Article

Flow Simulation and Storage Assessment in an Ungauged Irrigation Tank Cascade System Using the SWAT Model

Koppuravuri Ramabrahmam [1], Venkata Reddy Keesara [1], Raghavan Srinivasan [2], Deva Pratap [1] and Venkataramana Sridhar [3,*]

[1] Department of Civil Engineering, National Institute of Technology Warangal,
Warangal 506004, Telangana, India; rambrahmam@student.nitw.ac.in (K.R.); kvreddy@nitw.ac.in (V.R.K.);
deva@nitw.ac.in (D.P.)
[2] AgriLife Research, Texas A&M University, College Station, TX 77843, USA; r-srinivasan@tamu.edu
[3] Department of Biological Systems Engineering, Virginia Polytechnic Institute and State University,
Blacksburg, VA 24061, USA
* Correspondence: vsri@vt.edu

Abstract: In the semi-arid regions of South Asia, tank systems are the major source of irrigation. In India, the Telangana state government has initiated the Mission Kakatiya program to rejuvenate irrigation tank systems. Understanding the hydrological processes that supply water to these systems is critical to the success of these types of programs in India. The current study attempted to comprehend the hydrological processes and flow routing in the Salivagu watershed tank cascade system in Telangana. There are a lot of ungauged tank cascade systems in this region. Soil Water Assessment Tool (SWAT), a physically-based model, was used to simulate flow patterns in the Salivagu watershed with and without tank systems. The geospatially extracted area and volume were used for this study provided by WBIS-Bhuvan-NRSC. Additionally, the Katakshapur Tank Cascade System (KTCS) was chosen to analyze the water availability in each tank using the water balance approach. The Salivagu watershed flow simulation without tanks overestimated streamflow. The volume difference in flow between with and without tank was 606 Mm^3, 615.9 Mm^3, and 1011 Mm^3 in 2017, 2018, and 2019, respectively. The SWAT simulated volumes of the Ramchandrapur and Dharmaraopalle tanks in KTCS were merely satisfied because the tank size was less than 0.7 km^2 and the storage capacity was up to 1 Mm^3. Due to tank sizes more than 0.8 km^2 and capacities greater than 2 Mm^3, the Mallampalli and Katakshapur tank simulation findings were in good agreement with WBIS-Bhuvan-NRSC. This research advances our understanding of the hydrological processes in ungauged cascading tank systems in tropical semi-arid regions.

Keywords: flow simulation; geospatial data; SWAT; tank cascade system; WBIS-Bhuvan-NRSC; water balance

1. Introduction

Semi-arid areas in tropical zones face significant water resource management and food security challenges. Tanks and cascade tanks are the primary source of water for agricultural needs in the semi-arid region of Southern India. Because of the importance placed on major dams, these systems have been neglected over the years. People and governments have recently begun to recognise the negative effects of dams and the benefits of tank systems. Tank systems account for more than one-third of the irrigated land area in southern India [1]. A tank is built by erecting earthen embankments across sloping terrain to collect rainwater during the monsoon and store it for use during the remaining dry seasons. These tanks are connected in a series over a single watercourse in south India, and this is known as the Tank Cascade System (TCS) [2]. Spilled water in TCS flows through the upstream tank command area and into the downstream tank catchment. Since the time of the Kakatiya rulers, the Indian state of Telangana has been awash in tanks [3,4]. Due to

siltation, bund flagging, unmaintained sluice gates, and extensive use of agricultural bore wells, these tank systems were neglected over time. The state government launched the Mission Kakatiya programme, which aims to restore all 46,531 minor irrigation tanks in Telangana in order to boost the development of tank agriculture-based income for small and marginal farmers [5,6]. The success of these programmes will be determined by a thorough understanding of the hydrological processes that contribute water to these systems.

