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Creation of Geospatial Database and Estimation of Irrigation Water Requirement of a Canal Command in Gayathri Irrigation Project, Kerala

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The water requirement of crops in the canal command of distributaries of Gayathri Irrigation Project in Palakkad district, Kerala was estimated using GIS and CROPWAT 8 model. The geospatial data base for canal network, land use, soil and climate were prepared using Geographic Information System (GIS) tools. This data base was used as input to CROPWAT model to estimate irrigation water requirement of different distributaries of the canal command. The gross irrigation requirement was estimated for the historical climate data (2004-2018) as well as the predicted climate data for the years 2026 and 2031. The net irrigation water requirement of different crops in the distributary command was found to vary spatially depending on soil, crop and climate. The net irrigation water requirement of paddy (*mundakan*) in distributaries located at head to tail reaches varied from

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1004.5 to 1573.6 mm. The high value of net irrigation requirement in tail reach was due to the influence of soil series with high infiltration rate compared to head reach soil. The net irrigation requirement also varied for the same crop in same soil series in different distributaries depending upon the climatic conditions. The net irrigation water requirement of paddy (*mundakan*) in distributaries located at head to middle reaches for the same soil series varied from 1056.5 to 1004.5 mm due to the influence of variations in rainfall. The gross estimated irrigation water requirement showed that distributaries at the middle and tail reaches required more water than the distributaries at the head end. The maximum gross irrigation water requirement of 25369.7 m^3/ha was observed for Peringhotukavu distributary in tail reach and lowest of 4390.9 m^3/ha for Parakkalchalla distributary in head reach. The estimation of irrigation requirement for projected climate data also showed the same trend as that of historical data.

Keywords: GIS; CROPWAT8; irrigation; crop evapotranspiration; delivery schedule; India.

1. INTRODUCTION

The current population of India is 1.40 billion and is expected to increase to 1.45 billion by 2028 [1]. The food demand is also expected to increase to 400 million tonnes in 2050 [2]. Irrigation is one of the main inputs required for the sustainable agricultural production. In India, 49.21 per cent of total net sown area is only under irrigation [3].

The utmost importance is required for the increase in productivity of land and water to meet this challenge. This can be achieved by the efficient planning and management of land and water resources. An efficient water management system requires optimum use of available water by supply it to the crop at right time, right place and right quantity. Therefore climate, land use and soil-based planning of irrigation water and its supply is very much essential [4]. The reliable and accurate data from small to large scale is essential for the proper planning and management of water resources. At the same time, the data is complex, and spatial- temporal in nature. The efficient water management is possible only by accurate estimation of spatially varied water demand [5]. The estimation of regional scale irrigation water requirement is critical because of change in agricultural production and water resources are significantly affected by climate change of the region [6]. Hence the challenge faced by irrigated agriculture is to utilise the limited water resources more sustainably by giving importance to variability in soil, crop, and climate spatially. Hence, the use of Geographic Information System (GIS) in irrigation water management is an effective tool to handle the complex, spatially and temporally varied data with accuracy and reliability.

Most of the canal command area in India is supplied with insufficient water and its reliability is also very less [7]. There exists a wide gap between the water demand and supply in canal command areas. This problem mainly exists due to less attention for water resource, mismatching of canal water releases with rainfall, water requirements of different crops and change in the cropping pattern. The current canal water-release policies in India are supply-based and not meet the water requirement of the existing cropping pattern [8]. Distributary is the last point of control of an irrigation canal network system. Hence the distributary level water demand estimation is more important for efficient planning and management of irrigation water into the field. It is very difficult to get quick, systematic and realistic estimates of the spatially varied irrigation demand in the distributaries manually. The estimation of distributary level irrigation demand, before beginning of each irrigation cycle helps the irrigation managers for proper scheduling of irrigation and operation of distributaries. Hence the present study using GIS and CROPWAT 8.0 model was aimed to create a geospatial data base of the command area for easy and quick estimation of the spatially varied irrigation demand of different distributaries. Further, future irrigation demand was estimated based on the data from climate prediction models and are integrated with information on crop and soil in CROPWAT in a GIS environment.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in the canal command area of Gayathri irrigation project (GIP) which is one of the medium irrigation projects in Palakkad district of Kerala coming under the Agro Ecological unit 23 (AEU-23). The location of the area is 10^o 35' 53.75'' N and 76^o 43' 44.03'' E. Meenkara (phase I) and Chulliyar (phase II) are the two reservoirs coming under this project in *Gayathripuzha*, which is one of the tributaries of *Bharathapuzha.* The canal network system consists of 19 distributaries, in which 10 in left bank canal system (LBC) and 9 in right bank canal system (RBC). The average annual rainfall of the study area was 1500 to 2000mm. The textural classes of soil in the study area were dominated by sandy clay loam and sandy loam [9]. The location map of the study area of Gayathri irrigation project canal command is represented in Fig. 1.

2.2 Data

The different distributaries with their identification number, name and other details are shown in Table 1.

