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Irrigation Performance of Western Canal, Kamala Irrigation Project Using Remote Sensing and GIS

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Abstract

This study focuses on evaluating the performance of the Western Canal command area of the Kamala Irrigation Project in Nepal using remote sensing (RS) and Geographic Information System (GIS) techniques. This study addresses a critical need for efficient and equitable water management in Nepal's agriculture sector, where irrigation systems are vital for sustaining livelihoods and economic growth. By leveraging remote sensing and GIS technologies, the research aims to enhance the understanding of irrigation performance and facilitate informed decision-making for sustainable agricultural practices. The study area covers 12,500 hectares (ha) and is characterized by a main canal, branch canals, minor distributaries, and water user associations. This research utilizes satellite imagery from Sentinel-2 to determine land use classification, estimation of yields, particularly focusing on winter crop cultivation when the water availability is low. Results indicate that the irrigation system tends to over-irrigate in season of 2020-021, with an RWS of 1.54 but during the 2021-2022 season, the irrigation system supplied less water than the demand. The study also reveals disparities in cultivated area and crop health between the head and tail ends of the canal, highlighting the need for equitable water distribution. The findings will provide valuable insights for sustainable water resource management, crop productivity enhancement, and strategy formulation to ensure food and water security in Nepal.

Keywords

GIS, Irrigation performance, Remote sensing, Water productivity

1. Introduction

Irrigation has long been pivotal in agriculture, enabling the world to meet the needs of a growing population and escalating food demands. With only 20% of cultivated area receiving irrigation, irrigation plays a major role in the world's food supply, accounting for about 40% of worldwide food output [1].

Nepal has a total cultivated area of 3.557 million hectares, out of which 2.536 million hectares are potentially irrigable. Currently, 1.555 million hectares are under some form of irrigation, with surface irrigation covering 65.47%, groundwater irrigation 34.11%, and newer irrigation techniques 0.15%. However, only one-third of this irrigated area receives irrigation throughout the year [2].

Nepal has a total of approximately 2,254 irrigation systems, covering nearly 728,000 hectares(ha). These systems include Joint Managed Irrigation Systems (JMIS) and Farmer Managed Irrigation Systems (FMIS). Of the irrigated area, 81% is located in the Terai region, while the Hill and Mountain zones account for 15% and 4%, respectively JMISs irrigate about 357,000 ha, primarily in the Terai region across 24 systems. FMISs represent 51% of the total surface water irrigation systems, covering 240,213 ha and consisting of 809 systems, with 97% of them located in the Terai region. In contrast, FMISs make up 18% of the irrigated area (131,181 ha) in the Hill and Mountain regions [3].

Monitoring, evaluating, and diagnosing the performance of irrigation systems are essential for understanding their efficiency and identifying areas for improvement. Performance indicators play a crucial role in describing the system's effectiveness across different dimensions, assisting decision-makers in optimizing management practices. By continuously monitoring the temporal and spatial variations of these indicators, the overall performance of the system can be enhanced. Real-time data enables timely interventions to address any inefficiencies. Remote sensing offers a valuable tool for assessing crop yield without the need for extensive field measurements, thereby allowing for a detailed study of water productivity variations within irrigation systems [4].

Over the past three decades, the assessment of irrigation systems has undergone notable evolution. Initially centered on traditional efficiency metrics, the focus has shifted towards comprehensive performance indicators and, more recently, frameworks emphasizing water accounting and productivity. These indicators now encompass diverse aspects such as water distribution efficiency, agricultural outputs, economic impacts, social benefits, and environmental considerations [5].

The Kamala Irrigation Project (KIP), established in the 1970s, currently struggles to adequately serve its command area during the wet season and provides minimal service during the dry season. Significant revitalization efforts are needed to improve operations, enhance access, and increase efficiency.

The objective of this study is to assess the irrigation performance of the Kamala Irrigation Western Canal system aims to enhance water productivity, ensure sustainability, and optimize economic returns.

2. Study Area

2.1 Study Area

The study area encompasses the command area of the Kamala Irrigation Western Canal system, situated in the Dhanusha district of the Madhesh province, with a total command area of 12,500 ha. The main canal stretches over 14.3 kilometers with a design capacity of 14 m^3/s. Additionally, there are four branch canals, namely Raghunathpur Branch, Parbaha Branch, Mahinathpur Branch, and Khajuri Branch, with a total length of 61 kilometers for all branch canals combined. The area is served by a total of 54 minor distributaries and 18 water user associations.

