Improvement of Water Use Efficiency and Remote Sensing Applications for Surface Soil Moisture Monitoring

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Abstract: ***Water is the most essential commodity for human beings to be alive and so it is very necessary to make proper use of water without wasting it. Irrigation sector is the biggest consumer of water as more than 80% of available water resources in India is being presently utilized for irrigation purposes. However, the average water use efficiency of irrigation projects in the country is assessed to be only of the order of 30 to 35%. In the north eastern region also, performance of the existing irrigation schemes (particularly, the major and medium irrigation schemes) suffer from low water use efficiency, distribution losses, poor operational maintenance and management and non-availability of water in the tail ends. The region has unique geographical, topographical, climatological settings and sociological characteristics, which are also influencing factors of low water use efficiency. Again, water demand for various purposes namely irrigation, drinking, domestic, power, industrial and other uses is increasing day by day leading to severe seasonal stress on water resources in the region. Its scarcity is more pronounced with increasing population and needs. In this paper the water use efficiency of the Sukla Irrigation Project is calculated as per methodology given in the guidelines for computing the Water Use Efficiency of the Irrigation Projects, CWC, February 2014. It has also been attempted to analyze the scope of improvement of the water use efficiency of the same. The water use efficiency of the project under existing condition was found to be 33.54%. The results reveal that management interventions of converting unlined canal sections into lined canal sections under practical achievable conditions can improve the conveyance efficiency (a component of water use efficiency) up to 75%. As a result, an amount of about 16 Mm3 water can be saved from which about 2673Ha additional area can be irrigated. With very good level of maintenance the conveyance efficiency can be further enhanced to 95%. This will lead to saving of 53 Mm3 of water from which about 8794 Ha of additional area can be irrigated. This paper also presents a review of the progress in remote sensing of soil moisture, with focus on technique approaches for soil moisture estimation from optical, thermal, passive microwave, and active microwave measurements.***

Keywords: Water use efficiency, conveyance efficiency, on farm application efficiency, CROPWAT.

1. Introduction

Irrigation being the main primary input for development of agriculture of any country, it has received its due priority in planning of the development programmes. But the irrigation sector particularly, has not delivered the expected benefit and has posed certain problems of techno-economic, social and environmental nature. This results in a wide gap between irrigation potential creation and utilization. This serious issue has drawn the attention of the water managers which has oriented them towards the basic objective to be achieved for better Water Use Efficiency through various intervention techniques including modernization and rehabilitation, operation and maintenance of irrigation networks, conjunctive use practices, and improved on-farm development works like construction of field channels, regulatory structures, land levelling and drainage, rotational system of irrigation distribution and periodical performance evaluation of all these measures etc. Again, the irrigation systems due to constant use are subjected to wear and tear, due to which a number of irrigation projects in the country have been operating much below their potential and also the performance of the existing irrigation systems (particularly, the major and medium irrigation schemes) suffer from low Water Use Efficiency, distribution losses, poor operation, maintenance and management and non-availability of water in the tail ends. Thus, it becomes necessary to study the efficiency of the project from time to time so that necessary steps can be taken to improve the performance of the system for maximum production from the command area.

2. Irrigation efficiency

In general, Irrigation Efficiency is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation.

The following are the various types of irrigation efficiency:

i. Water conveyance efficiency.
ii. Water application efficiency.
iii. Water use efficiency.
iv. Water storage efficiency.
v. Water distribution efficiency and
vi. Consumptive use efficiency.