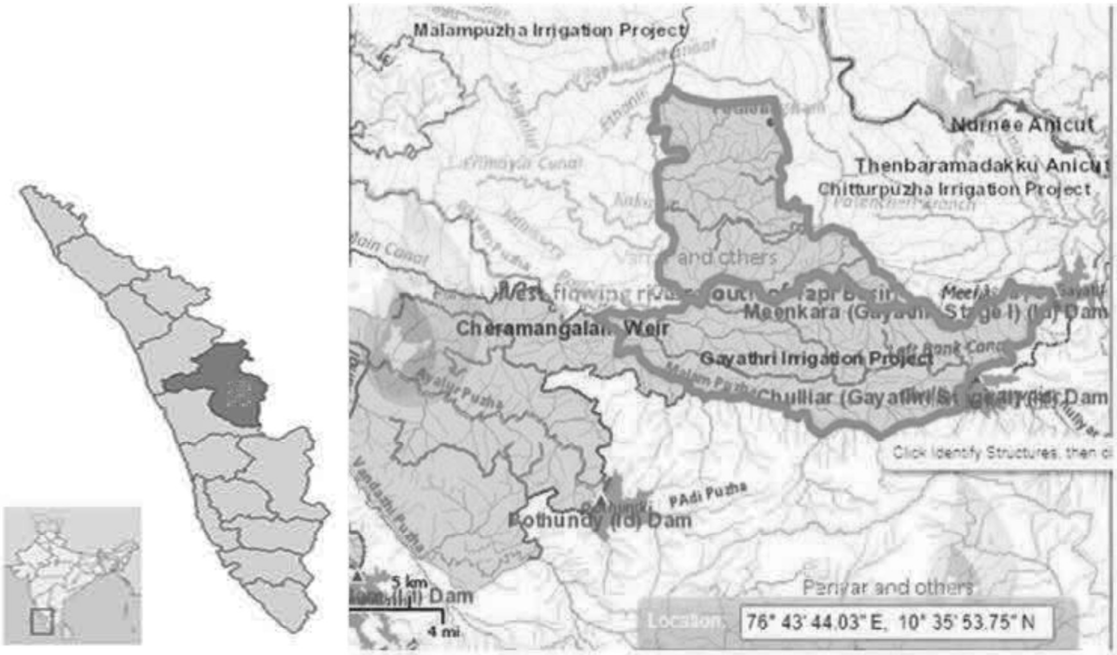

Fig. 1. Location map of Gayathri irrigation project canal command area

Table 1. Distributary details of Gayathri irrigation project

Distributary ID Number	Distributary Name	Gross command area (ha)	LBC/RBC	Reach
DB1	Parakkalchalla	95.02	LBC	Head
DB2	Pappanchalla	84.17	LBC	Head
DB3	Kambrathchalla	183.85	LBC	Middle
DB4	Pothenpadam	137.30	LBC	Middle
DB5	Kallukettychalla	97.64	RBC	Head
DB6	Poonthonichalla	75.93	RBC	Head
DB7	Ootara	198.94	RBC	Middle
DB8	Vadavannur	118.87	RBC	Middle
DB9	Pallasana	377.20	RBC	Middle
DB10	Karipode	254.16	RBC	Middle
DB11	Pudunagram	202.55	RBC	Middle
DB12	Peruvemb	66.28	RBC	Tail
DB13	Koduvayur	105.20	RBC	Tail
DB14	Peringottukavu	82.15	LBC	Tail
DB15	Payyalore	202.40	LBC	Middle
DB16	Nandankizhaya	279.60	LBC	Middle
DB17	Kizhekkaethara	254.10	LBC	Middle
DB18	Karimkulam	145.88	LBC	Middle
DB19	Kollengode	702.30	LBC	Middle

The data related to soil, crop, climate and canal network were collected from various line departments. Type of data used, their source and utility in this study is shown in Table 2. The important software and tools used are shown in Table 3.

2.3 Methodology

2.3.1 Creation of geo-spatial data base

The database consists of five types of maps and were created in ArcGIS platform. They were canal network map, land use map, soil map, land use-soil intersect map and climatic map of GIP canal command area. The canal network map of the GIP was prepared from Bharathapuzha river basin map. The land use map was prepared from Bharathapuzha basin land use map. Soil map was prepared from the data obtained from Directorate of Soil Survey and Soil Conservation, Kerala. The spatial maps of command area, land use, soil and land use- soil intersect were also prepared for the distributary command.

The historical climate data (HD) of maximum and minimum temperature, humidity, wind velocity, sunshine hours from station points Palakkad and Pattambi were used for the study. The historical climate data of rainfall from station points Meenkara, Chulliyar, Kollengode, Alathur and Chittur were used for the study. The inverse distance weighted average method was used for the data interpolation and creation of spatial map of the various climatological parameters for the command area of GIP. The predicted data (PD) of rainfall, maximum and minimum temperatures for the command area was collected from CMIP5 climate model for RCP4.5 scenario for the years 2026 (PD1) and 2031 (PD2).

2.3.2 Calculation of crop coverage

The land use-soil intersect maps were used for calculating the area under different crops in each distributary command of GIP.

2.3.3 Description of FAO CROPWAT 8.0 model

The model is a computer-based decision support system to estimate crop-based irrigation requirement. The different modules like climate, rainfall, crop and soil were the main input used in this model. The model details are available in FAO publications Irrigation and Drainage series No.56. The weighted average values of maximum temperature, minimum temperature, relative humidity, wind velocity, sunshine hours for months January to December estimated by IDW (Inverse Distance Weighted method) in GIS. These Arc Maps were used as input to Climate/ETo module. Similarly, IDW weighted average monthly values of rainfall was used to find the rainfall for the respective months in distributary command and used as an input to the rainfall module. The various crop data used in the crop module are planting date, crop coefficient values (Kc), growth stage in days, rooting depth, critical depletion factor, yield response factor, crop height etc. In addition, paddy requires data on puddling depth, nursery area, Kc values of rice (dry/wet) condition and number of days required for land preparation. The crop data of various crops in the command area of distributary viz. paddy (*mundakan*), paddy (*virippu*), coconut, mango, vegetables, banana and arecanut were entered in this module. The soil series were identified from generated soil map of command area. The texture of the soil series was obtained from Directorate of Soil Survey and Soil Conservation, Kerala. The soil properties like saturated hydraulic conductivity, field capacity, wilting point for different soil series were estimated using SPAW (Soil Plant Atmosphere Water) model developed by United States Department of Agriculture (USDA) - Agricultural Research Service (ARS). Total available soil moisture and maximum infiltration rate were used as soil data input to the soil module of CROPWAT. This data was estimated using the output values of filed capacity, wilting point and saturated hydraulic conductivity obtained from SPAW model.

2.3.4 Estimation of ETo

The CROPWAT8 software, estimated the reference crop evapotranspiration (ETo) using Penman-Monteith equation. The values were calculated on monthly basis.

2.3.5 Estimation of crop water requirement (ETc)

ETc was calculated using the formula, $ETc = Kc \times ETo$ (Eq. 2.1)

where, Kc is the crop coefficient. This estimation was done crop growth stage wise and total ETc for the entire growing period of the crop was then computedin decadal basis (10- day interval).

Table 2. Type of data, their source and utility

Data	Source	Utility
Canal network map	Kerala state land use board	Creation of geospatial database
Land use/land cover map	Kerala state land use board	Creation of geospatial database
Soil map	Directorate of Soil Survey and Soil Conservation, Govt. of Kerala	Creation of geospatial database
Climatological data- Historical data 2004-2018 (Maximum and minimum temperature, humidity, wind velocity, sunshine hours and rainfall)	Indian Meteorological Dept., Pune. Regional Agricultural research Station, Pattambi, Kerala Agricultural University. Water resource Dept., Govt. of Kerala.	Input to CROPWAT 8.0 Model
Climatological data- Predicted data for the years 2026 and 2031 (Maximum & minimum temperature and rainfall)	CMIP 5 Climate model, CCCR-IITM, Pune.	Input to CROPWAT 8.0 Model

Table 3. Software and models used in the study

Software/Model	Source	Use
ArcGIS 10.3.1	ESRI	Creation of geospatial database
SPAW	USDA & ARS	Estimation of soil properties for creation of geospatial database
CROPWAT 8.0	FAO	Estimation of ETo, ETc, effective rainfall and irrigation water requirement
CMIP5 Climate model	CCCR-IITM	Predicted data of the years 2026 and 2031 for future climate scenario RCP4.5

2.3.6 Estimation of effective rainfall

The United States Department of Agriculture (USDA)- Soil Conservation Service method available in the CROPWAT 8 model, was used to calculate the effective rainfall and is estimated on monthly basis.