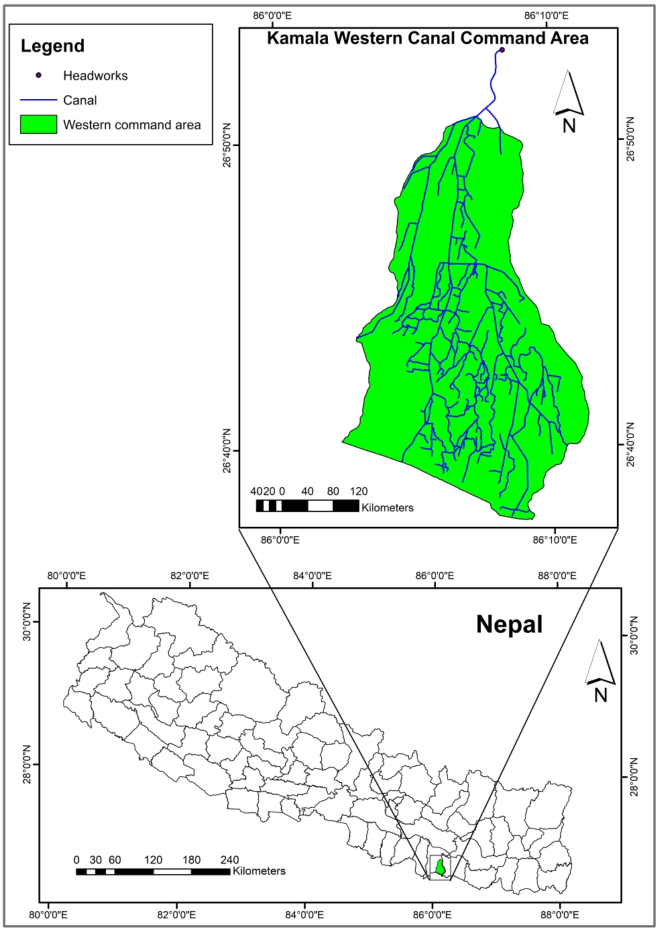

Figure 1: Kamala Western IP showing its branches and command area

2.2 Data Description

Various weather data necessary for calculating Potential Evapotranspiration (PET) were collected from relevant sources. Historical records, including daily maximum and minimum temperatures, precipitation, humidity, sunshine hours, and wind speed from meteorological and climatology stations within and near the KIP western canal command area, were obtained from the Department of Hydrology and Meteorology (DHM) in Babar Mahal. Specifically, Station 216 at Janakpur Airport was used for this study. PET was determined using the Penman-Monteith method with the CROPWAT 8.0 software.

Data concerning the command area and water diversion were sourced from the Kamala Irrigation Management Office in Portaha, Dhanusha. Information on agricultural land, predominant crops, and their productivity was obtained from the "Statistical Information on Nepalese Agriculture" report published by the Ministry of Agriculture and Livestock Development(MoALD).

3. Methodology

The performance assessment of the western canal command area began with the supervised classification of images of the Dhanusha district, and western canals command area of KIP using Sentinel-2 data on the Google Earth Engine (GEE) platform. This was achieved using the Random Forest classifier to classify land use land cover (LULC). Following this, the Normalized Difference Vegetation Index (NDVI) for the study period was mapped. The study focused on calculating NDVI, yield, crop water requirements, and finally, performance indicators from November to April, which is the growing season for winter crops.

3.1 Landuse Classification

For land use classification using Sentinel-2 data, the study utilized the GEE platform. Sentinel-2 was chosen over Landsat due to resolution limitations. Preprocessing involved cloud masking using the QA60 band, setting a cloud probability threshold, and detecting cloud shadows. Images were filtered for less than 20% cloud cover and within date ranges of November 16, 2020, to May 15, 2021, and November 16, 2021, to May 15, 2022. A median composite was created and clipped to focus on the Kamala region. Selected bands (B2, B3, B4, B5, B6, B7, B8, B8A, B11, B12) were used for land cover classification. Training data were collected for built-up areas, waterbodies, cropland, forest, and barren land, and split into training (75%) and validation (25%) samples. The Random Forest (RF) classifier was applied for classification, with results clipped to the region of interest.

The accuracy assessment of the LULC classification was conducted using GEE. Sample points were generated using the Sample Regions function, and a confusion matrix was employed to evaluate classification performance. Metrics such as overall validation accuracy and the Kappa coefficient were calculated to compare correctly classified instances with misclassified ones. For training accuracy, a confusion matrix was created to determine the proportion of correctly classified samples. Validation accuracy was assessed by applying the trained classifier to the validation sample, comparing predicted classes with true classes. The Kappa coefficient, ranging from -1 to 1, was calculated to measure agreement between predicted and actual classifications, accounting for chance agreement. These metrics provided a comprehensive evaluation of the classifier's performance and reliability.

3.2 NDVI Time series Analysis

The classified image is then is exported to ArcGIS for the converting raster data to vector polygons, calculating areas for each land cover class. The resulting clipped Geo TIFF and shapefile were exported for NDVI time series analysis in GEE. Classified crop land was added to the area of interest. Sentinel-2 images were acquired from November 16 to May 15 for both years, 2020-2021 and 2021-2022 enhanced by the Savitzky-Golay filter for noise reduction. The maximum reducer was used over time to develop an image containing pixels with the maximum NDVI value for each year. Similarly, the median reducer was applied over the region to obtain the median value of each image, and a time-series of median values was plotted to visualize the NDVI cycle.

NDVI can be defined by the following equation

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}}$$

NIR and R are the reflectance in the near infra-red and red regions, respectively.