3. Water use efficiency

The Central Water Commission, Ministry Of Water Resources, Government Of India has provided a guideline for computing the Water Use Efficiency of irrigation projects. CWC, vide the Guideline, carries forward the standardization of the definition of the Water Use Efficiency (Wp) which is broadly divided into the following components:

1. Conveyance Efficiency WC
2. On Farm Application Efficiency WF

The overall Water Use Efficiency of the project is taken as-

$$WP = WC \times WF \tag{1}$$

4. Details Of Sukla Irrigation Project

The Sukla Irrigation Project is located in Goreswar in the Baksa district of Assam. Goreswar is a town in the Baksa district, situated in the north bank of the river Brahmaputra, surrounded by Rangia and Baihata. It has its headworks in Naokata village of Goreswar. The command area of the project falls between latitude of $91^{O}40'$ and $91^{O}51'$ and longitude $26^{O}20'$ and $26^{O}40'$. It covers around 105 villages. The source of water for the Sukla Irrigation project is the Sukla River. The Gross Command Area of the project is 22842.00 Ha, Culturable Command Area is 18083.80 Ha and the Net Irrigable Area is 17165.99 Ha. With the introduction of this iirigation project it was expected to achieve an increase of 137 % in the cultivated area of the command area.

The Sukla Irrigation Project is a diversion type irrigation project. Its headwork consists of a weir and head regulators. There are two main canals namely D1 and D2. The canal D1 has twelve minor distributaries. The canal D2 has five minor distributaries and four sub minor distributaries. In order to supply water to the fields, pipe outlets are provided in the canals each having a capacity of 1cumec.

5. Irrigation potential created and utilized

Although the project was designed to command a gross command area of 22,842 ha but due to various reasons particularly damage due to floods the actual percentage utilization was quite less. The year wise potential created and potential utilized is shown in the table I.

I. **TABLE I**. YEAR WISE IRRIGATION POTENTIAL CREATED AND IRRIGATION POTENTIAL UTILIZED (SOURCE: [7])

Year	**Irrigation potential created X1000 ha**	**Irrigation potential utilized X1000 ha**	**% utilization**
1978-79	22.842	7.135	30
1979-80	22.842	12.5	53
1980-81	22.842	12.15	51
1981-82	22.842	14.257	60
1982-83	22.842	15.635	66
1983-84	15.635	15.635	100
1984-85	15.635	15.014	96.03
1985-86	15.635	12.702	81.24
1986-87	15.635	14.863	94.15
1987-88	15.635	14.768	94.45
1988-89	15.635	8.565	54.78
1989-90	15.635	3.573	22.8
1990-91	15.635	14.177	90.67
1991-92	15.635	14.98	98.26
1992-93	15.635	15.068	96.37
1993-94	15.724	14.603	92.87

1994-95	15.55	12.434	79.96
1995-96	12.047	10.419	86.49
1996-97	12.098	10.736	88.49
1997-98	12.116	10.052	82.96
1998-99	13.103	8.461	64.57
1999-2000	12.861	10.799	83.95
2000-01	11.976	11.694	97.65
2001-02	11.078	10.381	93.71
2002-03	4.6	3.11	67.61

The canals are unlined and hence there is huge seepage loss of the irrigation water. Also the farmers at the head and middle reaches make extensive use of the irrigation water. As a result the farmers at the tail end are not able to get benefits from the project till date because the water gets over even before reaching the tail end.

6. Conveyance efficiency

The conveyance efficiency reflects the losses in the conveyance system. It mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. While in transit through canals, losses like evaporation, deep percolation, seepage, bund breaks, overtopping of the bunds, runoff in the drain, rat holes in the canal bunds etc. eventually happen. So it is necessary to assess the losses to determine the quantity of water actually delivered to the fields in the project area. The monthly evaporation data have been collected for fourteen years from the DPR of the Sukla Irrigation project and based on that the average monthly evaporation for Kharif, Rabi and Summer season have been calculated. It was found that the average monthly evaporation for Kharif, Rabi and Summer seasons are respectively 65.31mm, 52.02mm and 75.16mm.

Water losses in the canal network have been computed by Inflow-Outflow Method: IS 9452 (Part-II) of 1980. Inflow – Outflow test was carried out in various sections of 8 canals. For the measurement of velocity, current meter conforming to IS 3910 was used. It was a cup – type magnetic water current meter. The current meter revolutions were taken at 0.6d. The depth of the various sections of the canals was measured by using a ranging rod.

On the basis of the data obtained from the Inflow-Outflow method and evaporation data the Conveyance Efficiency has been calculated and found to be 61.35% as shown in Table II.