2.3.7 Estimation of irrigation requirement

The CROPWAT 8 model calculate the daily water balance of the root zone considering the root zone depletion at the i^{th} day's end by considering the water content in the root zone of previous day, precipitation, surface soil runoff, net irrigation depth, capillary rise from the groundwater table, crop evapotranspiration and deep percolation of the i^{th} day Hence, ETc was estimated by water balance using CROPWAT 8.

2.3.8 Net irrigation water requirement of crops (NIWR)

Net irrigation water requirement of field crops (mm) was computed by deducting the effective rainfall from the crop evapotranspiration

Irrigation requirement = ETc - Peff (Eq. 2.2)

The net irrigation water requirement, in case of paddy is more than that of other crops because it requires operational requirement of water for nursery raising and land preparation. Hence calculation is required for the amount of water needed to saturate the soil for land preparation by puddling, percolation and seepage losses and amount of water needed to establish a water layer.

Irrigation requirement of paddy = ETc + SAT + PERC + WL – Peff (Eq. 2.3)

Where,
SAT- amount of water needed to saturate the soil for land preparation by puddling (mm),
PERC- amount of percolation and seepage losses (mm)
WL- amount of water needed to establish a water layer (mm)
Peff- effective rainfall (mm)

The net irrigation requirement of each crop in different soil series in each distributary are different. Hence the net irrigation requirement of major crops paddy (*mundakan*), paddy (*virippu*), coconut, mango, vegetables and banana were estimated separately for different soil series in the distributary command. The calculation was done on decadal basis (10-day interval) both for historical data (HD) and predicted data (PD). The total annual NIWR of crops in the distributary command on volume basis was found by multiplying net irrigation requirement of crops (mm) by the area under the respective crops. The total net irrigation water requirement of a distributary command was calculated as the sum of the net irrigation water requirements of all crops in that distributary command.

2.3.9 Estimation of gross irrigation water requirement (GIWR)

The estimation of GIWR involves the use of land use map in conjunction with soil, crop and climate data. Water losses from the distributary canal due to seepage was estimated by measuring the velocity of flow, depth, top and bottom width of the channel. The evaporation loss was considered negligible in all these distributaries.

Thus, GIWR is obtained using the equations as follows.

$$GIWR = NIWR + SI \qquad \text{(Eq. 2.4)}$$

where,

NIWR- Net Irrigation Water Requirement (m^3/ha)

SI- Seepage loss ($m^3/m^2/day$)

The overall methodology used in this study for the estimation of gross irrigation requirement is shown in Fig. 2.

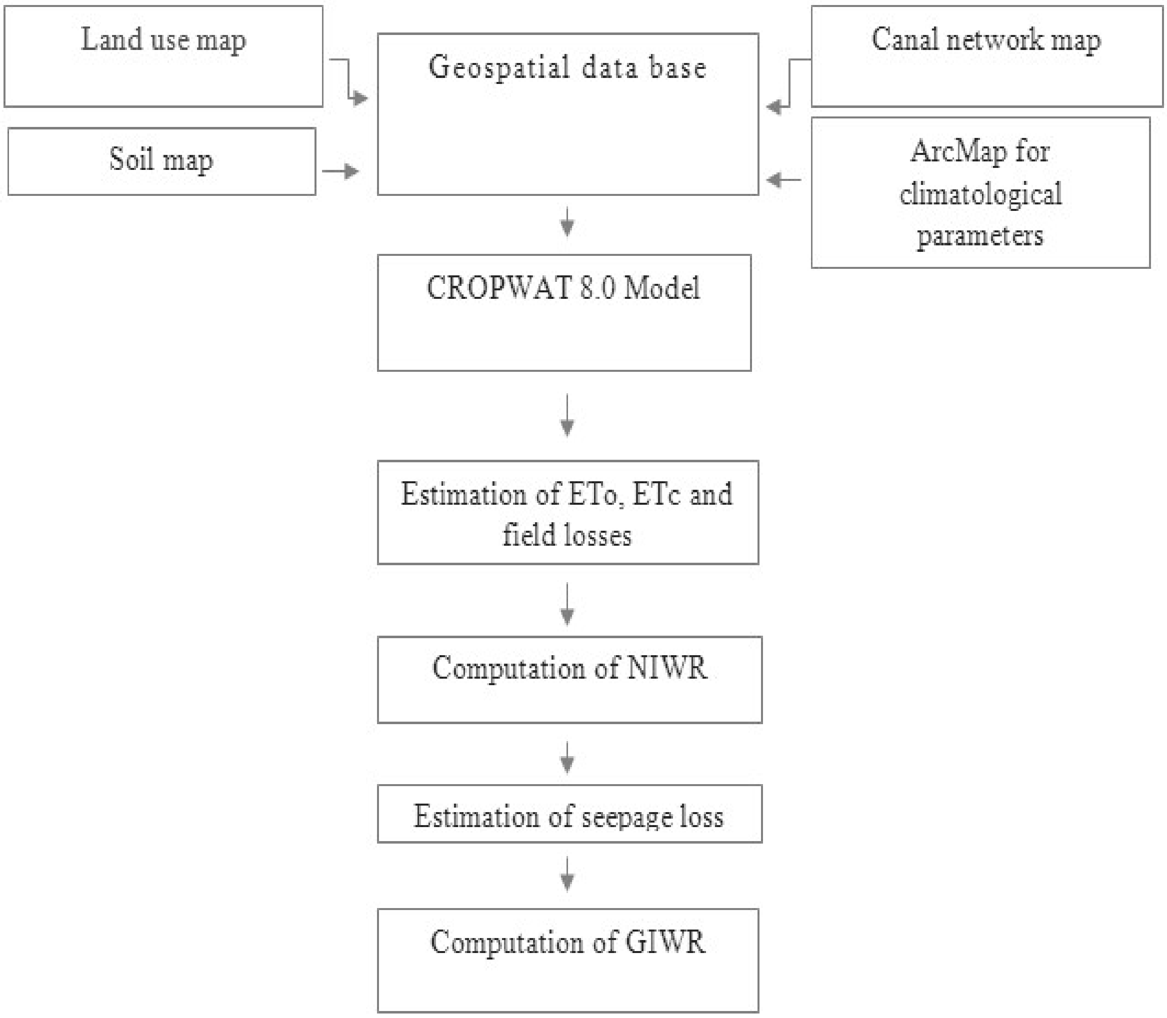

Fig. 2. Flow chart of the overall methodology

3. RESULTS AND DISCUSSION

3.1 Creation of Geo-spatial Maps

The various spatial maps viz. canal network map, land use map and soil map of GIP created in GIS is shown in Fig. 3, Fig. 4 and Fig. 5 respectively. The canal network map shows Meenkara and Chulliyar reservoirs and left and right bank canal system with their distributaries. The land use map showed the major crops of the command area includes paddy as the main crop followed by coconut, mango, mixed crops, vegetables, banana and arecanut. The major soil series identified from soil map were Bhavni Nagar, Mungilmada, Karinganthodu, Tolanur, Vadavannur and Kozhinjampara. The Bhavani Nagar series covers an area of 41.18 km^2 constituting 30.99 per cent of the command area. This soil series was mainly seen in the eastern part to the central portion of the command area. The soil series Karinganthodu (28.56 per cent) and Tolanur (11.62 per cent) were found in the central to western part of the command area. These soils are sandy clay and sandy clay loam in texture. The distributary command area map was prepared to identify the command area of distributaries and is shown in Fig. 6. The land use, soil and land use-soil intersect maps were also prepared for the distributary command. The interpolated arc maps were prepared using Inverse Distance weighted (IDW) method for maximum, minimum temperature, humidity, wind velocity, sunshine and rainfall for the months from January to December.