NDVI values range from -1 to 1, with higher values indicating healthier and denser vegetation. NDVI is sensitive to the amount of chlorophyll in plant leaves, making it a valuable indicator of vegetation health and productivity.

3.3 Yield Estimation by Satellite Image and Crop Model

Yield calculated for the winter crop growing season for region was calculated form this model and different parameter is adjusted and result is validated against the statical report published by the MoALD. And after with the adjusted parameter is used for the command area located in KIP for yield calculation.

Yield was estimated using a simple model derived from [6],[7]

$$\mathrm{Yield} = \mathrm{APAR} \times \varepsilon \times \mathrm{HI}/(1 - \mathrm{moi}) \tag{1}$$

where, APAR is Absorbed Photosynthetically Active Radiation ($\mathrm{MJ/m^2/day}$), ε is light use efficiency in units of g biomass (MJ $\mathrm{PAR^{-1}}$), and HI is the harvest index ,moi is moisture content of product during harvest.

In this case, as in most studies, HI and ε refer only to above-ground biomass and do not include roots.

Measurements of APAR (MJ between 400 and 700 nm), which are calculated as the growth season's total of the proportion of PAR absorbed by the canopy (fAPAR) and incident photosynthetically active radiation (IPAR).

$$\mathrm{APAR} = G \times E_c \times \mathrm{fAPAR} \tag{2}$$

where, G is Global incident short wave radiation ($\mathrm{MJ/m^2/day}$), E_c is Climatic efficiency, fAPAR is fraction of PAR absorbed by the canopy

G and E_c are daily values; for G, they are the total; for E_c and fAPAR, they are the average. The primary factors influencing climatic efficiency are air conditions, although other factors include solar elevation, location, and time (hour, day, or month)[8] .

The following model was used to compute the fraction of absorbed photosynthetically active radiation (fAPAR) from the NDVI image [9].

$$\mathrm{fAPAR} = \frac{(\mathrm{NDVI} - \mathrm{NDVI_{min}}) \times (\mathrm{fAPAR_{max}} - \mathrm{fAPAR_{min}})}{(\mathrm{NDVI_{max}} - \mathrm{NDVI_{min}})} + \mathrm{fAPAR_{min}} \tag{3}$$

where, NDVI = average value of NDVI for the entire region, NDVI max= 98th percentile of NDVI for the entire region, NDVI min=2th percentile of NDVI for the entire region, fAPAR max =0.95, fAPAR min=0.01,

Key crop characteristics, such as moi, HI, and light use efficiency (ε) , were derived from the published values in the literature.

Given that the yield for the entire winter season crop is being computed for this study project, 2.45 was chosen as the value for ε, 0.4 was chosen for the Harvest Index at HI, and 12% was chosen for moisture content and E_c is 0.35 .

G is the value of solar radiation is taken form the Janakpur station which is used in all the region and hence yield is calculated for the region of interest.

3.4 Estimation of Crop Water Demand

Using the Cropwat software, the crop water requirement for the research period's season is calculated. Cropwat 8.0 software was utilized to compute the evapotranspiration values of the crops found in the crop pattern observed as shown in Table 1 in the study area . This software uses the Penman-Monteith method to calculate evapotranspiration values. For this computation, climate data from DHM were employed.

3.5 Performance indices

The irrigation system was evaluated using three performance indices across different categories. The first two indices (adequacy and equity) describe the water delivery system, while the last index, agricultural productivity, describes the irrigated agriculture system.

Cropped area, command area, potential evapotranspiration, water diverted from the main canal, NDVI value, rainfall, crop yield, etc. were all taken into account while computing the performance metrics.

3.5.1 Relative Water Supply (RWS)/Adequacy

The relative water supply (RWS) is used as an indicator of the adequacy of irrigation water delivery, comparing the supplied water with the demanded amount[10]. Defined by Levine (1982) [11] , is computed using the following expression:

$$\mathrm{RWS} = \frac{\text{Amount of water delivered to the scheme}}{\text{Water demand of the scheme}}$$

$$\mathrm{RWS} = \frac{IR + RN}{IRN}$$

where IR is the irrigation water supply, RN the rainfall and Net irrigation requirement (IRN) The major rainfall season for this region is June to October, with little rainfall from November to February (winter season). Net irrigation requirement (IRN) was computed using Equation below [12].

IRN=ETc-Pe where, ETc is the crop evapotranspiration, Pe is the effective rainfall

RWS value below 1 signifies an inadequate supply of water, indicating that less water than required has been provided. A value of 1 indicates that the water demand of the scheme has

Table 1: Cropping pattern of winter season crop of kamala IP

S. No	Canal System	Command area (ha)	Cropping area(ha)	Wheat	Lintel	Oil seed	Maize	Vegetable
1.	Kamala Western IP	12500	10750	45%	28%	14%	2%	11%

been fully met, while values greater than 1 suggest an excess of water applied compared to the demand[13].

3.5.2 Equity

To assess equity using RS data, the method was suggested by [14].