7. On farm application efficiency

The on farm application efficiency has two components:

a. WF1 known as water courses/field channels efficiency which accounts for the transit losses.

b. WF2 known as on field water application efficiency which accounts for the water loss from the field in deep percolation, leaching etc.

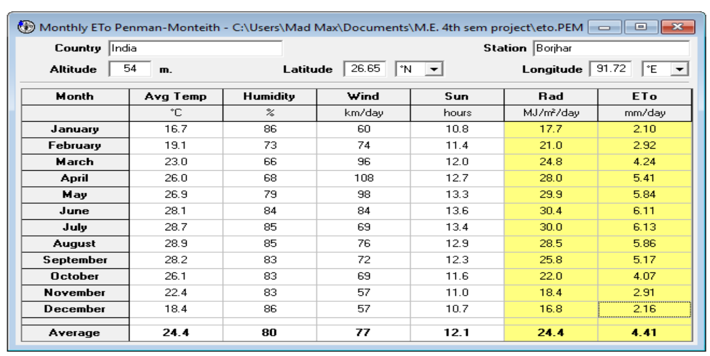
$$WF = WF1 \times WF2 \quad (2)$$

WF1 has been determined by the inflow-outflow method and is found to be 61.35%. For determining WF2, various parameters like Reference evapotranspiration, Effective Rainfall, Percolation losses in the fields, Crop Water Requirement and Net Irrigation Requirement have been calculated for two varieties of Sali paddy.

Reference evapotranspiration is calculated using Modified Penman-Monteith method using CROPWAT-8.0 software developed by FAO as shown in Figure 1.

II. **TABLE II.** CALCULATION OF CONVEYANCE EFFICIENCY, WC

Canal no.	Discharge at head cumec	Effective length m	Evaporation loss	Conveyance loss factor, m3/Sec per m3/Sec of inflow	Total conveyance loss	Delivery at check point	Ratio of 7/2	Conveyance efficiency Col. 8 X 100 %
D1	6.65	25000	0.004	0.344	2.290	4.356	0.655	65.50
D2	7.49	28000	0.0052	0.298	2.233	5.251	0.701	70.11
M1D1	0.62	5900	0.0004	0.353	0.219	0.401	0.646	64.61
M6D1	0.68	6500	0.0005	0.393	0.267	0.412	0.606	60.65
M9D1	0.28	2000	0.0001	0.434	0.122	0.158	0.565	56.52
M1D2	0.74	5000	0.0005	0.469	0.347	0.393	0.531	53.06
M3D2	0.68	3600	0.0003	0.423	0.288	0.392	0.577	57.65
S2M3D2	0.14	1500	0.0009	0.367	0.051	0.088	0.627	62.70
Average								61.35


Monthly ETo Penman-Monteith - C:\Users\Mad Max\Documents\M.E. 4th sem project\eto.PEM

Country India Station Borjhar

Altitude 54 m. Latitude 26.65 °N Longitude 91.72 °E

Month	Avg Temp	Humidity	Wind	Sun	Rad	ETo
	°C	%	km/day	hours	MJ/m²/day	mm/day
January	16.7	86	60	10.8	17.7	2.10
February	19.1	73	74	11.4	21.0	2.92
March	23.0	66	96	12.0	24.8	4.24
April	26.0	68	108	12.7	28.0	5.41
May	26.9	79	98	13.3	29.9	5.84
June	28.1	84	84	13.6	30.4	6.11
July	28.7	85	69	13.4	30.0	6.13
August	28.9	85	76	12.9	28.5	5.86
September	28.2	83	72	12.3	25.8	5.17
October	26.1	83	69	11.6	22.0	4.07
November	22.4	83	57	11.0	18.4	2.91
December	18.4	86	57	10.7	16.8	2.16
Average	24.4	80	77	12.1	24.4	4.41

Figure.1. Reference Evapotranspiration, ET_o, in the command area computed using CROPWAT 8.0 software