3.2 Crop Coverage in Distributary Command

The acreage of different crops in the distributary command was obtained from land use soil-intersect map which showed that DB19 (Kollengode distributary) has the highest irrigable area followed by DB9 (Pallasana distributary) with 554.837 and 309.762 ha respectively. The lowest was found in DB1(Parakkalchalla distributary) with 15.089 ha.

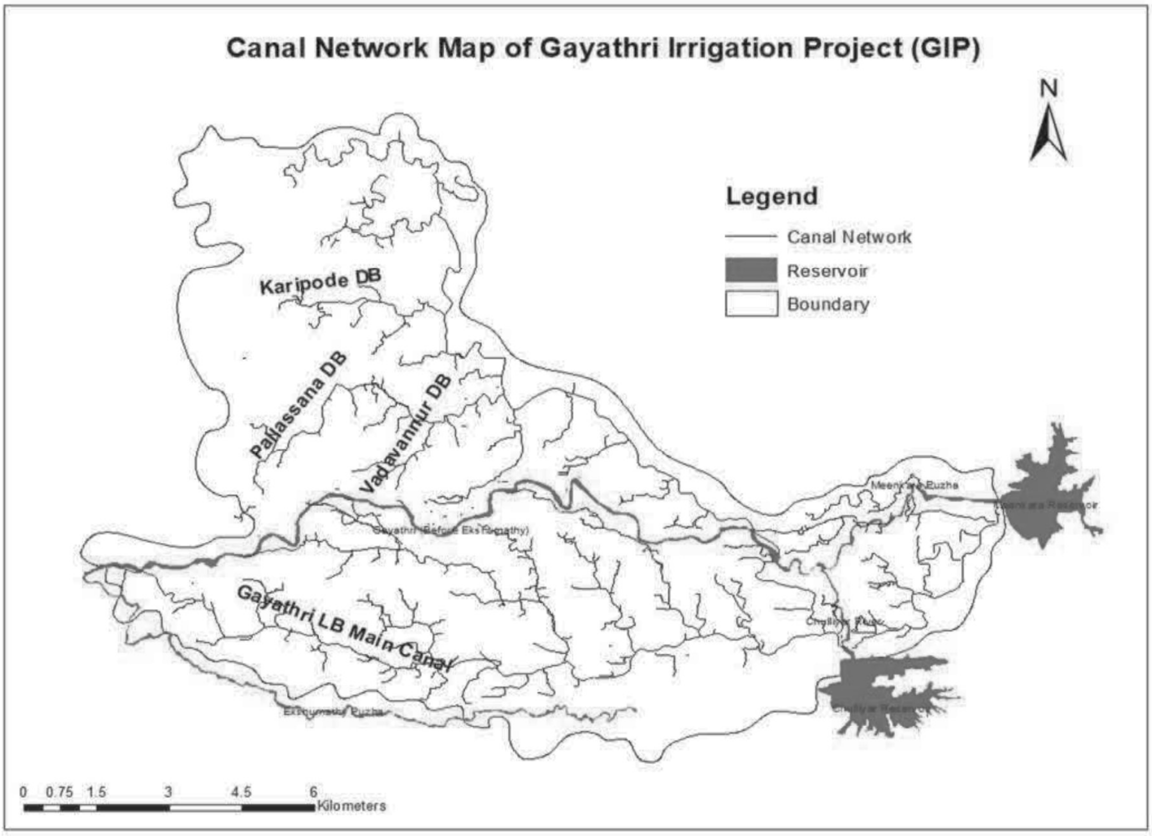

Fig. 3. Canal network map of Gayathri irrigation Project

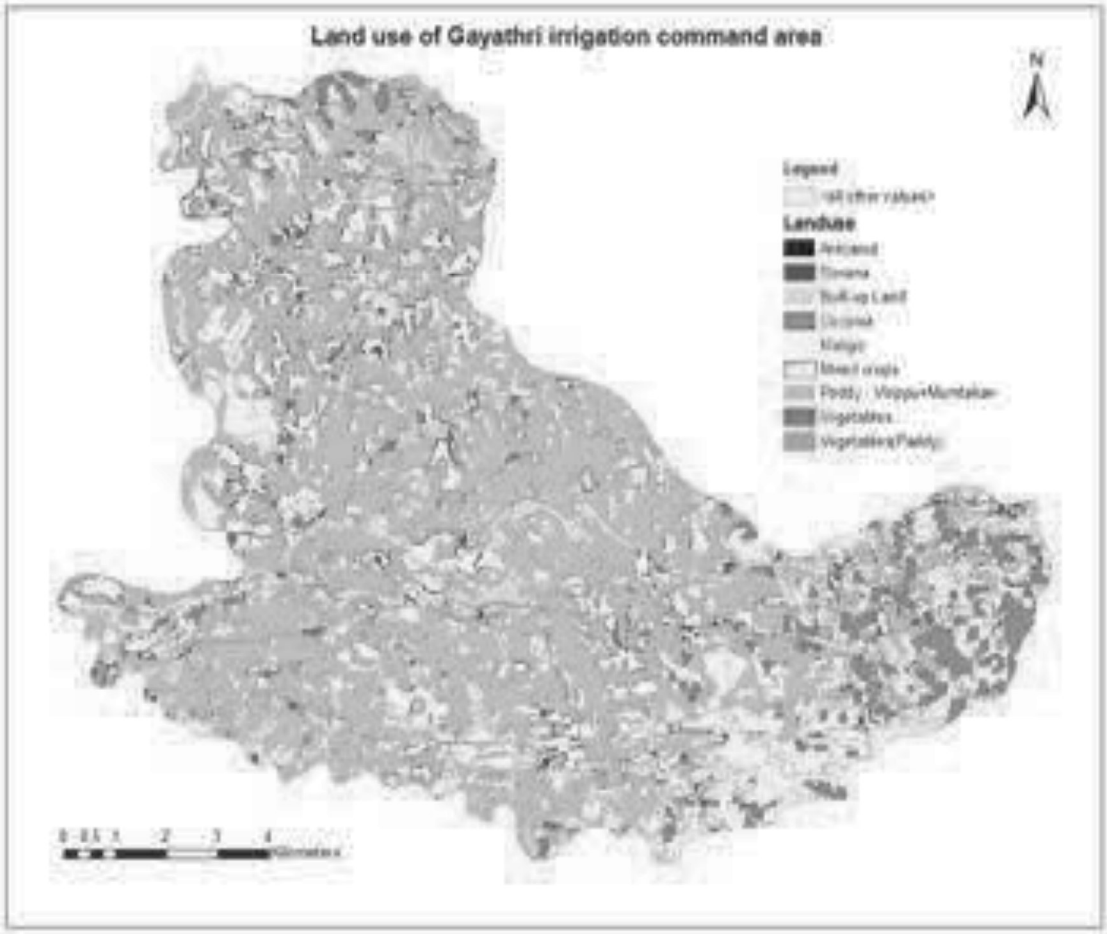

Fig. 4. Land use map of Gayathri irrigation command area

3.3 Reference Crop Evapotranspiration (ETo)

The reference crop evapotranspiration was computed by CROPWAT 8.0 model on monthly basis and its variation is shown in Fig. 7. The average ETo value were varied from 5.45 to 2.97 mm/day. The ETo values were found high during January to March and low during July. The high temperature, sunshine hours and wind velocity might have influenced the ETo values from January to March. The solar radiation values were found high during January to March and temperature values were also found high during January to May. This might be the reason for the high ETo in these months. This was found in close agreement with the studies of Trivedi *et al*., [10], which reported that ETo values increased with increase in temperature and decreased with decrease in temperature. The study by Gangwar et al. [11] also found that rate of ETo was directly proportional to solar radiation and among the various climatic factors, solar radiation and temperature are the most important factors affecting ETo. Hence the variation in ETo had a profound influence on irrigation demand of crops in the study area. This was in close agreement with the findings of Surendran *et al*. [12] which showed that ETo was lowest during the peak of the rainy season and highest during the peak of dry season. ETo was mainly depend on temporal changes in climatic factors. The ETo values were used for finding the net irrigation water requirement of crops in the distributary command.

3.4 Crop Water Requirement (ETc)