For the western canal command area, the whole command area was divided into three regions. Zone, I include the command area belonging to branch canals, namely Raghunathpur branch, Parbaha branch and Zone II command area belonging to Mahinathpur branch and Zone III includes Khajuri branch as shown in Figure 2. This was done since the branches

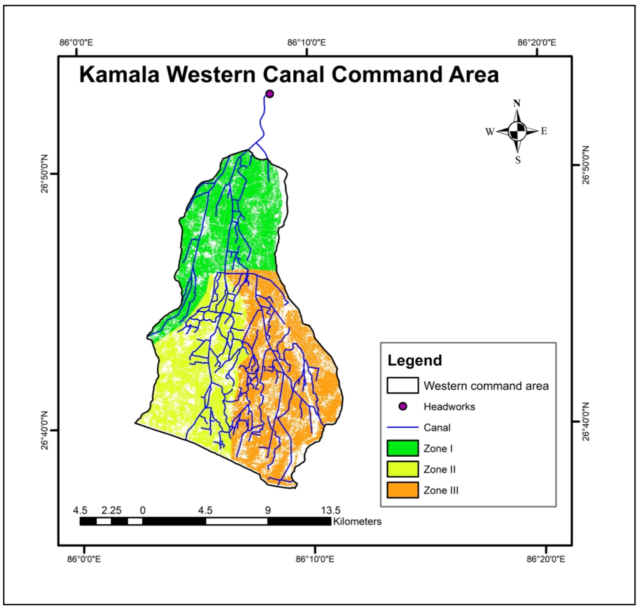

Figure 2: Kamala Western IP command area and its classification

Levine and Coward (1989)[15] emphasized the significance of perceived fairness in irrigation systems, proposing that systems designed to balance productivity and equity tend to be more efficient. They suggested that crop health and planted area would be consistent throughout the distribution chain in an equal system. On the other hand, the system cannot be deemed equal if there are notable variations in cropped area and health between the head and tail ends of the dis-tributaries.

3.5.3 Water Use Efficiency (WUE)

Cropping intensity, the ratio of planted to harvested area, annual yield, land productivity, and water productivity are important measures of agricultural production performance [16].

Using data from RS, an estimate of water production has been attempted in this study. Water productivity sometimes referred to as Water Use Efficiency (WUE), can be expressed[17].

$$\text{Water Productivity} = \frac{\text{Crop yield}}{\text{Volume of irrigation water supplied}}$$

Water productivity is a measure of the yield per volume of irrigation water supplied. It is generally represented in units of kg/m^3, where crop production is measured in kg/ ha and water supplied is converted on m^3/ha. The WUE in many countries measured from 0.52 to 1.42 kg/m^3 with average measured water productivity of 1.00 kg/m^3 indicating that value below 0.52 kg/m^3 is poor performance [18].

4. Result and Discussion

4.1 LULC Classification

Dhanusha District

In the year 2020-2021, the predominant land use in Dhanusha district consisted mainly of agricultural and forested areas. Agriculture lands covered 53,295.56 ha, accounting for 44.80% of the total land use, making it the most extensive land use category. Forest areas followed as the second largest land use type, encompassing 33,650.790 ha, or 28.28% of the district. Built-up areas were the third most significant land cover, occupying 18,845.44 ha and representing 15.84% of the land. Barren land represented the smallest portion of the study area, covering 4775.05 ha or 4.01% of the total area. Water bodies were the second least extensive land use type, occupying 8,404.50 ha and accounting for 7.06% of the district's area.Figure 3 and Figure 4 presents the detailed LULC of the Dhanusha district .