Despite the fact that the tanks have been rejuvenated, tank storage information is required based on an analysis of hydrological flow and water balance in the TCS. If the hydrology of one or more tanks is changed to accommodate more capacity or to expand the command area, the overall cascade system may suffer [7]. TCSs are hydro-geologically and socio-economically linked in terms of water storage, conveyance, and utilisation [8]. Tank storage is a significant factor that influences the magnitude and timing of watershed runoff [9]. For an accurate prediction of watershed hydrology and water budget, explicitly accounting for tanks in a cascading pattern in the flow simulation is crucial. Although the majority of small and medium-sized local irrigation tanks are ungauged, a better understanding of storage and fluxes is required for successful water consumption and management within those ungauged cascade systems. Tank water fluxes (inflows and outflows, evaporation, groundwater recharge, and sluice outflows) are required for accurate tank water availability evaluation while managing single and cascaded tanks [10,11].

Understanding the operations of such systems and determining the water balance components are made possible by hydrological modelling of the TCS [12]. There have been studies that used an appropriate hydrological modelling approach to address the flows and water balances of single tanks and TCS. Li and Gowing (2005) [13] developed a catchment-tank-command water balance model to estimate the dynamics of tank storage and suggested that the model be used to evaluate existing tank water management techniques. Kanagaraj et al. (2021) [14] used the USDA-NRCS (Natural Resources Conservation Service) curve number approach to model irrigation tank surface runoff for a small ungauged watershed. The simulated flows were within 10% to 20% of the measured flows. Dessie et al. (2015) [15] used the Wase–Tana model to estimate the runoff input for a lake from gauged and ungauged catchments for two scenarios: with and without the flood plain area. According to the findings, 6% of river inflows were kept in the flood plain's lake.

Gal et al. (2016) [16] employed a remote sensing approach to estimate the inflow volume of lakes in ungauged basins using the HVA (Height-Volume-Area) model. Over the last 60 years, the water inflow ratio has increased, but the patterns have not been statistically significant. Ovakoglou et al. (2016) [17] used MODIS satellite images to map shorelines at different time scales for sedimentation deposition pattern in Lake Kerkini, Greece, and their study discovered the use of satellite images in lakes to assess depth and sediments volume where bathymetry is not possible. Ogilvie et al. (2018) [18] used the GR4J hydrological model and satellite observations to simulate the volume of small lakes. Except in the smallest and most data-scarce lakes, the NSE improved from 0.64 to 0.94 on a daily basis. Bishop et al. (2006) [19] developed the HYLUC-CASCADE model to assess the impact of cascade tanks in the watershed and reported better monthly runoff values, with a wider range for daily runoff. Jayatilaka et al. (2001) [20] developed the Cascade Water Balance Model (CWBM) to predict the water availability in the tank cascade system. The model results revealed important information about the cascade system's water balance and interconnections. Due to the inadequacy of field observations, the simulated results were not directly comparable with the observed data, and the model was not fully validated. With improved CWBM and modified evaporation and seepage equations, Jayakody et al. (2004) [8] evaluated the hydrological components and runoff at each tank. The model results showed that monthly simulations were better than daily simulations in the dry zone.

Jayatilaka et al. (2003) [21] developed the Reservoir Operation Simulation Extended System (ROSES) model to estimate water availability by accounting for dynamic hydrologic components in the tank cascade system. Although the model simulated results agreed well

with the observed data, model validation was not performed. Van Meter et al. (2016) [11] investigated the water-exchange dynamics of RWH (Rain Water Harvesting) tanks at the tank, cascade, and catchment scales in order to calculate the hydrological components using a conceptual water balancing approach and large amounts of observed data. According to the study, ground water recharge and outflows are the most important components of tank water budget, and the most downward tank (last tank in cascade) received more ground water exchange benefits at the cascade scale. Krishnaveni and Rajeswari (2019) [9] applied the physical distributed model (MIKE SHE/MIKE 11) to simulate the physical process of tank cascades in a small watershed's stream network. The flow simulation results showed that the model has good predictive capability, and cascade tanks stopped the flow of water, which has a significant impact on water balance analysis. Bucak et al. (2017) [22] used the SWAT model to forecast future lake water availability. The findings revealed a decrease in future water availability and hydrological impact as a result of land use scenarios. Jayanthi and Keesara (2019) [23] used the SWAT model to predict the future inflow of Pakhal Lake. The study found a 57% decrease in tank inflows in the future and recommended that the SWAT model be used for semi-arid tank systems via parameter transfer from gauged watersheds, when applied to ungauged watersheds. Perrin et al. (2012) [24] used ponds and well observations to assess water availability in tanks at the regional scale in a semi-arid region and found that percolation tanks provide 23% of the annual aquifer recharge for normal monsoons.