The crop water requirement was computed for all crops in the distributary command. The computed crop water requirement (ETc) values showed variations with crop coefficient (Kc) and ETo values. The crop coefficient values (Kc) was high during the initial stages of crop growth and ETo was mainly depend on temporal changes in climatic factors. The ETc values were required for finding the net irrigation water requirement of crops in the distributary command.

3.5 Net Irrigation Requirement (NIWR) of Crops in a Distributary Command

The net irrigation requirement of seasonal crop paddy and perennial crops viz. coconut, mango, banana, vegetables and arecanut were computed based on the crop growth period and spatial variations in climate and soil. NIWR of paddy (*mundakan*) in the command area of DB6 (Poothonychalla distributary), DB9 (Pallasana distributary) and DB13 (Koduvayur distributary) are shown in Fig. 8, Fig. 9 and Fig. 10. respectively. These distributaries were located at head, middle and tail reach of canal irrigation system. This indicated the variations in irrigation requirement depending on soil, crop and climate conditions. The NIWR of paddy (*mundakan*) varied from1004.5 to 1576.3 mm from the head end to tail reaches. The high value of 1576.3 mm of NIWR in DB 13 (Koduvayur distributary) was found in tail reach due to soil the series Karinganthode having high infiltration rate compared to Bhavani Nagar series which is the prominent soil series in head reach. Karinganthodu was the major soil series in tail reach of distributary command. The rainfall also observed low in the distributaries of tail reach. The low NIWR of 1056.5 and 1004.5 mm in head end and middle reach respectively was due to the soil series Bhavani Nagar which has low infiltration rate. The Bhavani Nagar series at distributary DB6 (1056.5mm), distributary DB 9 (1004.5 mm) showed variation at head and middle reaches respectively. This was mainly attributed to the variations in rainfall. The NIWR of other crops were also calculated and showed the same trend. A sample calculation for DB 9 (Pallasana distributary) for all crops in Karinganthodu series is shown in Table 4. These values of NIWR were in close agreement with the findings of Surendran et al. [12]. Similarly, the net irrigation water requirement of all crops in each distributary command was computed on decadal basis (10-day interval) for historical data as well as for predicted data.

