Determination of Equity and Reliability in Water Allocation Using Delivery Performance Indicators and Validation Using Remote Sensing-Based NDVI Parameter: A Case Study of Mula Command Area In Ahmednagar District

Akshay Sunil and Ashwini. B. Mirajkar
Water Resource Engineering VNIT, Nagpur, India
**Corresponding author email id: akshaysunil172@gmail.com, ashmirajkar@gmail.com*

Abstract: Equitable allocation and distribution of water is a major concern because of the ever-increasing water demand and changing climatic conditions and therefore it is mandatory to check the delivery performance of water supply systems periodically to ensure the balance in demand-supply gap. The reliability in the delivery performance of the canals is checked by statistically analyzing the delivery performance ratio (DPR) and further validation of the results is done using remote sensing-based normalized difference vegetation index (NDVI) parameter. The total demand for water includes the demand for irrigation, domestic, industrial and urban purposes. The net irrigation requirement (NIR) has been calculated from the CROPWAT 8.0 model and has been used to calculate the irrigation demand. The total demand (Q_d) and the actual releases (Q_a) has been compared using the DPR values for 30 years from 1984 to 2014 in the study. The reliability in supply has been calculated for the Kharif and Rabi seasons for the flood, dry and normal years. Reliability check of the DPR values was done statistically using the temporal coefficient of variation (CV). The results show an inequity in water allocation with an overall reliability index of 38.5%. Remote sensing-based NDVI parameter was found out for selected months to validate the obtained results and the change detection in the cropland and agroforestry was observed. The months with a DPR value in the equity range, i.e. 0.7<DPR<1.2 showed a higher percentage of cropland and agroforestry in the NDVI maps and therefore NDVI analysis is a recommended method for checking equity in water delivery and allocation.

Keywords: Delivery Performance Ratio (DPR), equitable distribution, Mula reservoir, NDVI, Net irrigation requirement (NIR), reliability.

1. Introduction

The Ahmednagar district is the largest district in Maharashtra and occupies a total area of 17,413km^2. The district is drought-prone with a yearly average rainfall of 616mm (CLIMWAT data of the years 1975 to 2000 for the Ahmednagar station) and requires water for irrigation and domestic purposes. The Mula irrigation project is a major irrigation project in the district of Ahmednagar and has a capacity to supply water to irrigate an area of 80,800 ha, primarily through two main canals MLBC (Mula left bank canal) and MRBC (Mula right bank canal). The MLBC serves a total command area of 10,100 ha while the MRBC command area of 70,700 ha. In this study, equity and reliability of the canal releases into both the MLBC and MRBC has been studied and conclusions were drawn from it.

The delivery performance indicators were found for the years 2010-11 and 2011-12 from the discharges measured in the 11 head regulators of Jamrao canal command in the Mirpurkhas subdivision **(Mirajat et al. 2017)**. It was observed that the DPR values of the most favored canals were very high indicating an excess in the supply while the least favored canals had very low DPR values indicating a deficit in water supply. The equity in water distribution was checked for the water distribution of secondary canals in the Sind province of Pakistan **(Murray-Rust et al. 2000)**. The overall reliability index was 33% indicating an inequity in water supply. The reliability check of canal releases should be done periodically and equity in water allocation should be maintained in the command area for the optimal utilization of water.

Recently remote sensing-based parameters have been used to judge the equity in water allocation systems. The water delivery performance was assessed for selected Water User Associations (WUA's) in the Gediz basin using the NDVI values for the years 2004 and 2005 **(Akkuzu et al. 2007)**. The extent of variation in NDVI values for the years 2004 and 2005 was used to conclude the equity in water allocation. The water scarcity on land use patterns was delineated using MODIS images to identify the changes in rice crop area and to modify the current water distribution scenario **(Turral et al. 2008)**. The high spatial resolution Landsat images were used to assess the adequacy in water supply for irrigation purposes in the semi-arid Haouz plain, located in central Morocco **(Kharrou et al. 2013)**. **Latif and Tariq (2010)** used the Relative Water Supply (RWS) and the DPR values for assessing the performance of Maira Branch Canal in Pakistan. The high values of RWS were observed from October to December 2015 indicating over-irrigation and may lead to waterlogging and crop deterioration.

