Original Research Article

Assessment of irrigation water loss and water balance in the Thenpennaiyaru basinof Tamil Nadu, India

Abstract

This study employed a comprehensive technique for the systematic estimate of the water balance in Thenpennaiyaru river basin irrigation systems (TRB-IS) in Tamil Nadu, India. KRP reservoir and Sathanur reservoir in TRB are the primary water sources in the study area. We computed the actual water loss in open canals (e.g., leakage and evaporation). A water balance technique provides for the accounting of various system volume inputs (e.g., water abstraction, imported water, water volume owing to precipitation or surface runoff), authorizedconsumptions, and water losses in canals and intermediate reservoirs. The proposed methodology enables the evaluation of various water loss components (e.g., evaporation losses, unauthorized uses, metering errors, leakage, and discharges) and the calculation of water loss performance indicators that enable the identification of the most significant water loss problems and provide guidance for managing water losses. The approach is evaluated and implemented using a hybrid irrigation system. Results indicate that discharges in canal systems account for over half of the total volume of water loss, followed by leakage in canals and metering problems. These findings emphasize the need to enhance the everyday operation of these systems and restore their infrastructures.

Keywords: Water balance, Thenpennaiyaru river basin irrigation systems, Intermediate reservoirs, leakage, anddischarges.

1. Introduction

Growing population tripled in the 20th century and has significantly increased according to the water management system. Agriculture is the single largest consumer of water in the State, using 75 percent of the state's water [1]. As the global population increases, so dothe demand for food and the pressure on irrigated agriculture, which accounts for only 20 percentof the total, cultivated land contributes 40 percent of the world's total food production [2]. Therefore, more water is needed to meet food production needs. It is essential that irrigation systems utilizewater resources efficiently in order to compensate for the irregularity of precipitation in time and space.

Irrigation was employed by ancient cultures throughout the planet. Indeed, without some type of irrigation, civilization would be impossible. People carrying water from wells or rivers to throw on their crops was most likely the oldest type of irrigation [3]. Irrigation canals, dams, and water storage facilities were created in Egypt and China as better technology emerged. Aqueducts were built by ancient Rome to transport water from the alps' snowpack to the cities and towns below. This water has been used for irrigation, drinking, and washing.

Water for crops is supplied by modern irrigation systems, which include reservoirs, tanks, and wells. Aquifers, snowmelt basins, lakes, and dam-created reservoirs are all examples of reservoirs. Water flows from reservoirs to fields via canals or pipes.Like ancient Roman aqueducts, canals and pipelines frequently rely on gravity for their support. Water can also be moved from reservoirs to fields using pumps.

Irrigating crops can be done in a variety of ways, including flooding an entire field, routing water between rows of plants, spraying water through big sprinklers, or having water fall onto plants through holes in pipes. Drip irrigation, which involves letting water drip onto plants through perforations in pipes, is one of the most efficient irrigation technologies. Drip irrigation concentrates water on the plant. Other methods of wastewaterby allowing it to soak into the earth where no plants exist. When water is sprayed through sprinklers, it might evaporate into the air.

Water losses and miss management are directly relatedtodecreasing water use efficiency of the farm, water losses from canals are heavily influenced by soil permeability, canal lining, water depth, and groundwater levels. The soil plays a significant part in canal leakage, with new research revealing that soil compaction is also an important aspect of surface runoff reduction [4]. Canal seepage rates of 25 to 50 L/ (m^2.day) have been widely acknowledged as reference values for canals that meet their obligations [5].

Tamil Nadu has utilized more than 90percentof its available surface water resources to capacity. The groundwater estimation committee (GWEC) established by the National Bank for Agriculture and Rural Development (NABARD) with the Central Ground Water Board (CGWB, 2000) and the groundwaterwing of the public works department (PWD) estimated the groundwater potential in Tamil Nadu to be 22,432 Mm^3, of which 1,022 Mm^3 is designated for domestic and industrial water supply requirements (CGWB 2017). The real demand for water supply networks for combined urban and rural populations is 1,057 Mm^3.