In the research studies mentioned in the above section, flow was modelled by treating the tanks as a single storage node in the lumped rainfall-runoff models. The hydrological assessment and water balance in single and cascade tanks utilising conceptual, physically dispersed models yielded positive results, but more observed data was necessary. In addition to certain closely observed data and literature values, the empirical equation approach requires some close observed data. In ungauged areas, the use of a mix of hydrological modelling and remote sensing observations yielded better results for quantifying hydrological systems [16,18,25–28]. In its flow simulations, the SWAT is a spatially distributed model that can explicitly account for land use/land cover and anthropogenic changes [21,29]. The SWAT model was also used to simulate hydrological processes in ungauged watersheds with single tanks [18,23,24,30]. The hydrological process is simulated for gauged and ungauged watersheds, gauged tanks, and regional scale flow simulation of watershed with ungauged TCS. Most previous studies concentrated on watersheds, but only a few looked at the role of tanks and the Tank Cascade System (TCS) in the simulation of hydrological processes using a physical model. SWAT, on the other hand, is a physical distributed model that requires minimal data to model the hydrological process via tank cascade systems.

The goal of this research is to simulate the hydrologic processes of tanks and to analyze the water balance components of each tank in the selected TCS and the entire watershed using the hydrological model and remotely sensed data. In the present study, the SWAT model was used to simulate catchment hydrological processes in two ways. Initially, a SWAT model was created and used to simulate surface runoff by taking into account all of the tanks in the catchment area. Tank details were included in the simulation based on WBIS-NRSC-Bhuvan (Water Body Information System (WBIS) offered by Bhuvan, National Remote Sensing Centre (NRSC), Hyderabad, India) data. SWAT-CUP is used to determine the best fit parameters for the calibration and validation of the SWAT model. Later, same best fitted parameters were used to simulate the flow in the watershed without taking into account any tank systems. This is to determine the effect of tank systems on the outflow from the watershed. To analyze the impact of tanks presence in the water balance components of the watershed, one of the TCS (KTCS-Katakshapur Tank Cascade System) was considered for the detailed water balance analysis. This study aids in determining the accurate estimation of surface water resources and is useful for water allocation and management for the catchments that include intervening surface storage structures such as ponds, tanks and reservoirs. The findings of this study can be used to assess the efficacy of

tank rejuvenation process and to develop long-term water management strategies for Tank Cascade Systems (TCS).