The allocation of water can be done effectively with a proper understanding of the actual irrigation, urban and industrial demands. The NIR was calculated for various crops in Iraq using CROPWAT8.0 software and was used to chart out the irrigation scheduling throughout the year **(Ewaid et al. 2019)**. The reference evapotranspiration ET_0 for different crops varied from 2.18 to 10.5 mm/day. The effective rainfall varied was from 0.0 to 23.1 mm throughout the year. It was concluded that CROPWAT 8.0 model is an effective tool in finding crop water demands and irrigation scheduling. Studies on irrigation efficiencies in the Savili and Mogtédo reservoirs in Burkina Faso were done to provide better solutions on cropping patterns for the rural farmers and to ensure the sustainability and improvement in irrigation infrastructure **(Kambou et al. 2019)**. The irrigation networks performed poorly with low values of water application efficiency and crop productivity.

The objective of the present study involves equity determination in water allocation using performance indicators and NDVI parameters. The DPR indicates the demand-supply gap and is an effective tool in determining the water allocation efficiency. The land use/land cover pattern has been studied after reclassification of the NDVI images for the selected years and the change detection analysis in cropland and agroforestry has been done for the validation of the DPR values.

2. Methodology

2.1 Study Area

The area selected for the present study is the Ahmednagar district, in the state of Maharashtra. The Mula reservoir is major irrigation in the Ahmednagar district and falls under the Upper Godavari sub-basin of the Godavari River basin in India.

