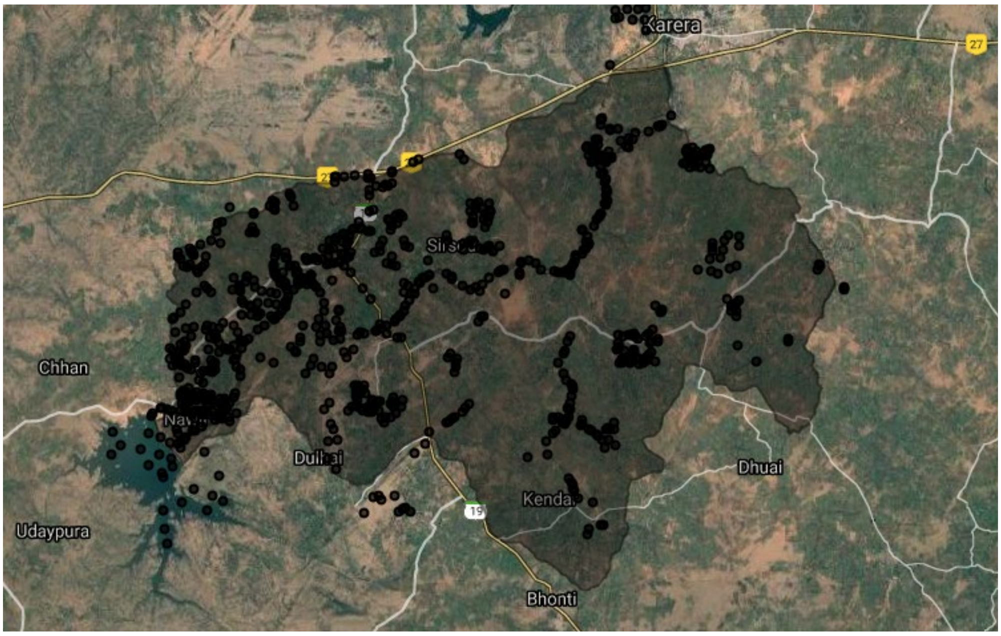


Figure 21: Google Earth satellite image showing the Mahuar scheme and sample points

Using Sentinel 1 and 2 data for the year 2019/20 and the machine learning algorithm Random Forest, a land cover map was constructed as shown in figure 22, where the light green are agricultural fields, brown are trees/forest and grey depicts the class 'other' (water, infrastructure, houses, roads, bare soil etc.).

The overall accuracy of the classification is 95%. The producer accuracy of class 'agriculture' is 97%, for 'trees' 85% and 'other' 95%. The overall accuracy is very good.

The command area covers 8320 hectares.