In 2025, the water requirements for irrigation, residential, livestock, and industrial sectors in Tamil Nadu would be (52.7), (1.5), (1), and (2) billion m^3, respectively, compared to the available availability of 24.6 BCM of surface water and 23 BCM of groundwater. A balance between demand and supply is often hard to maintain [6].

There are no perennial rivers in Tamil Nadu, and the vast majority of rivers have concerns with water shortages and sustainability [7]. In this research, we examine the water challenges in the Thenpennaiyaru river basin, which have been the subject of significant public debate and action over the past two decades. The majority of the controversy was initiated by farmer about water demand and supply gaps in this basin.

Alegre*et al.* [8] introduced a water balance for urban water supply systems, which has shown to be a useful tool for assessing water losses. A reliable water balance enables utilities to diagnose their systems, develop strategic plans to reduce water losses, improve infrastructure asset management, and track the success of applied measures/actions over time. The water balance developed for urban water distribution systems cannot be directly applied to all collective irrigation systems because the latter can include huge reservoirs and outdoor canals that are subjected to different system input volumes and water losses (evaporation, canal discharges, reservoir storage variation [9]. Although WUAs have already reviewed these many components, an integrated method in which systems are analyzedas a whole is currently lacking.

2. Methodology

2.1. Water loss management accounting approach

This study proposes and describes a thorough water accounting approach for Thenpennaiyaru river basin irrigation systems. The Thenpennaiyaru river originates from the south-eastern side of the chennakesava hills and the north-western side of the nandihills. It flows for a distance of about 85 kilometers within Karnataka and flows 400 kilometers (km) from its point of origin before joining the bay of bengal (Figure 1), it has a catchment area of 1,424 square miles (3,690 km^2) located in Karnataka and Tamil Nadu states. Krishnagiri (KRP) dam with (1.6) TMCft capacity and sathanurdam with (7.3) TMCft capacity are built across this river. Ponnaiyar is the sole water source in Krishnagiri, Tiruvannamalai, Villupuram, andCuddalore districts majority of the population dependson this river for agricultural and allied activities [10].