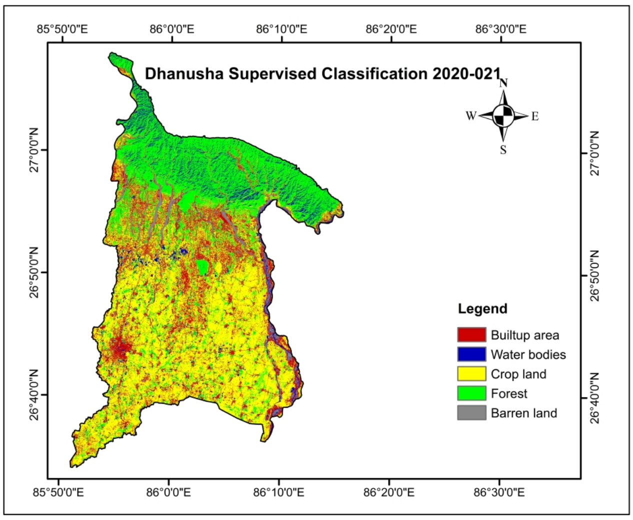

Figure 3: Land Use Land Cover Map of Dhanusha District in 2020-021

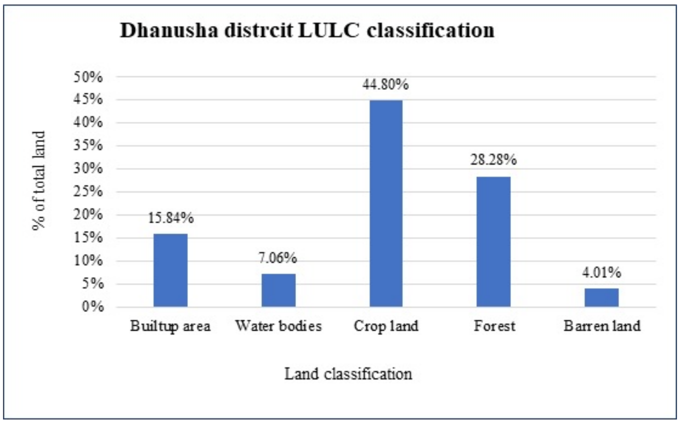

Figure 4: Land Use Land Cover Data in Dhanusha 2020-021

Western canal command area

In the 2020-2021 period, Kamala IP western command area land use was primarily dominated by agricultural and built-up. Agriculture lands, the most extensive land use category, spanned 15,192.00 ha, which constituted 73.31% of the total land area. Built-up areas were the second largest land use type, covering 2,575.00 ha or 12.42% of the district. Forest areas ranked third, occupying 2,098.49 hectares and making up 10.13% of the land. Barren land constituted the smallest part of the study area in Kamala IP western command area, covering 266.88 ha or 1.29% of the total area. Water bodies were the second least extensive land use type, occupying 592.24 ha and accounting for 2.86% of the area.Figure 5 and Figure 6 presents the detailed LULC of the command area.

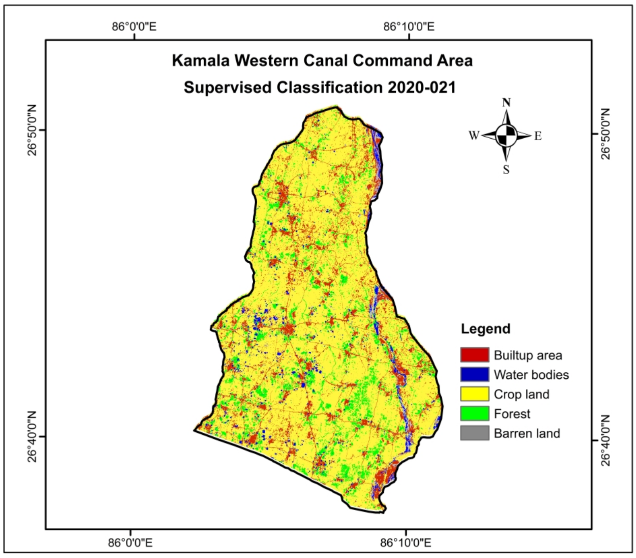

Figure 5: Land Use Land Cover Map of Kamala Western Command Area in 2020-021

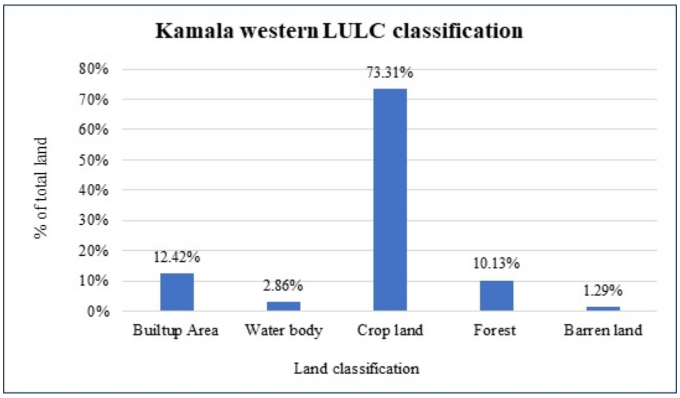

Figure 6: Land Use Land Cover Data in Western command area 2020-021

Accuracy Assessment of LULC

For the LULC of 2020-021, the accuracy assessment was done for Dhanusha district and western command area of KIP. The stratified random samples were used for the creation of samples. The samples were verified using google imagery and satellite image then overall accuracy and kappa coefficients were evaluated form GEE. Table 2 shows the confusion matrix obtained from the classified map of 2020-021 to evaluate the performance of our classifier.

Table 2: Confusion matrix

S.N.	Region	Overall accuracy (%)	Kappa coefficient
1	Dhanusha district	85.99	0.81
2	Western canal system command area	88.11	0.83

4.2 Time Series of NDVI

Based on the classified map form GEE, the cropland was masked out and that crop land was used for NDVI time series analysis. Time series analysis was done for the winter cropping season i.e. 16- November to 15-May for the year of 2020-021 and 2021-022 for the district and command area of KIP.The graph is shown in Figure 7,8,9 and 10.The summary of NDVI values for the NDVI time series analysis used in crop yield prediction is given in Table 3.

Table 3: Summary of NDVI time-series

S.N.	Region	Year	NDVI	NDVI max	NDVI min
1	Dhanusha District	2020-021	0.259	0.403	0.099
		2021-022	0.313	0.427	0.170
2	Western canal system command area	2020-021	0.259	0.420	0.128
		2021-022	0.283	0.458	0.170

4.3 Yield Assessment

Accuracy assessment of yield

The NDVI values derived from winter season satellite data along with other parameters (Ec, ε, HI and moi) was utilized for the yield calculation for the Dhanusha district with the adopted value of parameter and validation is done with the average yield calculated from data published from MoALD.The deatiled calculation is shown in Table 4.