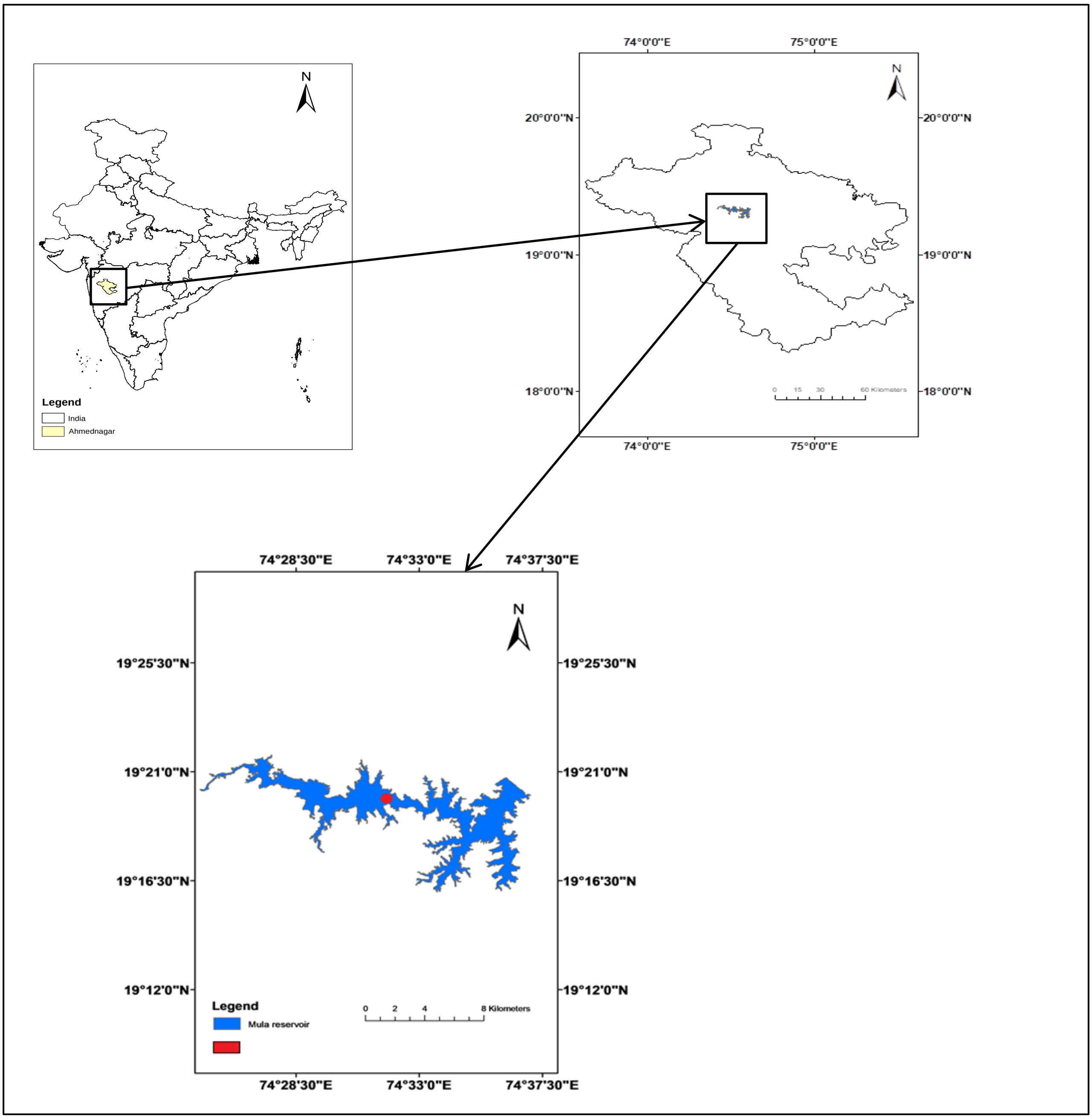


Figure 1. Location Map of Mula reservoir in Ahmednagar district.

The Ahmednagar district extends from 18.2 to 19.9-degree longitudes in its north to 73.9 to 75.5-degree latitudes in the east. The average values of minimum and maximum temperature in Ahmednagar are 22.1°C and 34°C respectively (CLIMWAT data of the years 1975 to 2000 of the Ahmednagar station). The primary left bank canal (LBC) and right bank canal (RBC) of the Mula extends downstream to the Aurangabad district from the district of Ahmednagar and is the source of irrigation requirement for the drought-prone eastern region district of Ahmednagar. The urban and industrial water requirement of the Ahmednagar district is also satisfied by the Mula reservoir. The location of the Mula reservoir in the Ahmednagar district is shown in Figure 1.

The total average cultural command area of Mula reservoir is 70,689 ha (Total irrigated area data for 15 years from 2001-2002 to 2017-2018, Mula Irrigation Division, Ahmednagar) and supply water for irrigation purposes in Rahuri, Newasa, Shevgaon and Pathardi taluka. The total storage capacity of the dam is 26 TMC. The major crops cultivated in the command area include Wheat, Pulses, Vegetable, Fodder, Groundnut, Maize, Millets, Cotton, Sunflower, Sorghum, Sugar cane, and Soya Bean. The total calculated yearly water demand, Q_d for the command area is 858.350 MCM. The scarcity in rainfall in the district in the dry years could be met only through proper planning and allocation of water during the wet periods.

2.2 Materials and methods

The climatic, soil and crop data were obtained from the CLIMWAT 2.0 software. The seven long-term monthly values of mean climatic parameters which include monthly average, maximum and minimum temperatures (°C), wind speed (km/h), mean relative humidity (%), average daily sunshine hours (h), average rainfall data (mm), and effective rainfall (mm) for various crops in the command area were obtained from the CLIMWAT 2.0 software and added to the CROPWAT 8.0 model. The crop data for the major crops were obtained from the 5th revised project report, volume 1, Godavari Marathwada irrigation development corporation, Aurangabad. The crop data including the root zone depth (mm), crop coefficient K_c, critical depletion, sowing and harvesting dates, and the yield response factor Ky were also added to the model in calculation of the NIR values. The soil parameters including total available soil moisture content, initial moisture depletion, and maximum rain infiltration rate were obtained from the FAOCROPWAT8.0 model. The monthly NIR (MCM) values were obtained from the CROPWAT model.

The reservoir inflow values, canal releases from the reservoir, monthly evapotranspiration, industrial and urban releases (all values are in MCM) were obtained from Command area development authority (CADA) office, Ahmednagar. The monthly Q_d values were found out taking the sum of the irrigation, urban and industrial demand for the particular month. The years from 1984 to 2014 were classified into flood/wet, normal and dry years based on the percentage dependable inflows. Gridded rainfall data from the Indian meteorology department (IMD), Pune has been used for the given study area. The actual releases into the primary canals were added to the effective rainfall values to get the total Q_a values. The existing cropping pattern (ha) for all the major crops in the Mula cultural command area (CCA) were obtained from the Mula irrigation division, Ahmednagar.