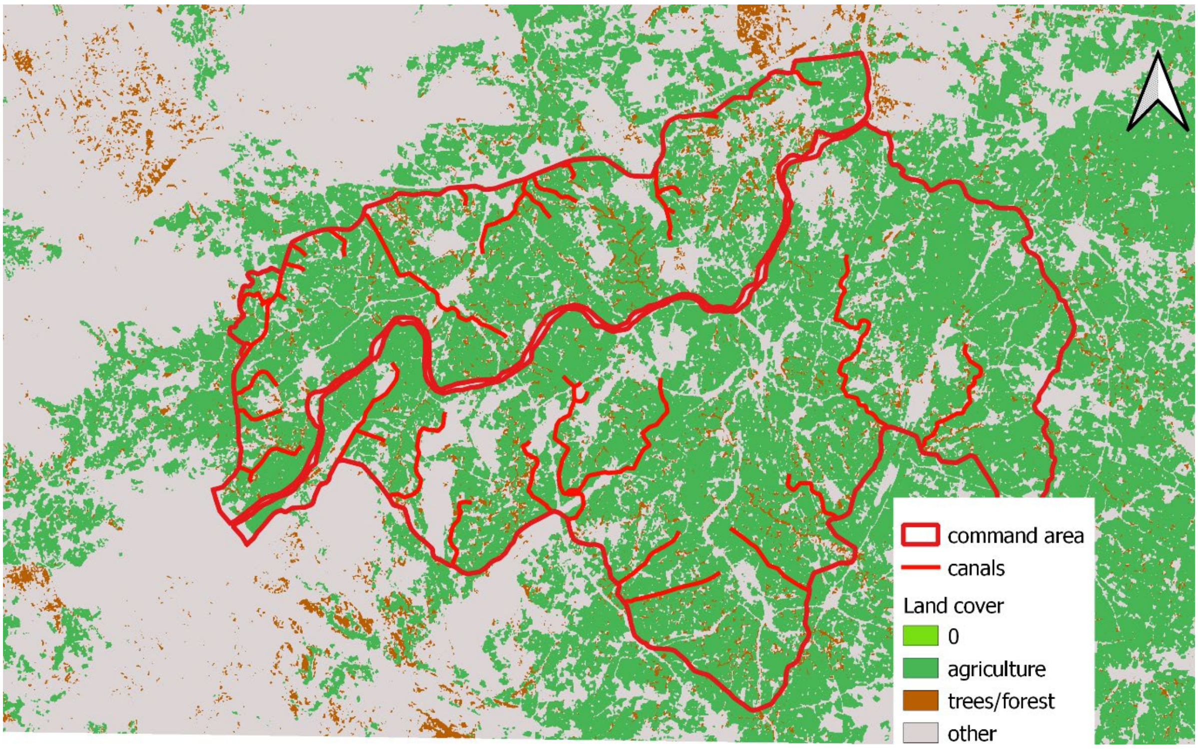


Figure 22. Mahuar land cover map.

Step 2: NDVI and irrigated areas

First, the NDVI for the Rabi and Kharif 2019/20 season is calculated with the normalized difference formula in Javascript in GEE, based on Sentinel 2 data with 10m resolution. For the Kharif 2019/20 only one cloud free image is available; for the Rabi season 2019/20 there are 7 cloud free images. The seasonal NDVI is estimated as the median value over the 7 images. Secondly, the threshold value is estimated by taking the median value of the NDVI over the pixels classified as 'agriculture' falling within the command area. During Rabi 2019/20 this is 0.36. To enable a visual inspection, the pixels with NDVI > threshold are coloured red. To estimate the irrigated area, the total area of the red pixels is computed. The results are depicted in figures 23 and 24.