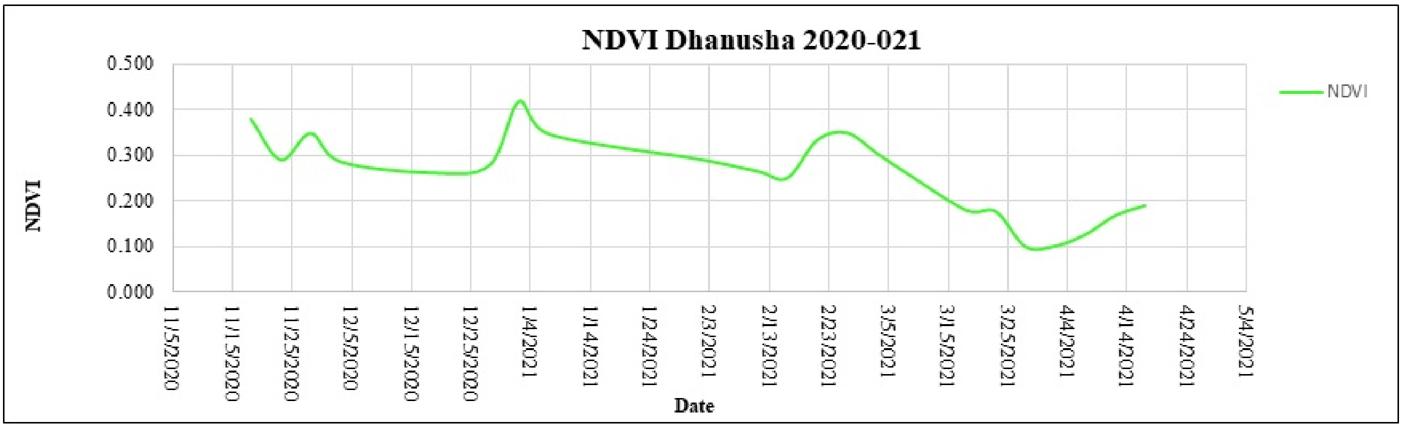

Figure 7: NDVI time-series of Dhanusha 2020-021

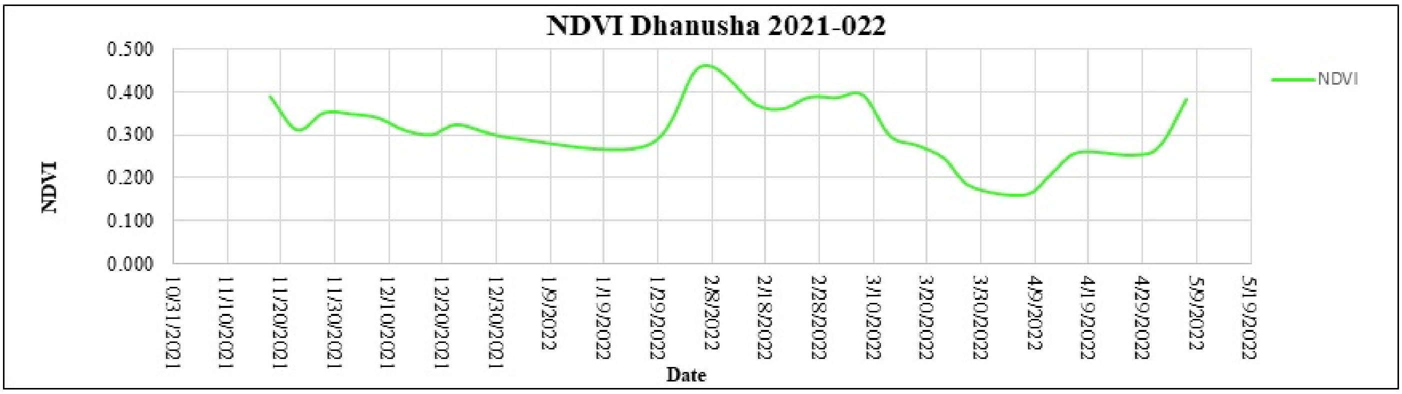

Figure 8: NDVI time-series of Dhanusha 2021-022

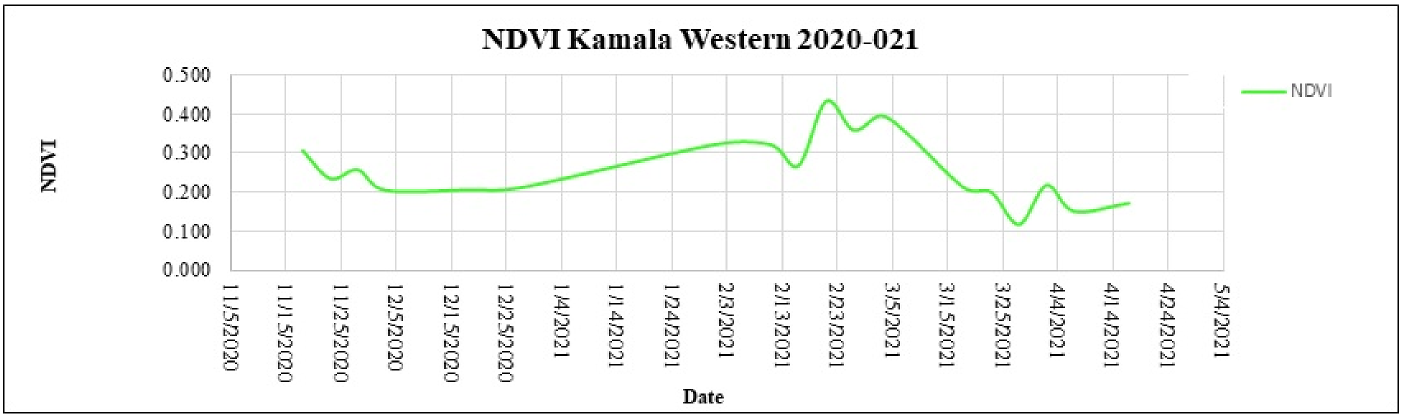

Figure 9: NDVI time series of Kamala Western command Area 2020-021

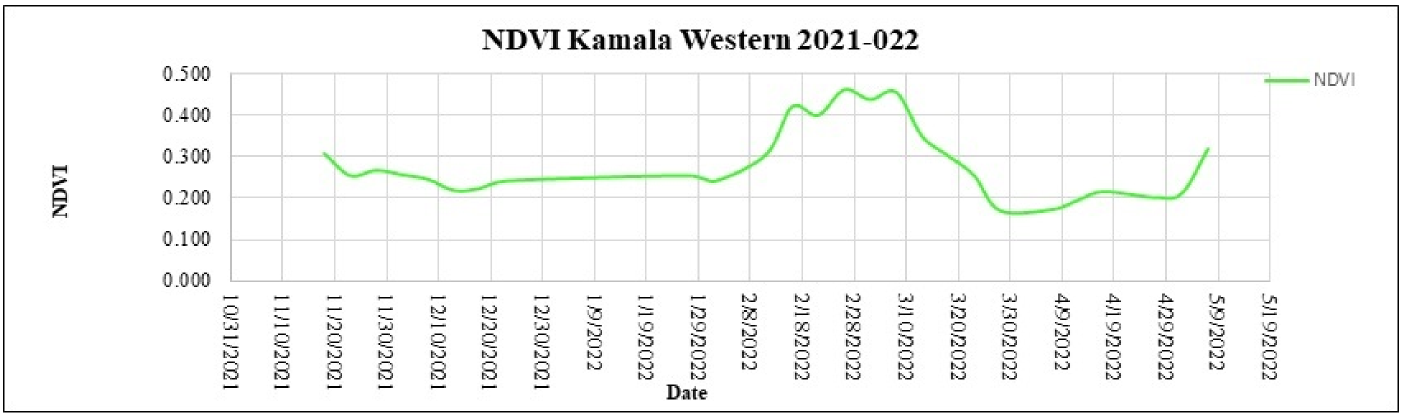

Figure 10: DVI time series of Kamala Western Command Area 2021-022

Table 4: Yield comparison between Statistical and Calculated data

Calculation Parameters	Dhanusha district		Remarks
	2020-021	2021-022	
fAPAR max	0.950	0.950	
fAPAR min	0.010	0.010	
NDVI	0.259	0.313	From time series analysis
NDVI max	0.403	0.427	"
NDVI min	0.099	0.170	"
fAPAR	0.505	0.535	
G (Mj/m{2}/day)	13.569	15.497	Janakpur station
Ec	0.350	0.350	
APAR (Mj/m{2}/day)	2.400	2.900	
APAR (Mj/m{2})	287.994	348.045	For 120 days
ε (g/Mj)	2.450	2.450	Value from literature
HI	0.400	0.400	"
(1-moi) @ moi=0.12	0.880	0.880	"
Yield (g/m{2})	320.721	387.595	
Yield (Mt/ha)	3.207	3.876	
Average Yield reported from MoALAD (Mt/ha)	3.589	3.665	
% of deviation	-10.63%	5.77%	

Yield estimation for command area

After the values of parameter calibrated for the district and NDVI values derived for western canal command area yield was calculated. Hence the yield estimated for for western canal command area was 2.745 and 2.746 Mt/ha for the year of 2020-021 and 2021-022 respectively.

4.4 Adequacy

The assessment of water supply adequacy in the command area was conducted by calculating the RWS for the winter season of 2020-21 and 2021-022 for canal system.

Table 5: Relative water supply in western canal system in 2020-021

Month	Irr. req. for actual area (l/s)	Diverted from Canal (l/s)	Relative Water Supply (RWS)
Nov 2020	322.5	242.27	0.75
Dec 2020	1,397.50	3,158.36	2.26
Jan 2021	2,365.00	10,445.70	4.42
Feb 2021	4,192.50	10,249.08	2.44
Mar 2021	5,697.50	2,810.43	0.49
Apr 2021	3,547.50	-	-
Annual	**17,522.50**	**26,905.84**	**1.54**

The results in Table 5 indicate a general tendency among farmers in canal command areas to apply slightly more water than necessary for irrigation. During the winter season of 2020-2021, the average water supply ratio was determined to be 1.54, suggesting that farmers provided 54% more water than what is typically required. A detailed assessment of the water supply ratio for this period showed considerable variation, ranging from a high of 4.42 to a low of 0.49. Notably, January had the highest water supply ratio, while March had the lowest. This analysis underscores a significant surge in water usage in January compared to the other months, pointing to potential inefficiencies in water management during that time.