The value of DPR which is the ratio of the total water Q_a supplied to the total demand value Q_d was calculated from the collected data.

$$\text{DPR}=\frac{Q_a}{Q_d},$$

The DPR values falling in the range of 0.7 to 1.2 was considered to be in equity (*Design of Canals - revised design procedure GOVERNMENT OF MAHARASHTRA WATER RESOURCES DEPARTMENT Government Circular No. MIS-2015/ (CR. No.253/15)/MP*, 2015). The reliability index for each year was calculated taking the ratio of the number of months in which the DPR value is in equity to the total months in a year. The yearly DPR values were further analyzed by computing the percentage CV to determine the reliability of the DPR values. The CV is the ratio of the standard deviation to the mean of the yearly DPR values expressed in percentage.

The satellite images of Resourcesat 1 (IRS-P6/LISS III) having a spatial resolution of 23m was used for the NDVI analysis using the raster calculator tool using ArcGIS 10.2.2 software. The following equation was used for the NDVI analysis

$$\text{NDVI} = \frac{\text{NIR}-\text{RED}}{\text{NIR}+\text{RED}}$$

where RED is visible red reflectance, and NIR is near infrared reflectance. The NIR band, Red band, and Green band has a wavelength of 750-1300 nm, 600-700 nm, and 600-550 nm respectively. The NDVI images were identified and the areas were reclassified into 5 classes. The images were reclassified into water bodies, built-up areas, Fallow land agricultural land and cropland based on their NDVI values shown in Table 1. The NDVI value ranging from 0.2 to 0.4 was classified as cropland and the values ranging from 0.4 to 0.4429 as agroforestry. The least NDVI value obtained in the study area was -0.556 indicating deep water and the highest value was 0.4429 indicating agroforestry.

Table 1. NDVI value ranges for different features

Water bodies	-0.566 to -0.1
Build-ups /river sand	-0.1 to 0.05
Fallow/ Wasteland	0.05 to 0.2
Agricultural land/ Crop land	0.2 to 0.4
Agroforestry	0.4 to 0.4429

3. Results and Discussion

3.1 Monthly demand values obtained in MCM

The monthly NIR values of the crops were calculated and the monthly Q_d (MCM) values were obtained by adding the values with the industrial and urban demand. The NIR value of sugar cane was found to be the highest with a value of 1268.6 mm/year followed by wheat with a value of 801.1 mm/year from the CROPWAT model. The total monthly demands obtained are provided in Figure 2. The demand value obtained was the least in the month of February with a value of 35.401 MCM and the maximum demand to be satisfied was observed in the month of December with a value of 128.308 MCM.

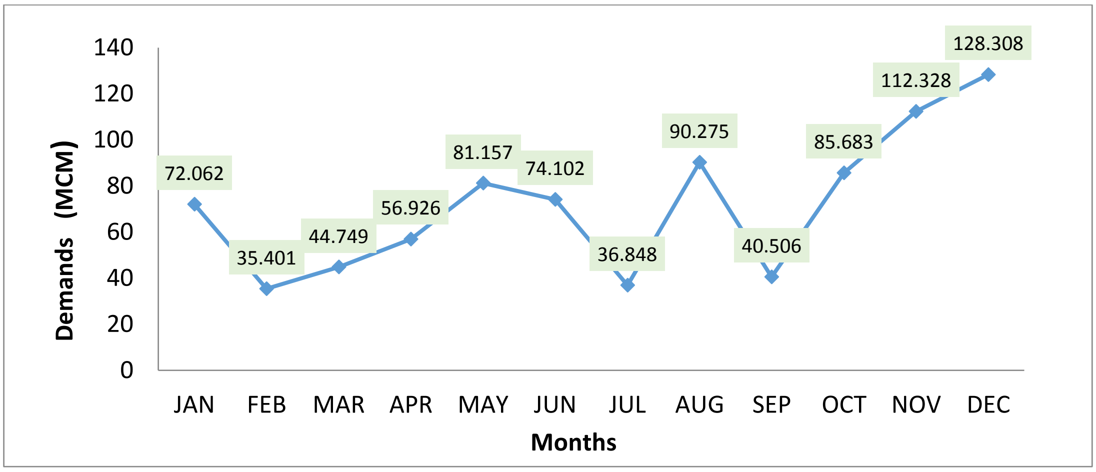


Figure 2. The monthly demands (MCM) to be satisfied by the canal releases in a year.