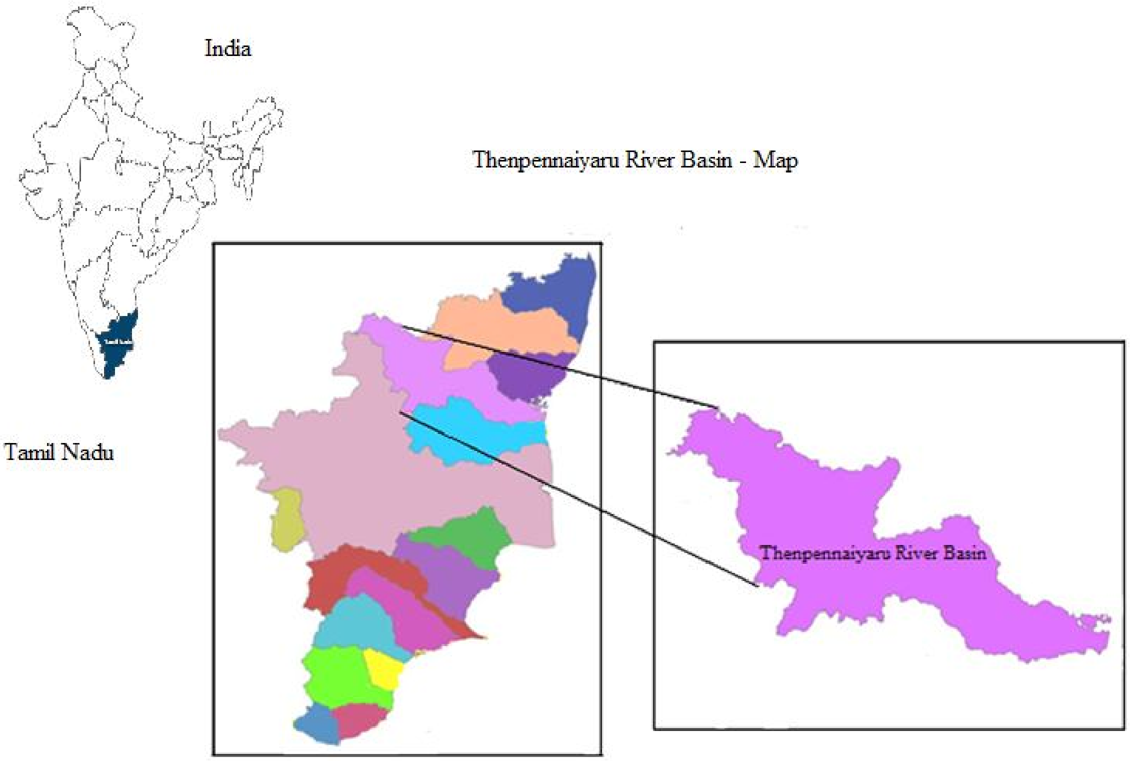

Fig 1. Study area Thenpennaiyaru river basin of Tamil Nadu

Here the first step is to define the boundaries of the irrigation system. The evaluated system should encompass all water transportation and distribution infrastructures to farms like reservoirs, intermediary reservoirs, canals, andpipelines, with the goal of increasing water use efficiency. The current investigation focuses on water fluxes that transcend specific boundaries during the system's operational time in 2021. It differs significantly from a normal water balance study [11]. in that its borders, and thus its components, are significantly different, as illustrated in (Figure 2&3).The water balance boundaries do not include irrigation fields or catchments (shown as grey in the diagram), but rather the conveyance and distribution network of irrigation systems up to the point of user delivery and current system discharges.