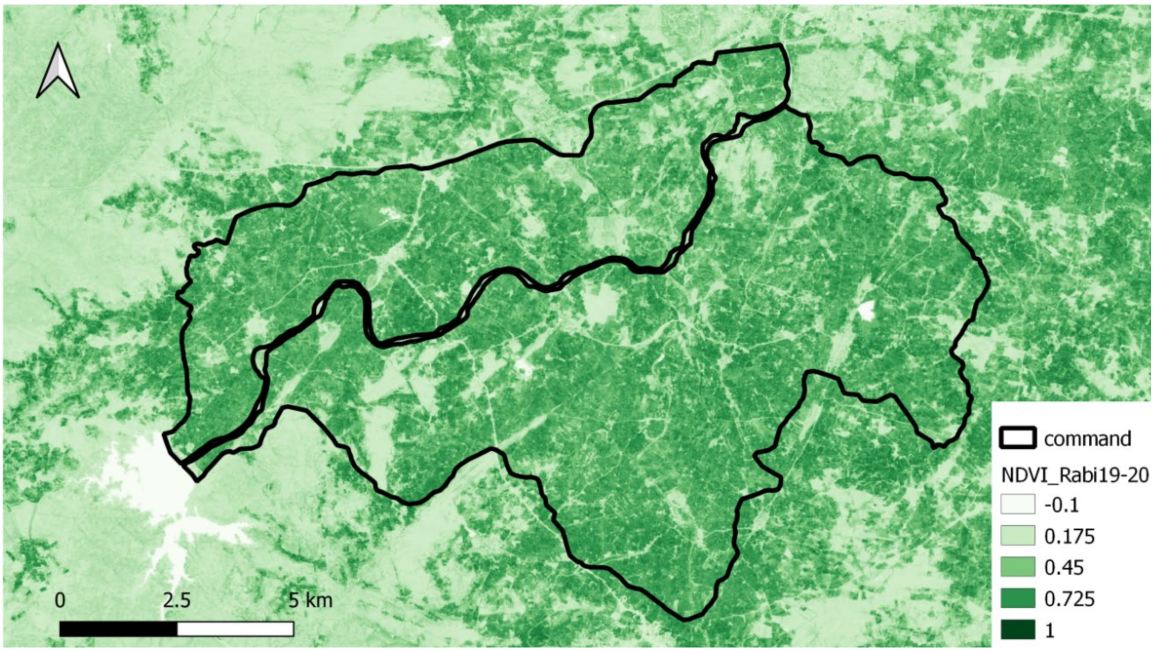


Figure 23. NDVI in the Mahuar scheme Rabi 2019/20.

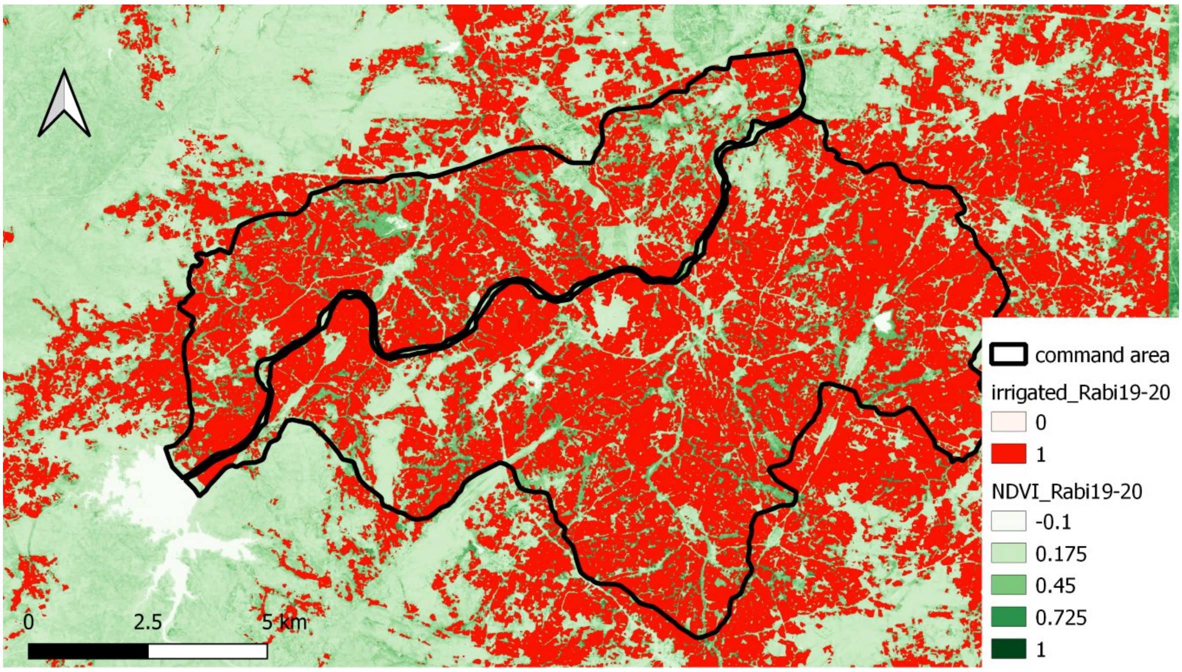
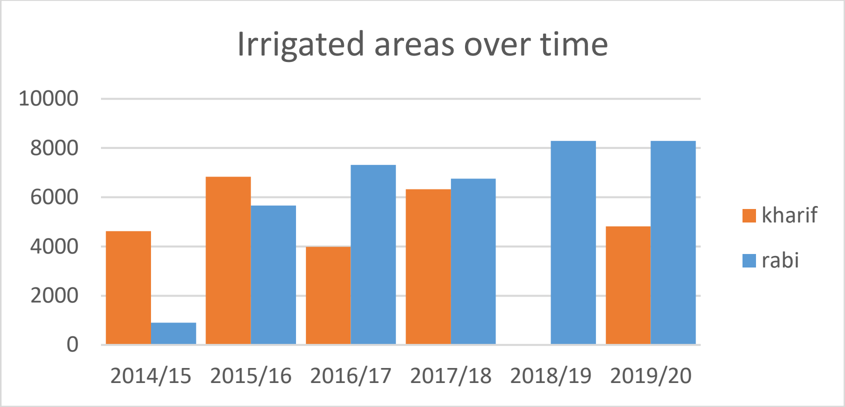