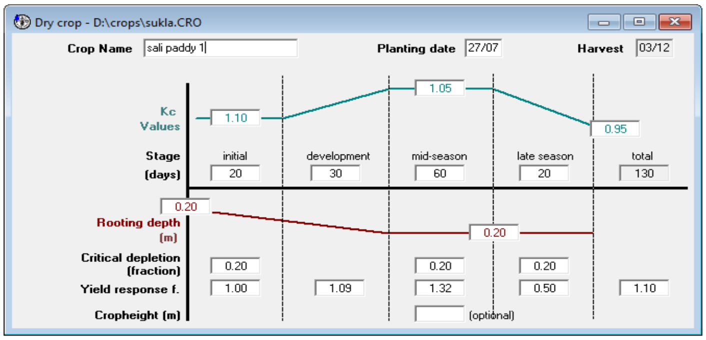


Figure. 2. Window of CROPWAT for feeding the various inputs relating to the crop Sali paddy1

To account for the effect of crop characteristics on crop water requirement, crop coefficients (Kc) are required to relate ETo with the crop evapotranspiration (ETcrop) or consumptive use.

The four stages of crop development are as follows:-

i. 1st stage (nursery and initial) – Germination and initial growth

ii. 2nd stage (development stage) – From end of initial stage to attainment of effective full ground cover.

iii. 3rd stage (mid stage) – From attainment of effective full ground cover to time of start of maturing.

iv. 4th stage (late stage) – From end of mid-season stage until full maturity or harvest.

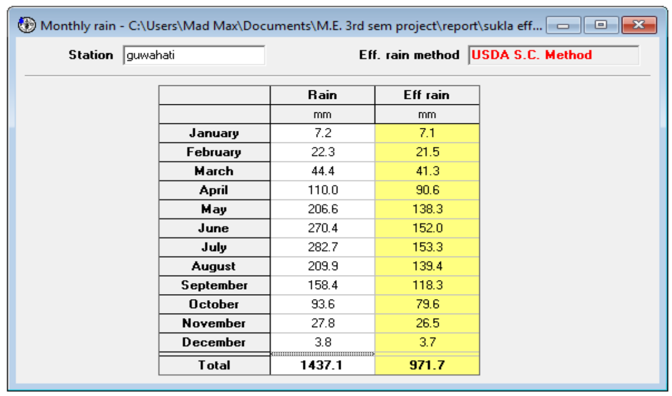
The values of Kc are fed into the CROPWAT software as shown in Fig. 2 for Salipaddy 1. The process is repeated for Salipaddy 2.

For the determination of Effective Rainfall, the rainfall data of 26 years of the command area have been collected partially from the DPR of the Sukla Irrigation Project and partially from the Water Resource Department. From these data, the average monthly rainfall has been calculated. These average monthly rainfall values have been input into the CROPWAT software. The effective rainfall is calculated using USDA Soil Conservation Service Method.

Double Ring Infiltrometer Test was performed in the fields in 5 locations to determine the percolation rate and the type of soil. From the results it was seen that the infiltration rates lie between 5 – 10 mm/hour. Therefore, the soil in the command area of the Sukla Irrigation Project is clay loam type.

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. With the help of the parameters like Crop Coefficient, Reference Evapotranspiration, Crop Evapotranspiration, Effective Rainfall and the soil data, the CROPWAT software calculates the Crop Water Requirement as shown in Fig. 4 for Sali paddy 1 and similarly for Sali paddy 2.

Net Irrigation Requirement is the amount of water required to bring the soil moisture level in the effective root zone to the field capacity before applying irrigation water. For paddy crop, net irrigation requirement (NIR) is calculated as the amount of water required to meet the crop water requirement plus water required for nursery, land preparation, standing water requirement, percolation losses minus the effective rainfall.