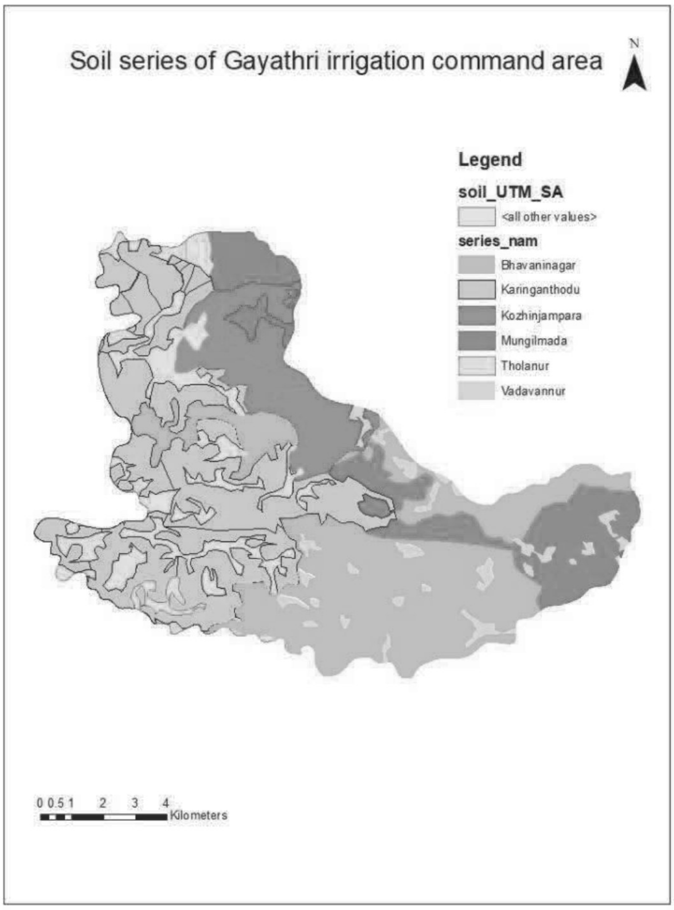

Fig. 5. Soil map of Gayathri irrigation command area

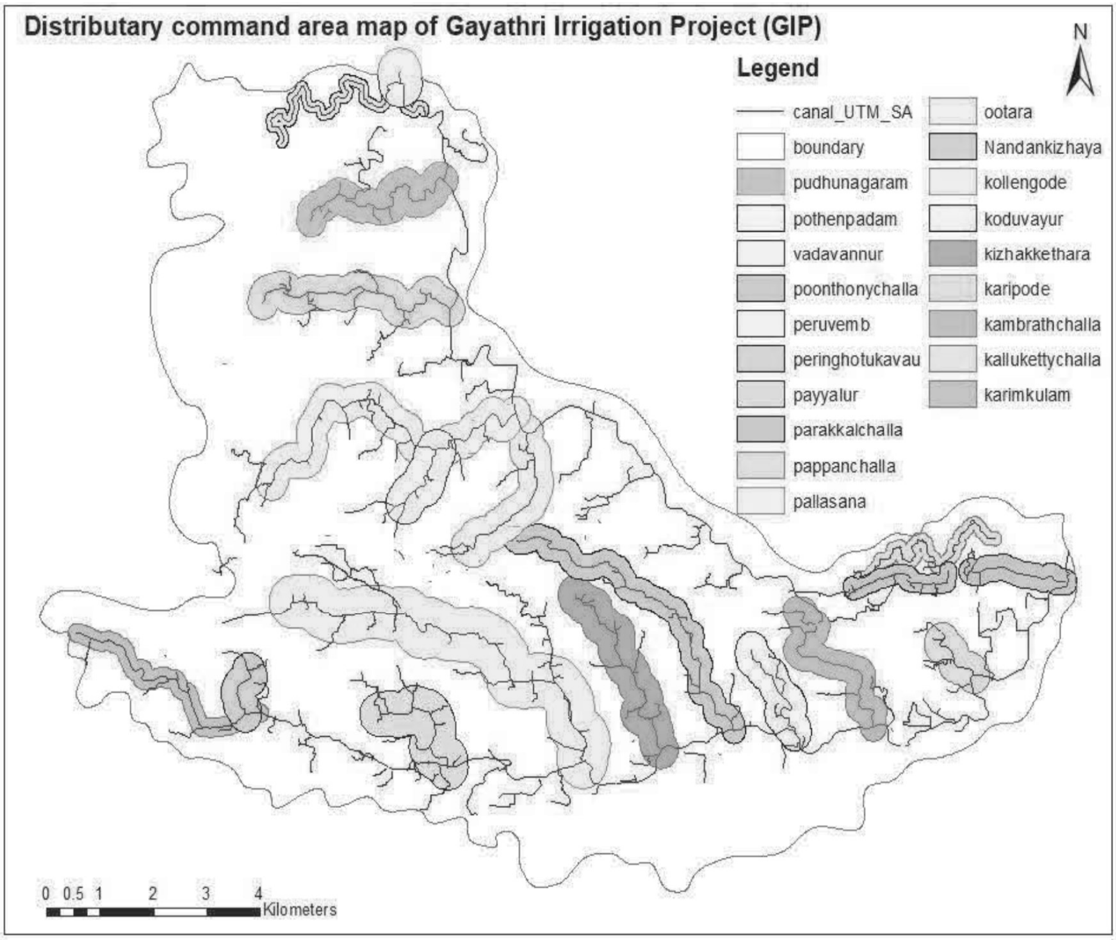

Fig. 6. Distributary command area map of Gayathri irrigation project

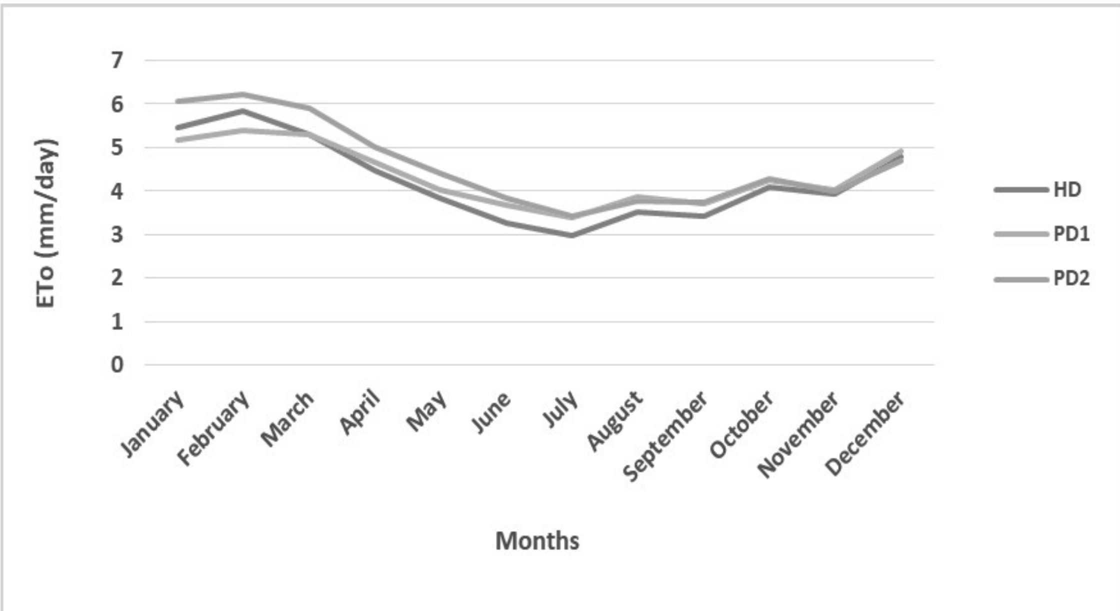

Fig. 7. Average monthly variation of ETo in the command area

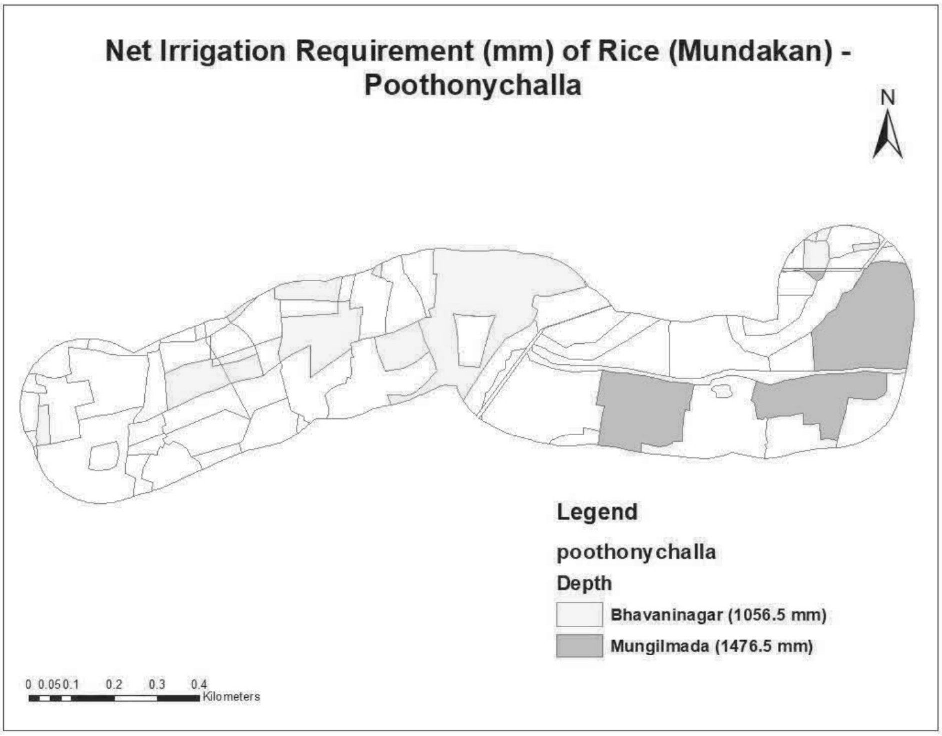

Fig. 8. Net irrigation water requirement (mm) of Rice (*mundakan*)- Poothonychalla distributary with different soil series