Figure 24 Mahuar scheme irrigated area Rabi2019/20: all pixels classified as ‘agriculture’ with NDVI > 0.36 are coloured red.

The total area of red pixels during Rabi 2019/20, considered as irrigated area is 8294 hectares, corresponding with 99% of the command area.

Following the procedure as described above, the cropped/irrigated areas during the Kharif and Rabi seasons are determined for the years 2015 to 2020. The results are depicted in figure 25.



	2014/15	*2015/16*	*2016/17*	*2017/18*	*2018/19*	*2019/20*
% of command area cropped during Kharif	56%	82%	48%	76%	no data	58%
% of command area irrigated during Rabi	11%	68%	88%	81%	100%	100%

Figure 25. Time series data of irrigated areas in the Mahuar command area

During the Rabi season the area exhibit a rising trend close to 100% of the command area irrigated during Rabi 2018/19 and 2019/20.

Step 3: ETa based indicators uniformity, adequacy and reliability

Following the steps as described above, the results are given in table 3.

	Uniformity command	Uniformity irri area	Adequacy	Reliabity
Rabi 2014/15	0.15	0.13	0.85	0.33
Rabi 2015/16	0.19	0.18	0.82	0.34
Rabi 2016/17	0.14	0.11	0.90	0.33
Rabi 2017/18	0.24	0.17	0.84	0.38
Rabi 2018/19	0.21	0.20	0.75	0.33
Rabi 2019/20	0.09	0.08	0.89	0.17

Table 3. Time-series values of the ET based indicators, Mahuar scheme

Summarizing irrigation performance indicators for the Lower Panjara scheme

- During the Rabi season most of the command area is irrigated; during the last few years 99% of the command area is irrigated. During Kharif less area is cultivated. During the Kharif season of 2018/19 no cloud free images were available. Also during the other years lack of cloud free data during the Kharif season affected the analysis.
- The seasonal adequacy is well above the acceptable value of 0.70, indicating that water is sufficient to meet crop water requirements.
- Reliability values are low, indicating large fluctuations over the months.

- Uniformity/equity performance is low and differs over the years, indicating an uneven distribution of irrigation water over the command area and irrigated area. During the 2019/20 seasons uniformity seems improved compared to previous years.
- While the protocol gives a good overview of performance over time, the analysis is only as good as the data and assumptions being used. No recent field data on agricultural practices and cropping patterns were available; the analysis depends on remote sensing data exclusively. Ground truth information would render this analysis more reliable.

D. Reflections on the protocol

The objective of this study was develop a protocol for assessing irrigation performance for small and medium irrigation schemes. A major requirement of the protocol was the ease of use and replicability to other small and medium irrigation schemes in India. The biggest challenge encountered in the development of this protocol is the lack of reliable field data. In none of the three irrigation schemes visited in March 2019, basic data on reservoir releases, cropping patterns, canal flows and irrigation application to fields etc. was available. Therefore, it was decided to use remote sensing data.

The indicators used are 1) irrigated areas over time; 2) uniformity; 3) adequacy and 4) reliability. These indicators are widely used in irrigation performance assessment and a growing number of studies describe the use of remote sensing data to compute these indicators.

This study computes the indicators in three steps: 1) develop a land cover map with three broad classes (agriculture, trees, other) using Sentinel data and machine learning (Random Forest); 2) estimate the irrigated areas using NDVI; and 3) compute the indicators uniformity, adequacy and reliability using ETa raster data (derived from Landsat 8 with METRIC algorithm).