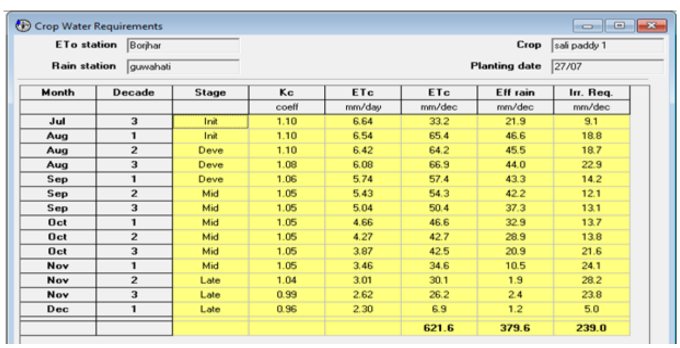


Monthly rain - C:\Users\Mad Max\Documents\M.E. 3rd sem project\report\sukla eff...

Station: guwahati   Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	7.2	7.1
February	22.3	21.5
March	44.4	41.3
April	110.0	90.6
May	206.6	138.3
June	270.4	152.0
July	282.7	153.3
August	209.9	139.4
September	158.4	118.3
October	93.6	79.6
November	27.8	26.5
December	3.8	3.7
Total	1437.1	971.7

Figure. 3. Effective rainfall (mm) computed by CROPWAT 8.0 software of FAO



Crop Water Requirements

ETo station: Borjhar   Crop: sali paddy 1

Rain station: guwahati   Planting date: 27/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	3	Init	1.10	6.64	33.2	21.9	9.1
Aug	1	Init	1.10	6.54	65.4	46.6	18.8
Aug	2	Deve	1.10	6.42	64.2	45.5	18.7
Aug	3	Deve	1.08	6.08	66.9	44.0	22.9
Sep	1	Deve	1.06	5.74	57.4	43.3	14.2
Sep	2	Mid	1.05	5.43	54.3	42.2	12.1
Sep	3	Mid	1.05	5.04	50.4	37.3	13.1
Oct	1	Mid	1.05	4.66	46.6	32.9	13.7
Oct	2	Mid	1.05	4.27	42.7	28.9	13.8
Oct	3	Mid	1.05	3.87	42.5	20.9	21.6
Nov	1	Mid	1.05	3.46	34.6	10.5	24.1
Nov	2	Late	1.04	3.01	30.1	1.9	28.2
Nov	3	Late	0.99	2.62	26.2	2.4	23.8
Dec	1	Late	0.96	2.30	6.9	1.2	5.0
					621.6	379.6	239.0

Figure. 4. Crop water requirement for Sali paddy 1.

The net irrigation requirement (NIR) has been worked out based on the "Modified Penman Method" as shown in Fig 5 and Fig 6.

Therefore, NIR = (624.6+578.5)/2 = 601.55 mm

Now we know that FIR = NIR/WF1 = 601.55/(.6135) = 980.19 mm

And WF2 = FIR/(Actual supply) = 980.19/1100.00 X 100%

= 89.11 %

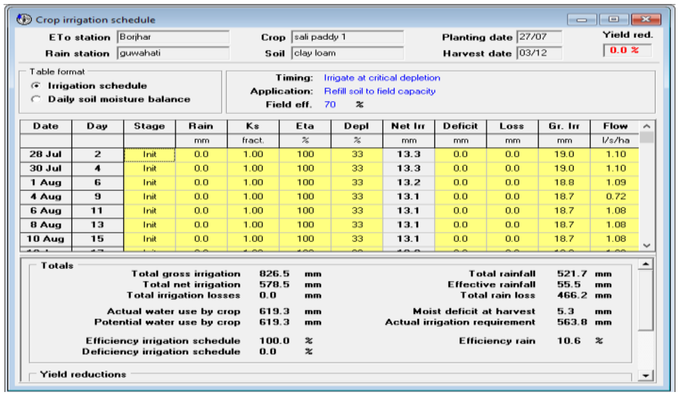
Hence, On Farm Application Efficiency, WF

= 61.35/100 X 89.11/100 X 100% = 54.67 %

Therefore Water Use Efficiency = WC X WF

= 61.35/100 X 54.67/100 X 100% = 33.54 %

Thus it is seen that the Water Use Efficiency is very low.