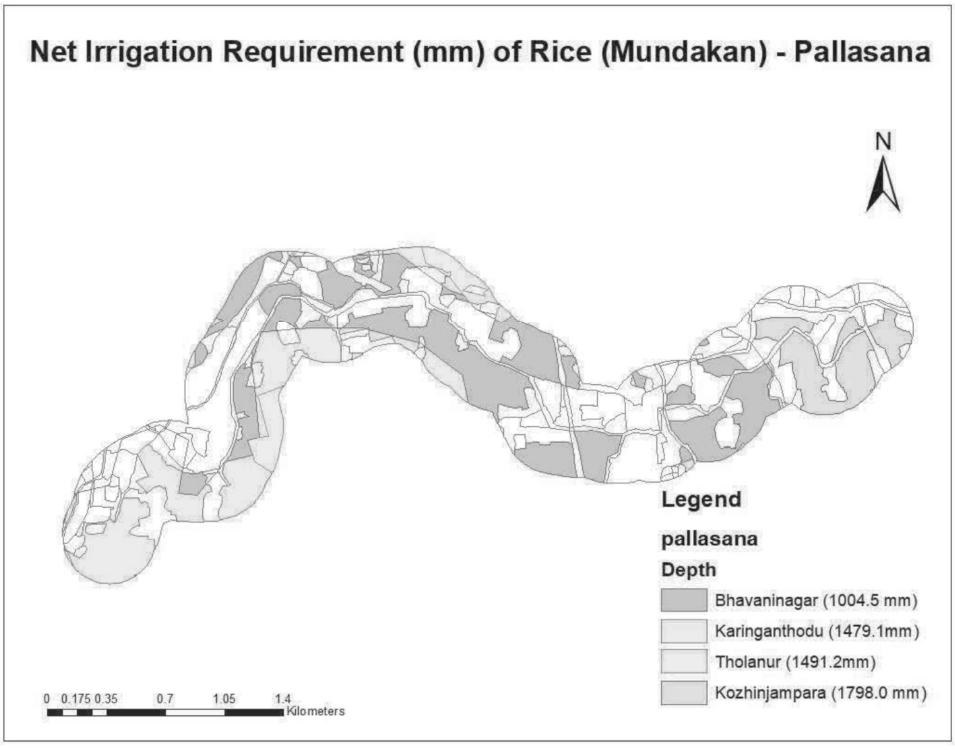

Fig. 9. Net irrigation water requirement (mm) of Rice (*mundakan*)- Pallasana distributary with different soil series

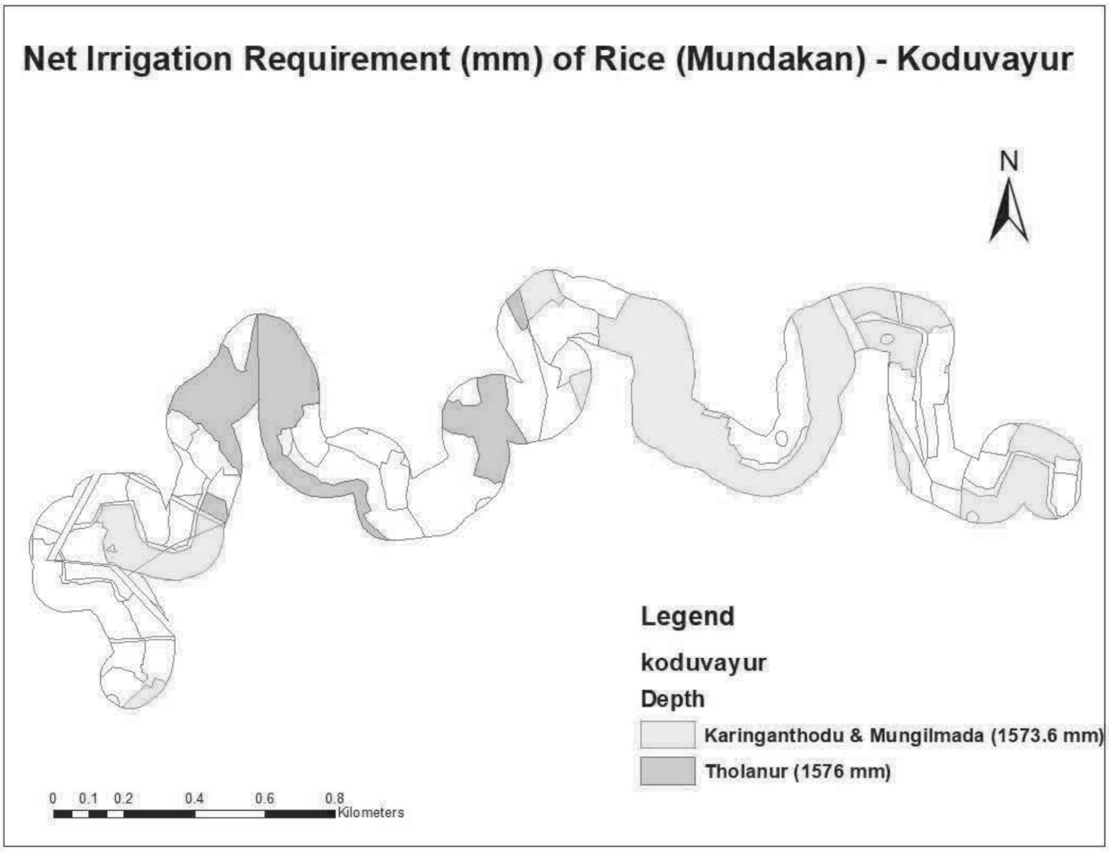

Fig. 10. Net irrigation water requirement (mm) of Rice (*mundakan*)- Koduvayur distributary with different soil series