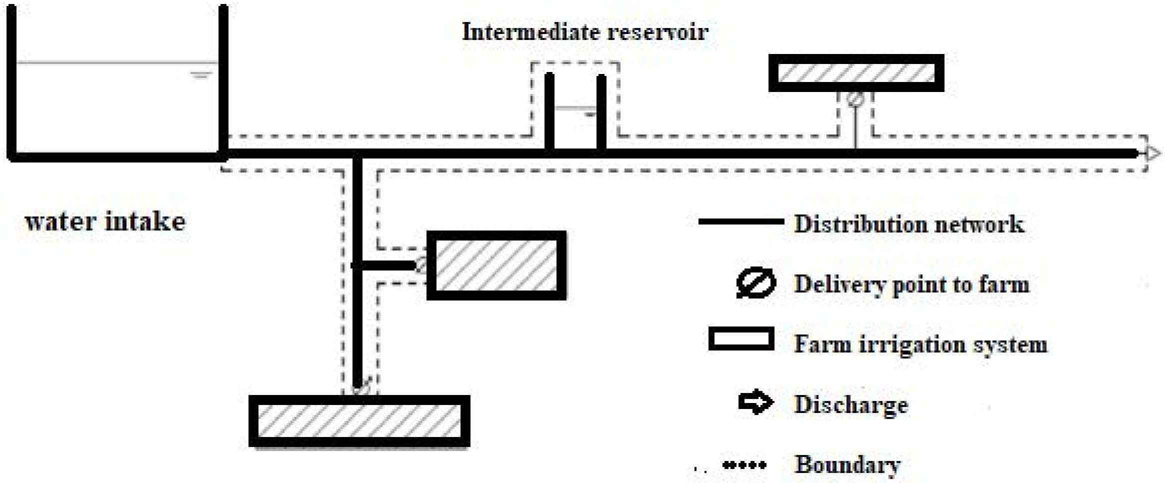

Fig 2. System boundary to consider for water balance calculation

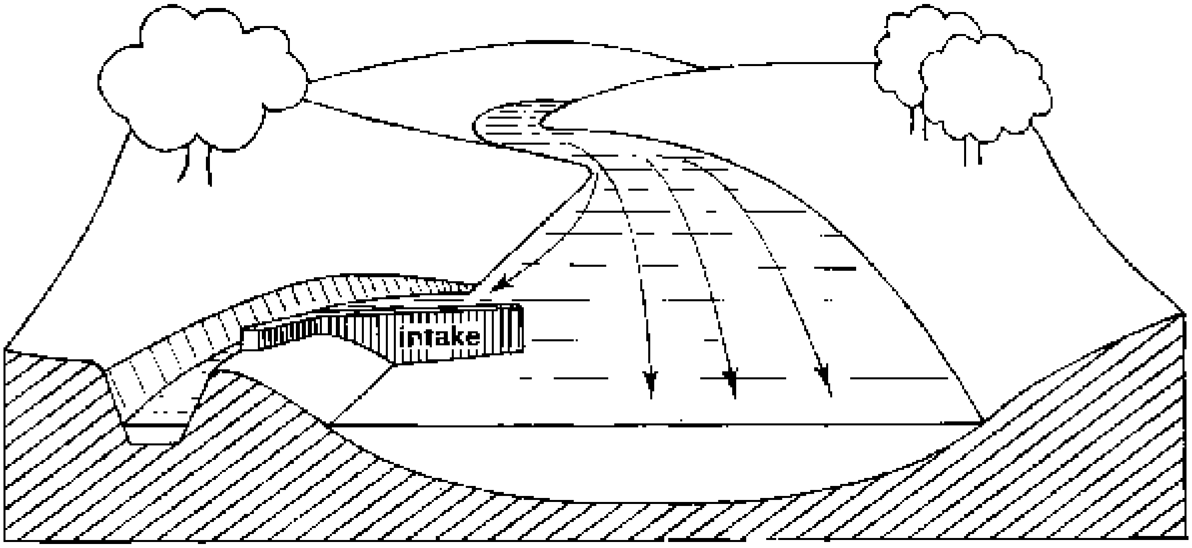

Fig 3. Intake structure of the reservoir

2.1.1 Data set

New components have been considered when calculating the water balance because the system may contain open canals and intermediate reservoirs. Table 1 illustrates the proposed water balance strategy for irrigation systems. The data on reservoir inflow for a period (2020-2021) was collected from the WaterResources Department of the Governmentof Tamil Nadu and (PWD) Dam-water resource Department Government of Tamil Nadu. The precipitation and evaporation data were collected from nearby meteorological stations.

Table 1. Water balance components for Thenpennaiyaru river basin irrigation systems

System Input Volume	water Consumption	Authorized Consumption	
	Water Loss	Evaporation Loss	Evaporation Losses In Canal
			Intermediate Reservoirs
		Apparent Loss	Unauthorized Consumption
		True Loss	Leakage In Canal
			Leakage In Intermediate Reservoirs
			Discharge In Canal
			Discharge In Intermediate Reservoirs

2.1.2 The process for calculating the water balance is consisting of 7 key steps:

1. Estimate the system input volume water (for example, drained water, imported water, rainfall, runoff, and intermediate reservoir contributions).

2. Calculate the total water consumption by summing all authorizedConsumption units.

3. Water loss. Subtract the authorized consumption (2) from the total system input volume (1) to get the total volume of water losses (3).

4. Calculate evaporation losses in the canaland intermediate reservoirs.

5. Assess the components of apparent losses using the methodologies.

6. Subtract evaporation (4) and apparent losses (5) from total water losses to get an estimate of true losses.

7. Assess true loss components using the most up-to-date methodologies and compare them to the volume of true losses previously calculated (6).

The water balance computation then follows a bottom-up method, as indicated in step (7), where true loss components should be considered. The results acquired using these two methods aid in fixing the water balance with greater precision.

The system total input volume sub-components discussed are related to rainfall, runoff, and intermediate reservoir storage, with new authorized sub-components (i.e., minimal operating volume) and canal-related water loss elements (i.e., evaporative losses, canal leakage, and discharges) also covered.