Crop irrigation schedule

ETo station Borjhar | Crop sali paddy 1 | Planting date 27/07 | Yield red. 0.0 %

Rain station guwahati | Soil clay loam | Harvest date 03/12

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

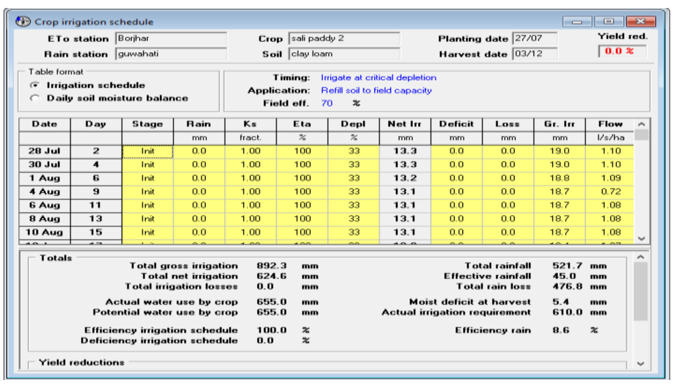
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
28 Jul	2	Init	0.0	1.00	100	33	13.3	0.0	0.0	19.0	1.10
30 Jul	4	Init	0.0	1.00	100	33	13.3	0.0	0.0	19.0	1.10
1 Aug	6	Init	0.0	1.00	100	33	13.2	0.0	0.0	18.8	1.09
4 Aug	9	Init	0.0	1.00	100	33	13.1	0.0	0.0	18.7	0.72
6 Aug	11	Init	0.0	1.00	100	33	13.1	0.0	0.0	18.7	1.08
8 Aug	13	Init	0.0	1.00	100	33	13.1	0.0	0.0	18.7	1.08
10 Aug	15	Init	0.0	1.00	100	33	13.1	0.0	0.0	18.7	1.08

Totals

Total gross irrigation	826.5	mm	Total rainfall	521.7	mm
Total net irrigation	578.5	mm	Effective rainfall	55.5	mm
Total irrigation losses	0.0	mm	Total rain loss	466.2	mm
Actual water use by crop	619.3	mm	Moist deficit at harvest	5.3	mm
Potential water use by crop	619.3	mm	Actual irrigation requirement	563.8	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	10.6	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Figure. 5. Net irrigation requirement (NIR) for Sali paddy 1


Crop irrigation schedule

ETo station Borjhar | Crop sali paddy 2 | Planting date 27/07 | Yield red. 0.0 %

Rain station guwahati | Soil clay loam | Harvest date 03/12

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
28 Jul	2	Init	0.0	1.00	100	33	13.3	0.0	0.0	19.0	1.10
30 Jul	4	Init	0.0	1.00	100	33	13.3	0.0	0.0	19.0	1.10
1 Aug	6	Init	0.0	1.00	100	33	13.2	0.0	0.0	18.8	1.09
4 Aug	9	Init	0.0	1.00	100	33	13.1	0.0	0.0	18.7	0.72
6 Aug	11	Init	0.0	1.00	100	33	13.1	0.0	0.0	18.7	1.08
8 Aug	13	Init	0.0	1.00	100	33	13.1	0.0	0.0	18.7	1.08
10 Aug	15	Init	0.0	1.00	100	33	13.1	0.0	0.0	18.7	1.08

Totals

Total gross irrigation	892.3	mm	Total rainfall	521.7	mm
Total net irrigation	624.6	mm	Effective rainfall	45.0	mm
Total irrigation losses	0.0	mm	Total rain loss	476.8	mm
Actual water use by crop	655.0	mm	Moist deficit at harvest	5.4	mm
Potential water use by crop	655.0	mm	Actual irrigation requirement	610.0	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	8.6	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

Figure. 6. Net irrigation requirement (NIR) for Sali paddy 2

8. Improvement of conveyance efficiency through canal lining

The conveyance efficiency of the Sukla Irrigation Project is only 61.35% which is quite low. This is mainly because the canal network is not fully lined and this causes huge seepage losses. The seepage loss in the canals accounts for major portion of water conveyance loss. Now, as per the "Guideline for computing water use efficiency (WUE) of irrigation projects" put forward by CWC, Ministry of Water Resources, Government of India, the Conveyance Efficiency can be improved and can be brought up to at least 75% for fully lined system. If the level of maintenance is very good, this value can be further improved and can be brought up to 95%. Now, if it is considered that the canal network is fully lined, then the seepage loss will reduce to a great extent. The probable water saving and predicted additional area that can be brought under irrigation after converting unlined sections of main canal and field canals into lined sections have been calculated.