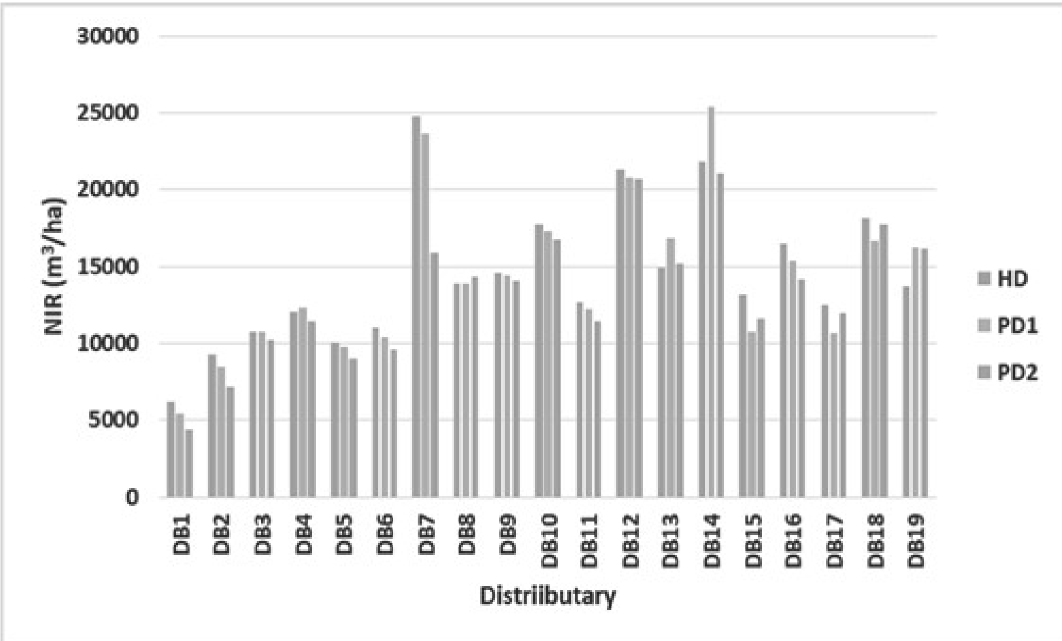

Fig. 11. Annual NIWR of all crops in the various distributaries estimated for HD and PD

Table 4. NIWR of crops in Kariganthiodu series in DB 9 (Pallasana)

Crop	NIWR (mm)
Paddy (*mundakan*)	1479.1
Paddy (*virippu*)	1081.0
Coconut	483.3
Mango	372.0
Vegetables	417.4

The total net irrigation requirement is the sum of water requirement of all crops in the distributary command. The total net irrigation requirement was calculated in volume basis. The annual net irrigation requirement was estimated for HD, PD1 and PD2 and is shown in Fig. 11.

Out of the 19 distributaries the highest net irrigation water requirement was found for DB14 (Peringhotukavu) and DB7 (Ootara) with approximately 25000 m^3/ha and lowest for DB1 (Parakkalchalla distributary) with less than 5000 m^3/ha. The high values for DB7 and DB14 may be due to influence of soil series Karinganthodu and Kozhinjampara, which are the dominant soil series in these distributary command. The lowest value for DB1 may be due to the presence of Bhavani Nagar series which was the major soil series in this distributary command. There was remarkable variation in NIWR values between historical data (HD) and predicted data (PD) as shown by distributaries DB 14 and DB7. This might be due to the influence of rainfall. But the other distributaries, showed only less variations of NIWR between the HD and PD. The study revealed that soil series and rainfall had more influence in determining the net irrigation water requirement of crops in a distributary command.

3.6 Gross Irrigation Requirement (GIWR) of Crops in Distributary Command

The study showed that, from distributaries DB1 to DB6, the GIWR was found near to 10000 m^3/ha. These were the distributaries in head reach of canal irrigation system. The highest GIWR of 25369.7 m^3/ha was found for DB14 (Peringhotukavu) followed by DB7 (Ootara) with 24756.6 m3/ha. These were the distributaries in middle and tail reach of the irrigation system respectively. The lowest GIWR of 4390.9 m^3/ha was obtained for DB1 (Parakkalchalla). The results indicated that GIWR requirement was found more towards the middle and tail reach of GIP canal system. This is because, paddy crop occupied maximum area in the distributary command of middle and tail reaches of canal irrigation system. There was only small variation between NIWR and GIWR of crops in distributary command because of low amount of seepage loss. The annual gross irrigation water requirement for both HD and PD is shown in Fig. 12.

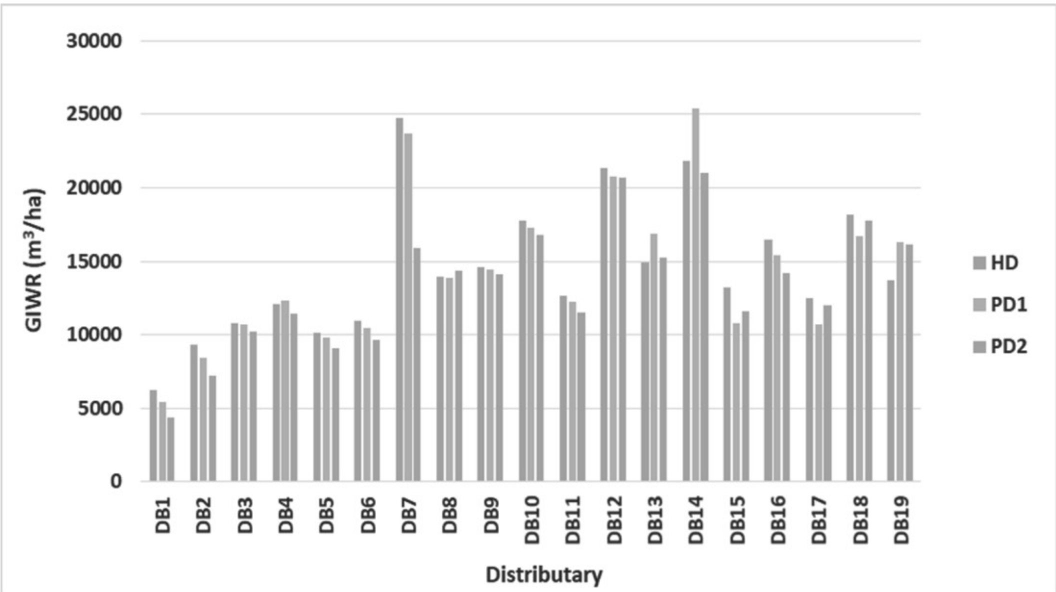

Fig. 12. The annual GIWR in various distributaries estimated for HD and PD

4. CONCLUSIONS

The geospatial database of canal network, land use, soil and climate were prepared for the canal command of GIP by spatial data analysis. FAO CROPWAT 8.0 software was used to compute the reference crop evapotranspiration, potential crop evapotranspiration and net irrigation requirement of major crops in the command area of distributaries. The annual gross irrigation water requirement of crops in distributary command was calculated by estimating the seepage loss from distributaries. The study revealed that soil series and rainfall have more influence in net irrigation water requirement of crops in distributary command. The highest gross irrigation water requirement was found for Peringhotukavu distributary followed by Ootara distributary which is located at tail and middle reach of GIP command. This clearly showed high water requirement was observed for distributaries located at middle and tail reach of command area which occupied the more paddy growing areas in the command. The study also showed that accurate estimation of irrigation requirement based on the spatial variability of soil, crop and climate is very essential for planning water allocation in a canal command to improve the water use efficiency.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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