<u>Reflections on the methodology</u>

- The construction of the land cover map works well. The Google Earth satellite images are of sufficient quality and resolution to construct a sample set for training and validation covering the three broad classes. In an earlier stage we planned to use NCRS land cover maps (60m resolution) but these maps were difficult to get and proved less accurate the ones developed for this study.

- Because of the lack of field information several assumptions were made which influence the final results. Though overall results seem to be in line with field observations during the field visit, no detailed information was available to validate the conclusions regarding areas, ET and ET based indicators. More specifically:
  - The NDVI threshold above which we assume areas are irrigated, is estimated using the median value of all NDVI pixels of the agricultural area. The resulting threshold values for three schemes tested was robust (ranging 0.33 – 0.38). However, may be different for other schemes with different cropping patterns. This assumption needs to be further tested and compared with field data on irrigated areas. Different threshold values lead to different results.
  - The ET values computed by METRIC algorithm and Landsat 8 data are not calibrated nor verified with field data. At first glance the data seem reasonable. The METRIC algorithm is described in literature and peer reviewed, but calibration is recommended.

- The use of EEFlux is cumbersome and time consuming and the interface is in dire need for an upgrade. An alternative (reliable) source of ET data would be an improvement. The use of SEBAL was considered but this algorithm proved difficult to implement and field data for calibration were lacking.
- The ET_{max} value is estimated as the 95 percentile of ET_a values. This is an approximation that needs further analysis. It implicitly assumes that the cropping pattern is more or less uniform over the command area and planting/harvesting dates are similar for all fields. In the absence of field data, it is difficult to verify this.
- During the wet and cloudy Kharif season very few cloud-free images are available. This affects the accuracy of the indicator value during Kharif. Fortunately images during the Rabi, the irrigation season, are generally of high quality.

Reflections on the ease of use and replicability

An important requirement of the protocol is the ease of ease and its replicability to other small and medium schemes. The protocol uses Google Earth Engine. This platform has some important advantages. First and foremost, the platform is free and a wealth of freely available remote sensing data can be accessed. Computations are cloud based and standard computers can be used without the need for large data storage. On the other hand, working with the platform requires knowledge of Javascript. This protocol was tested on three schemes. Adapting the Javascript code for application to another scheme is relatively straightforward and quick. However, users will need to learn some basic Javascript before being able to adapt the existing code to apply the protocol to other schemes.

Annex

Additional info: selected literature on remote sensing and irrigation performance indicators used

Bastiaanssen, W.G.M.; Bos, M.G. Irrigation performance indicators based on remotely sensed data: A review of literature. Irrig. Drain. Syst. 1999, 13, 291–311

Conrad, C.; Dech, S.W.; Hafeez, M.; Lamers, J.P.A.; Tischbein, B. Remote sensing and hydrological measurement based irrigation performance assessments in the upper Amu Darya Delta, Central Asia. Phys. Chem. Earth 2013, 61–62, 52–62

Karimi, P., Bongani, B., Blatchford, M., and de Fraiture, C.: Global satellite-based ET products for the local level irrigation management: An application of irrigation performance assessment in the sugarbelt of Swaziland, Remote Sensing, 11, 705, 2019.

Pareeth, S.; Karimi, P.; Shafiei, M.; De Fraiture, C. Mapping agricultural landuse from time series of Landsat 8 using random forest based hierarchial approach. Remote Sens. 2019, 11, 601

Zwart, S.J.; Leclert, L.M.C. A remote sensing-based irrigation performance assessment: A case study of the Office du Niger in Mali. Irrig. Sci. 2010 , 28, 371–385

Additional info: link to Javascript code in Google Earth Engine (Mahuar scheme)

https://code.earthengine.google.com/927bc750b94015228e3ad3a3e6399b1f
https://code.earthengine.google.com/c25acace5ce958811d8d54d429cee6ee
https://code.earthengine.google.com/c97bb213621779ae9839e1d65e0fa26a
https://code.earthengine.google.com/cf839c2468519cb6070aefc0095777bc

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