2.2. Precipitation-related system input volume in canals and intermediary reservoirs

Precipitation that falls directly on the surface area is included in the system's input volume in open canals and intermediate reservoirs [12]. To estimate the input volume owing to precipitation, precipitation data, canal reaches, and intermediate reservoir, as well as their geographical location. If geographic data is unavailable, the average value from nearby weather stations should be utilized.The total volume of direct precipitation entering the system is calculated by multiplying the precipitation head, P (m), by the canal/reservoir surface area, A (m^3).

2.3. System input volume due to intermediate storage

The water level inside the reservoirs should be computed to evaluate the positive or negative contribution of the intermediate reservoirs to the overall balance of the irrigation system. The variation in reservoir volume is given by:

$$\Delta V = (Vin + Vp + Vrun\ off)\ (Vout + Vevap + Vleaks + Vd)$$

Where V_{in} = the volume from the canal to the reservoir,
V_{p} = the precipitated volume in the reservoir,
V_{runoff} = the affluent runoff volume to the reservoir,
V_{out} = the volume from the reservoir to the canal,
V_{evap} = the evaporated volume in the reservoirs,
V_{leaks} = the volume of leaks,
V_{d} = the volume of reservoir discharges.

A positive volume indicates that there is water in the reservoir. In contrast, a negative volume is associated with a decreasein reservoir water level, resulting in a positive value for this system input volume component.

2.4. Water consumption.

Water consumption for irrigation purposes and another house domestic and livestock purposes is estimated where the water is consumed in authorized and non-authorized forms.

2.5. Water loss elements

The water loss elements included in the water balance are as follows: (i.e., apparent loss and true loss). Leakage, evaporation, and discharges are also new water loss components associated with the canal system and intermediary reservoirs. The current section describes water loss components, with a focus on elements that should be predicted for canals and intermediary reservoirs [13]. Estimates should be made when accounting for water losses due to evaporation if open canals or intermediary reservoirs are part of the system. Data from meteorological stations (i.e., precipitation records) should be acquired in the same way that precipitation estimates are in order to determine the evaporation volume.

$$ET_p = 16N_m\left(\frac{10\bar{T}_m}{I_a}\right)^a$$

Where ET_p = evaporation volume

N_m = latitude- and time-dependent correction factor,

T_m = the average monthly temperature (°C),

I_a = the yearly thermal index, and

a = polynomial function of the index.

3.Resultand Discussion

The proposed approach is applied to the Thenpennaiyaru river basin irrigation system; the principal sources of water are the KRP reservoir and Sathanur reservoir in the Thenpennaiyaru river basin. Nudugal anicut and Ichchampadi anicut are used to transport the water gathered at (KRP reservoir). This ancientwas constructed to allow two pumping stations to transport water to two distributors located at higher terrain elevations. The nextintermediate reservoir (Sathanur reservoir) holds excess quantities, lowering the volume released downstream. Along the system, water is gathered from the water line and introduced via pumping stations in Thirukoilur anicut and Somavur anicut, the collected water is carried by a canal that connects to the principal conveyance canal, and the remainingflows to the sea (Figure 4). Depicts a diagrammatic illustration of the system, and also shows the limits of the subsystem that will eventually be evaluated for runoff estimation utilizing water balance computation.