3.2 DPR values for the selected wet, dry and normal years

The DPR was calculated for a set of selected wet, normal and dry years and the reliability index was found out for each year. Figure 3 shows the DPR values falling in the reliable range, i.e. 0.7 to 1.2 and is indicated using dotted lines. The overall reliability for wet, normal and dry years was 52.08%, 28.33%, and 35.41% respectively. The reliability index during the Kharif season in a normal year was 25% and is observed to be low because the canal releases are not in accordance with the precipitation values. The reliability index in a Rabi season is found to be the least in a dry year with a value of 28.125% and is because of the scarcity in the water available for the supply. From figure 3, it is evident than the DPR values of February is very high and is exceeding the value 1.1 in most of the years. This indicates an excess in supply to the demand and leads to wastage of water. In the month of October, the DPR values obtained are very less indicating adequate water is not supplied to satisfy the demands. The average yearly CV of DPR for wet, normal and dry years is 0.668, 0.865 and 0.81 respectively. Higher values of CV are observed during the normal years indicating unreliable canal releases.

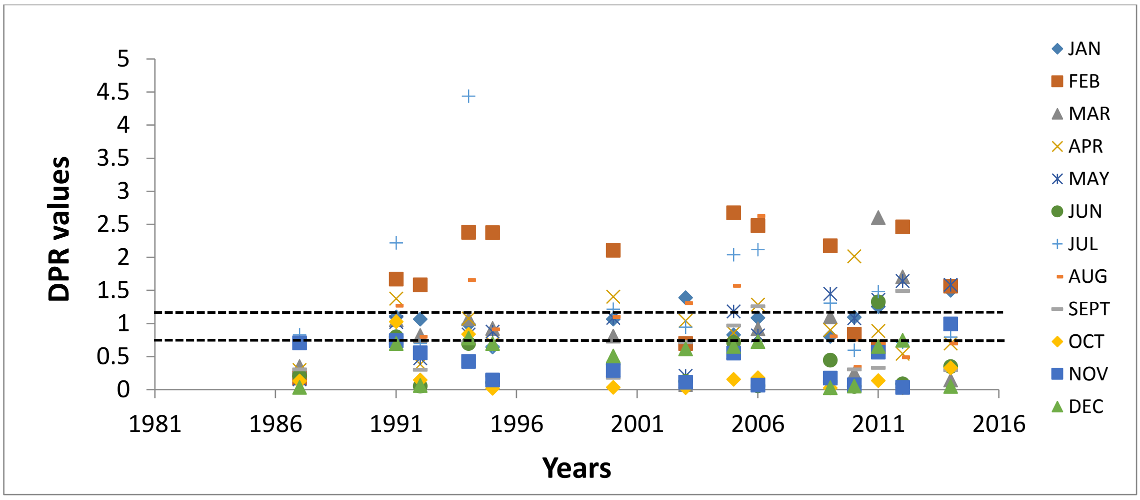


Figure 3. The DPR were calculated for a set of selected wet, normal and dry years

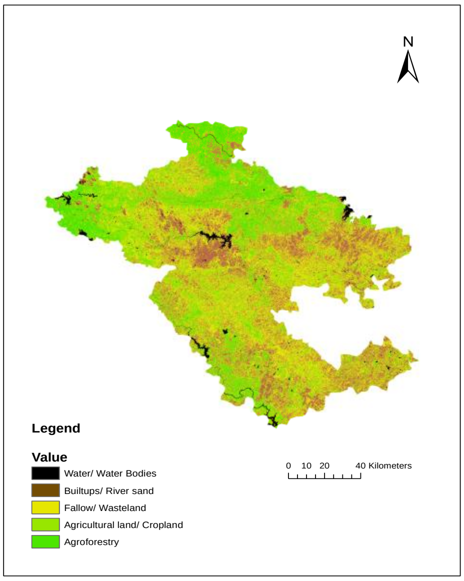
3.3 NDVI analysis and change detection in Cropland and Agroforestry

The NDVI values were used to determine the extent of vegetation cover in the study area. The reclassification was done for the proper understanding of how the area under vegetation changed with the change in DPR values. The percentage area obtained from the NDVI maps for a set of recent years (selected on the basis of availability of LISS III images) are provided in table 2. The increase in Cropland and Agroforestry was observed for months in which the DPR values were in equity.