As per the study carried out on eight canals, it is observed that a total volume of 16.04Mm3 can be saved if these canals are lined. With the help of this water an additional area of 2672.74 ha can be irrigated. Apart from lining, if the maintenance level is also very good then 52.76 Mm3 of water can be saved which can irrigate an additional area of 8794.01 ha. Thus, the tail end of the project, which at present does not receive much benefit from it, can easily be irrigated if the canals are lined.

The increase in the Conveyance Efficiency will also lead to an increase in the Water Use Efficiency.

Thus, it is seen that under practical achievable limits, the Water Use Efficiency can be increased up to 41 % by lining the whole canal network. With very good level of maintenance, it can be increased up to 51.93 %. Thus, the gap between the irrigation potential created and that utilized can be reduced to a great extent. As a result wastage of water can be avoided along with providing irrigation facilities to a larger area.

9. Remote sensing applications

There are a fairly wide variety of approaches, which may be used to retrieve soil moisture from optical, thermal infrared, passive microwave and active microwave satellite measurements. The basis of the optical technique for soil moisture estimation rests on the connection between soil surface reflectance and moisture contents. Several empirical approaches and physical models have been proposed to describe the soil moisture effects on surface reflectance with satisfactory results. However, the fact that the contribution of other factors that influence the soil reflectance may not be effectively minimized limits the utility of solar reflectance measurements for soil moisture content determination. Approaches based on either the surface temperature or the complimentary temperature/vegetation index is powerful and has clear physical principles but have limitations in addition to those common to all optical techniques. Such approaches are often empirical and thus vary across time and land cover types and generally cannot be extrapolated from one location to another. Microwave remote sensing is the most effective technique for soil moisture estimation, with advantages for all-weather observations and solid physics. Soil moisture can be estimated using passive radiometer or active radar measurements. Both radiometer brightness temperature and radar backscattering measurements have been shown to be sensitive to soil moisture. Passive microwave has more potential for large-scale soil moisture monitoring but has a low spatial resolution. Active microwave can provide high spatial resolution but has low revisit frequency and is more sensitive to soil roughness and vegetation. For future soil moisture retrieval algorithms, it would be more beneficial to synergistically integrate the spaceborne measurements from multiple sensors, physically based model predictions, as well as in situ observations. The priority areas for future research should also include the approaches for mapping soil moisture in densely vegetated areas.

10. Conclusion

The irrigation sector requires better attention in order to achieve optimum water use efficiency and to reduce the gap between the irrigation potential created and irrigation potential utilized. This can be achieved through various intervention techniques including modernization and rehabilitation, operation and maintenance of irrigation networks, conjunctive use, maintenance practices, and improved on-farm development works like construction of field channels, regulatory structures, land levelling and drainage, rotational system of irrigation distribution and periodical performance evaluation of all these measures etc.

With the introduction of the Sukla Irrigation Project it was expected to achieve an increase of about 137 percent in the cropping pattern of the region. But due to various reasons like poor management and wear and tear of the channels the increase in the cropping pattern is far less than that expected. The Conveyance Efficiency of the project based on the selected eight canals has been found to be 61.35% and the On Farm Application Efficiency is found to be 54.67%. The overall Water Use Efficiency is thus found to be 33.54%.

On the basis of the study done on the eight canals it has been observed that if these canals are lined then 16.04 Mm3 of water can be saved. Also with very good level maintenance along with providing lining, an amount of 52.76 Mm3 of water can be saved. With the help of this water, the tail end of the Sukla Irrigation Project can be easily irrigated.

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