Table 6: Relative water supply in western canal system in 2021-022

Month	Irr. req. for actual area (l/s)	Diverted from Canal (l/s)	Relative Water Supply (RWS)
Nov 2021	322.5	483.76	1.5
Dec 2021	1,075.00	983.53	0.91
Jan 2022	2,257.50	1,423.83	0.63
Feb 2022	752.5	1,083.41	1.44
Mar 2022	5,267.50	159.86	0.03
Apr 2022	2,042.50	17.84	-
Annual	**11,717.50**	**4,152.24**	**0.35**

The average Relative Water Supply (RWS) for the Kamala western canal system was found to be 0.35 during the winter season of 2021-2022 shown in Table 6, indicating that the water supplied was significantly lower than the demand. The assessment for the water supply ratio in 2021-2022 revealed a wide range of variations, from as low as 0.03 to as high as 1.50, with November recording the highest ratio and March the lowest. Throughout most months of the cropping season, the water supply consistently fell short of meeting the demand, highlighting a substantial deficit in irrigation supply relative to crop requirements.

4.5 Equity

The head and tail zones of the canal were compared for differences in cultivated area and crop health. From the head to the tail, the command regions were separated into three zones. The results in western canal system showed a decrease in the crop area from 75.19% in the Zone I to 70.81% in the Zone III of the command area (Table 7). NDVI values, tended to be lower in zones located towards the middle of the canal system in year 2020-021 but for the year 2021-022 the values from zone I (0.484) decrease in zone II (0.460) but again it increases to zone III (0.491), which again shows indifferent in water distribution.

Table 7: Head-to-tail difference in cropped area and NDVI value in 2020-021 and 2021-022 in Kamala irrigation western canal system

S.N.	Zone	Crop Area (% of Geographical area)	NDVI mean value	
			(2020-021)	(2021-022)
1	Upper	75.19	0.465	0.484
2	Middle	72.03	0.442	0.460
3	Lower	70.81	0.457	0.491

Since the change in 0.1 unit of NDVI values represent the significant changes in crop health so here we can see that the change in NDVI is deferable. Therefore, it is not possible to say that the distribution system upholds equity.

4.6 Water Use Efficiency (WUE)

An important metric for evaluating irrigation effectiveness is water productivity, which shows the connection between crop yield and the volume of water applied to an irrigation program.

Table 8: Water Use Efficiency for 2020-021 & 2021-022

Command area	Water Use Efficiency (WUE) (Kg/m^3)	
	(2020-021)	(2021-022)
Western canal system command area	0.144	1.055

The yield for the western canal system 2020-021 and 2021-022 is 2.745 Mt/ha and 2.746 Mt/ha. The average water diverted from the canal system during this year was recorded as 26.91 m^3/s and 4.15 m^3/s. the water productivity observed on a supply basis was 0.144 kg/m^3, which is poor yield for per unit of water supplied and 1.055 kg/m^3 which is more or less satisfactory which is shown in Table 8.

5. Conclusion

Based on the computed irrigation performance of the KIP western canal command area, the RWS of irrigation system was determined to be 1.54 for 2020-021 it demonstrates that farmers in the canal command area typically have a tendency to over irrigate. But for the year 2021-022, RWS was 0.33 which show very less water is supplied than demand indicating that the system performance is very low.

It can be concluded that the irrigation system performance is not satisfactory as it produced a lower output per unit of water i.e. 0.144 kg/m^3 for 2020-021 in western canal command area. But for the year 2021-022 the water productivity reaches to d 1.055 kg/m^3 in western canal. This was because of low water supplies in year of 2021-022 which is near one fifth of previous year (2020-021) although the average yield remains the almost same for both years.

This indicate that the farmer of the region not only depends of canal supply they may be using other underground source of water for the irrigation purpose. Also, there CWR for the year 2021-022 reduces around 20% due to increase in rainfall in that year. Furthermore, it has been discovered that increased or decreased canal irrigation does not affect crop productivity.

The distribution of the water supply is likewise unfair, with the head receiving more than the tail end. In year 2020-021 for command area since the NDVI value of head (zone I) region is higher than tail end (zone III) but for the year 2021-022 NDVI higher in tail end head region.

Therefore, the integration of remote sensing (RS) data and Geographic Information System (GIS) tools can provide irrigation managers with valuable information for efficiently managing irrigation systems. By regularly computing performance indices using RS and GIS, managers can monitor and evaluate the performance of the irrigation system, identify areas for improvement, and make informed decisions to optimize water use and crop productivity. This approach can lead to more sustainable and effective management of irrigation systems.

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