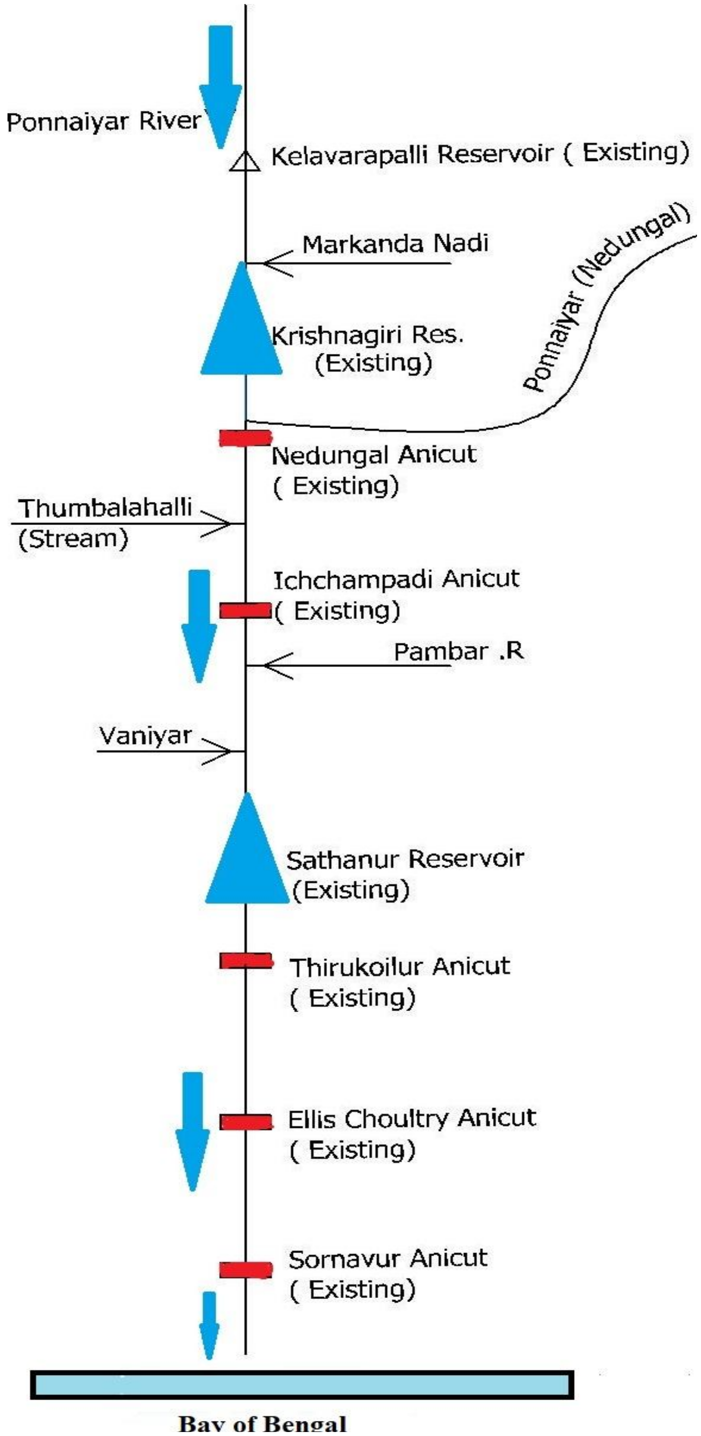

Fig 4. Schematic diagram of the Ponnaiyar river system with Major structures and link canal*Source: Public Works Department Governmentof Tamil Nadu*

Irrigation systems are extremely dependent on rainfall, not only from a water storage perspective, but also because precipitation is a significant role in determining the water consumption of users. **Figure 5** depicts rice production and rainfall records from 2011 to 2021.

Given that rice farmers have consumed an average of 21,880 m^3/ha of water per hectare over the past decade, they are the greatest users of water.

Fig 5. production and average rainfall for the lastten years

The impact of rainfall fluctuations on user water demand is depicted in theyears with greater rainfall, water usage achieves lower values, but in years with inadequate rainfall, water demand rises.

3.1. Water balance

Based on the availability data, the reference period for the water balance computation was developed. The agricultural season began in June 2021 and ran through october 2021, during which the system was operational. During this period, the total amount of water collected from the system's sources (reservoirs and pumping stations) was computed, with source-specific information provided in Table 2.