Table 2. The DPR values and percentage area obtained from the NDVI maps for the 5 classes

Date	Type of year	DPR	Water bodies	Built-up area	Fallow land	Cropland	Agroforestry
28-Jul-14	normal	0.794	1.54	23.73	34.144	25.083	15.49
28-Sept-09	normal	0.119	1.541	24.926	38.429	20.128	14.976
02-Jul-11	flood	1.48	1.56	20.22	39.34	22.199	16.68
17-Feb-12	normal	2.45	1.535	24.001	38.16	21.3	15.004
28-Dec-11	flood	0.652	1.552	26.86	31.787	23.88	15.91

The percentage area of Cropland and Agroforestry was observed to be the least on the date of 28 September 2009 with a value of 20.128% and 14.976% indicating the supply was in inequity with the demand. The DPR value in the month of September for the year 2009 was 0.119 which is very less and hence the percentage area of cropland showed a considerable decrease compared to the remaining years. The DPR value for the month of February in the year 2012 is very high with a value of 2.45 which indicates an excess supply of water. The percentage area of cropland and Agroforestry on the date 17 February 2012 was found out to be less with values of 21.3% and 15.004% respectively. The results indicate that a high DPR value indicating excess supply to the demand also results in poor crop production and is not suitable for crop growth. The value of Agroforestry showed and increasing trend in flood years due to excess rainfall. The percentage area of the cropland was found to be the maximum in the date of 28 July 2014. The DPR value obtained for July 2014 was 0.794 and is in the equity range. The NDVI maps for the selected years are provided in figure 4,5,6,7 and 8 respectively.



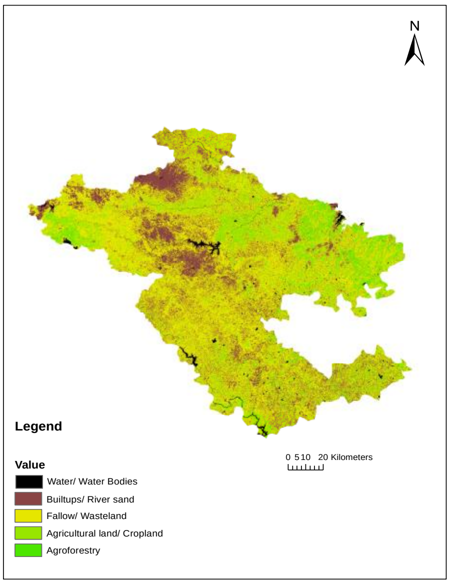
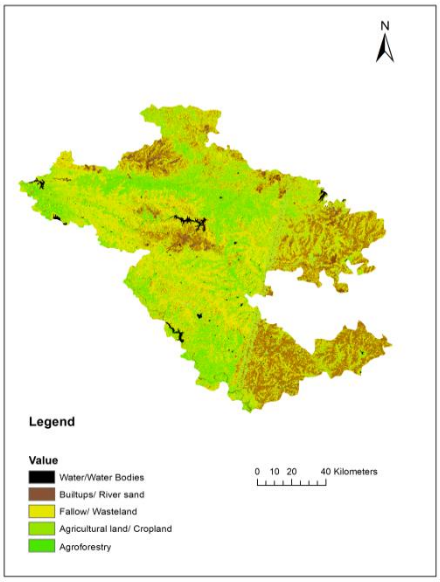