Table 2. Estimated system input volume components

System input Volumes components		**Volume (m^3)**
Abstracted water	from reservoirs	51,33,14,02
	from the river	2795319
Precipitation	in canal	116864
	in intermediate reservoirs	2172
Runoff to canal		953813
Total system input volume		**55199570**

In order to compute the total input volume owing to rainfall, data from the weather stationsweregathered and the cumulative rainfall for each weather station over the reference period was calculated. Due to the lack of geographical information on the canal reaches, the average collected precipitation from nearby stations was used for the whole canal network. For the weirs and intermediate reservoirs, rainfall totals from the meteorological station closest to each structure wereutilized. The total inflow volume of water to the reservoir was 328 cusecs, while the discharge was 138 cusecs *(Reservoir Storage Bulletin central water commission, dated 1.09.2021).* Cusec is a measure of flow rate and it stands forliters per second [14]. One cusec is equal to 28.31 litersper second. 138 cusecs = Flowing or Running 3906.78 liters per second. The storage in the reservoir was 1,441.27 TMCFT against the total 1,666.29 TMCFT on the date of the systemoperational period 2021.

3.2. Water Loss component

In estimating the water loss components considering that the majority of the irrigation system is an open canal, evaporation losses were calculated. The evaporation estimation was performed for the same two reservoirs before being extrapolated to the whole network. In order to determine evaporation in the river portion of the conveyance system, the average surface width in meters and total length in kilometers were utilized. Considered evaporation value was the average value reported throughout the irrigationseason by weather stations. For the calculation of the intermediate reservoir and the two weirs, the evaporation value recorded at the closest meteorological station to each structure was utilized.**Table 3** presents the outcomes.

Table3. Estimated water losses due to evaporation in canals and intermediate reservoirs in 2021

Particulars	Extension (km)	Evaporation (m^3)
Conveyance system (river)	154	194302.2
Conveyance system (canal)	290	185470.3
Distribution network (canal)	242	26495.76
Intermediate reservoir	-	35327.68
Total	686	**4,41,596**

Results show various water loss components in the study area and the complete water balance for the 2021 irrigation season is presented in Table 4. The total system input volume of water was (5, 51, 99, 570 m^3). In the system operation period, the amount of 33.5% (18,215,858 m^3) of water was lost as evaporation loss, apparent loss, leakages, and discharge losses.

Table4. Results of the water balance calculation for the system in 2021

System input volume 55199570m^3	Water consumption 36983711.91 m^3 (66.5%)	Authorized Water consumption 36983711.91 m^3 (66.5%)	
	Water losses 18215858 m^3 (33.5%)	Evaporation losses 441596m^3 (0.8%)	Evaporation losses in canal 441596.56 m^3(0.8%)
			Evaporation losses in intermediate reservoirs66239.48 m^3 (0.1%)
		Apparent losses 4967961m^3 (9.3%)	Unauthorized consumption 496796 m^3(9.3%)
		True losses 13247896 m^3 (24.1%)	Leakage on pipe network 55199.57 m^3(<0.1%)
			Leakage in canals 3974369.04 m^3(7.2%)
			Discharge in intermediate reservoirs 71759.44 m^3(0.1%)
			Discharge in canals 9383926.90 m^3(17.0%)

Leaks and discharge were seen as actual water loss due to poor management and less infrastructure maintenance as presented by Vermersch *et al.* [15].

Estimation of network pipe leakage was based on the real loss reference value for urban distribution systems with poor service quality, 5m^3/ (km/day). Due to the age of the infrastructure, which is past its expected technical operational life, and many pipe ruptures recorded by the WUA, a pessimistic figure was evaluated [16].

Presently, the state of the canals implies that the true losses may exceed the levels mentioned in the literature. In order to determine a value for the leaks, the inflow-outflow statistics in a representative section of the canal were calculated. The length of the surveyed canal is around 30 kilometers, and at the time all canal gates were locked. However, AMIL gates are not completely waterproof, allowing a limited discharge to pass through. The reported inflow at the canal head was 140 L/s, and as there was no flow meters downstream of the canal, the outflow was estimated to be 19 L/s based on in-situ observations. The estimated water leakage via the canal is 120 L/s, which equates to a water loss rate of 48 L/ (m^2.day) based on the geometrical parameters of the canal.

The total water balance including genuine water loss components for the 2021 irrigation season is presented in Figure 6.

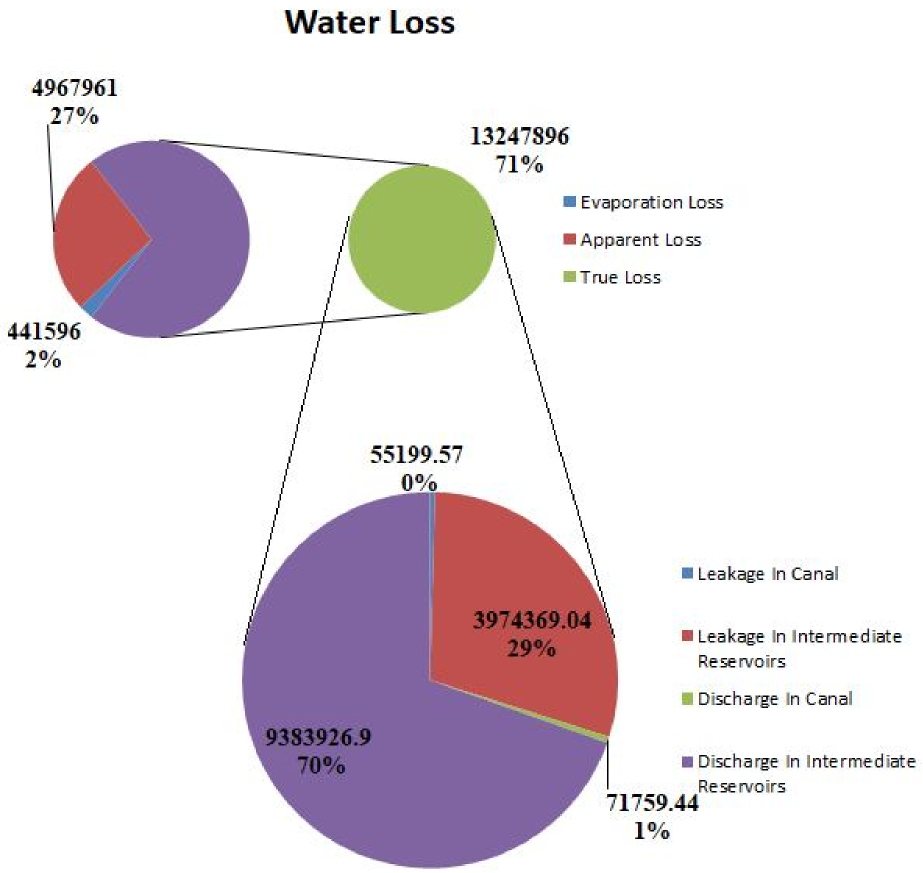

Fig 6. water balance and true water loss projection

4. Conclusion

An innovative, comprehensive approach for calculating the water balance in irrigation systems has been presented and illustrated. This technique has the potential to become an essential performance evaluation tool for canal and pressurizedsystems, hence assisting farmers in implementing more effective water management strategies. The water balance computation enables a system diagnostic in terms of the system input volume, consumption, and water losses, so enabling farmers to implement improvement actions. The water balance is also an essential tool for calculating a set of water loss indicators, which will enable farmer organizations to evaluate their performance over time and compare the performance of other river irrigation systems. The systematic water balance calculation for each irrigation season enables the evaluation of the effectiveness of implemented improvement measures. The suggested water balance is influenced by the urban water balance principles and contains additional components on system input, authorizeduse, and water losses. This technique was evaluated for the first time in the Ponnaiyar river system, emphasizing the significance of true water losses to the irrigation system. To confirm the acquired results, it is necessary to conduct hydrological modeling of the basin that contributes to runoff. Concerning measurement errors, the inaccuracy of the watermeters, and, in open canal systems, the hydraulic performance of the modules responsible for deriving flow to the user should be reviewed. It was found that the flow range of certain installed metersdoes not meet the range of water demand linked with rice crop needs; this is due to the improper selection of meter size. The results reveal the necessity to rehabilitate the conveyance and distribution facilities and limit canal discharges. In the future, additional canal irrigation systems should be evaluated in order to strengthen the approach and enhance the management of canal leakage.

7. References

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