Figure 4. NDVI map of 28-Oct-2014

Figure 5. NDVI map of 28-Aug-2009



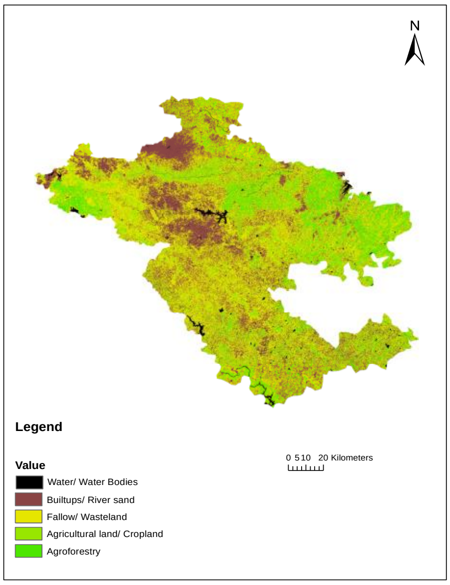


Figure 6. NDVI map of 02-Jul-2011

Figure 7. NDVI map of 17-Feb-2012

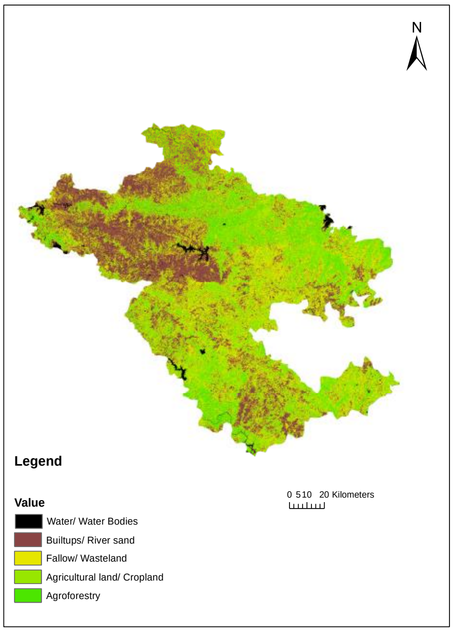


Figure 8. NDVI map of 28-Dec-2011

4. Conclusion

The DPR value is a good indicator in determining the water allocation efficiency of canal systems. The canal releases should be done in such a way that the DPR values are in equity range and the CV of the DPR values are kept less. The rainfall extent and intensity should be considered when the supply of water is done during the Kharif season, especially during the wet and normal years. The water supply efficiency during the Rabi season in a dry year is very low because of the scarcity in available water, and this could be overcome only through proper allocation of water during the wet seasons thereby preventing excess supply when the demand is less. The irrigation, urban and industrial demand values should be periodically checked and updated to ensure equity in the canal releases. Remote sensing vegetative indices are also good parameters in checking the efficiency of the water delivery network. A comparative study of the statistical and remotely sensed parameters should be done and suitable rotation policies should be adopted in order to ensure a reliable water supply system.

References

Akkuzu, E., and Unal, H. B. (2007). Determination of Adequacy and Equity of Water Delivery in Irrigation Systems : A Case Study of the Gediz Basin. https://doi.org/10.3923/jas.2007.607.611

Design of Canals - revised design procedure GOVERNMENT OF MAHARASHTRA WATER RESOURCES DEPARTMENT Government Circular No. MIS-2015/(CR. No.253/15)/MP. (2015).

Gaur1 A; Biggs T., Gumma M., Parthasaradhi G., and Turral H. (2008). Water Scarcity Effects on Equitable Water Distribution and Land Use in a Major Water Scarcity Effects on Equitable Water Distribution and Land Use in a Major Irrigation Project — Case Study in India. 9437. https://doi.org/10.1061/(ASCE)0733-9437(2008)134

Hussein Ewaid Salam., Ali, A. S., and Al-Ansari Nadhir. (2019). Crop water requirements and irrigation schedules for some major crops in southern Iraq. Water (Switzerland), 11(4). https://doi.org/10.3390/w11040756

Javiad, M. L. (2010). Improving Operational Performance and Management of Canal Irrigation System Using Hydraulic Modeling Improving Operational Performance and Management of Canal Irrigation System.

Kadam, U. S. (2015). Performance Assessment of Heterogeneous Irrigation Schemes in India By U . S . Kadam Doctoral Thesis Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University.

Kambou, D., Degre, A., Xanthoulis, D., Ouattara, K., Destain, J. P., Defoy, S., and De L’Escaille, D. (2019). Evaluation and Proposals for Improving Irrigation Performance Around Small Reservoirs in Burkina Faso. Journal of Irrigation and Drainage Engineering, 145(6). https://doi.org/10.1061/(ASCE)IR.1943-4774.0001386.

Kharrou, M. H., Le Page, M., Chehbouni, A., Simonneaux, V., Er-Raki, S., Jarlan, L., and Chehbouni, G. (2013). Assessment of Equity and Adequacy of Water Delivery in Irrigation Systems Using Remote Sensing-Based Indicators in Semi-Arid Region, Morocco. Water Resources Management, 27(13), 4697–4714. https://doi.org/10.1007/s11269-013-0438-5.

Mirajat, M. U., Talpur., M. A., Mangrio, M. A., Tagar, A. A., Junejo, S. A., and Shaikh, I. A. (2017). Water Delivery Performance of A Secondary Canals in terms of Equity and Reliability in Sindh Pakistan. Sindh University Research Journal -Science Series, 49(003), 563--570. https://doi.org/10.26692/surj/2017.09.17.

Murray-Rust., H., B. K. Lashari., and Y. Memon. (2000) Water distribution equity in Sindh Province, Pakistan: International Water Management Institute (IWMI).