2. Study Area

The Salivagu watershed (Figure 1a) is located in the Warangal urban and rural districts of Telangana, India, between latitude 18°0′8″ N and 18°23′3″ N and longitude 79°14′25″ E to 79°57′41″ E. The watershed covers an area of 1879 square kilometers and receives an average annual rainfall of 846 mm (1951–2016). The Salivagu river flows into the Manair river, a tributary of the Godavari. The Salivagu watershed has a semi-arid climate and no major perennial rivers nearby. To augment the water resources for agriculture, the Kakatiya dynasty (1200–1300 AD) constructed numerous tanks and TCS. This watershed has 315 small and medium-sized tanks (Figure 1) and majority of which are ungauged. All of these tanks collect water during monsoon (June to Oct) and use it for agricultural purposes all year. These tanks lack adequate control structures for inflow and outflow management. In all tanks, maximum storage is observed during each monsoon season. This watershed has one large tank at the end (downstream) of every stream reach that collects all of the spill over water from the upstream cascade tanks. At the moment, these medium-sized tanks are unable to store the excess water from the upstream tanks. The majority of the tank spillover sections are located near the main road, posing a threat to the local public and transportation systems. Figure 2 depicts two tank spillover sections during full and overflow conditions. This study addresses the need to quantify inflows into the TCS rather than individual tanks in order to better design controlling structures.
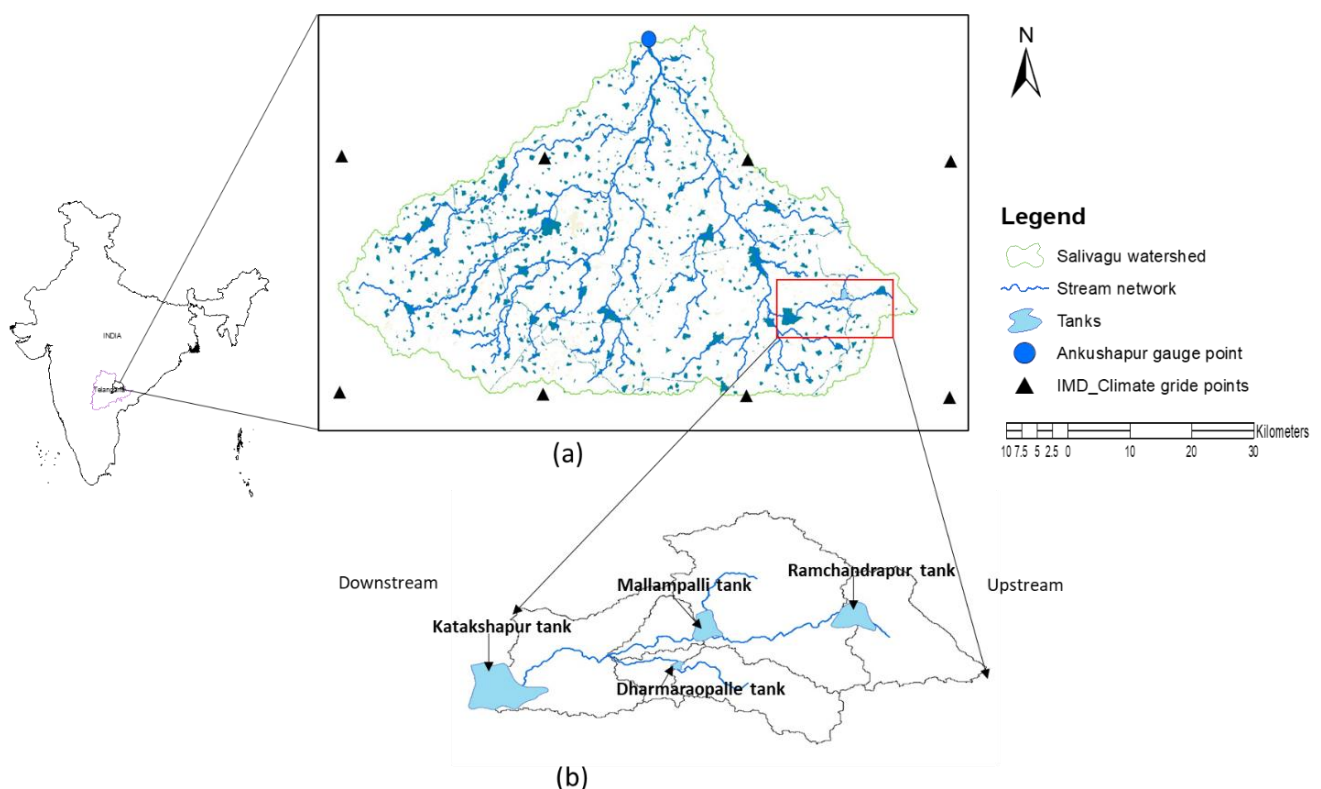
Figure 1. Location of study area, (**a**) Map of Salivagu watershed with tanks and (**b**) Katakshapur Tank Cascade System (KTCS).
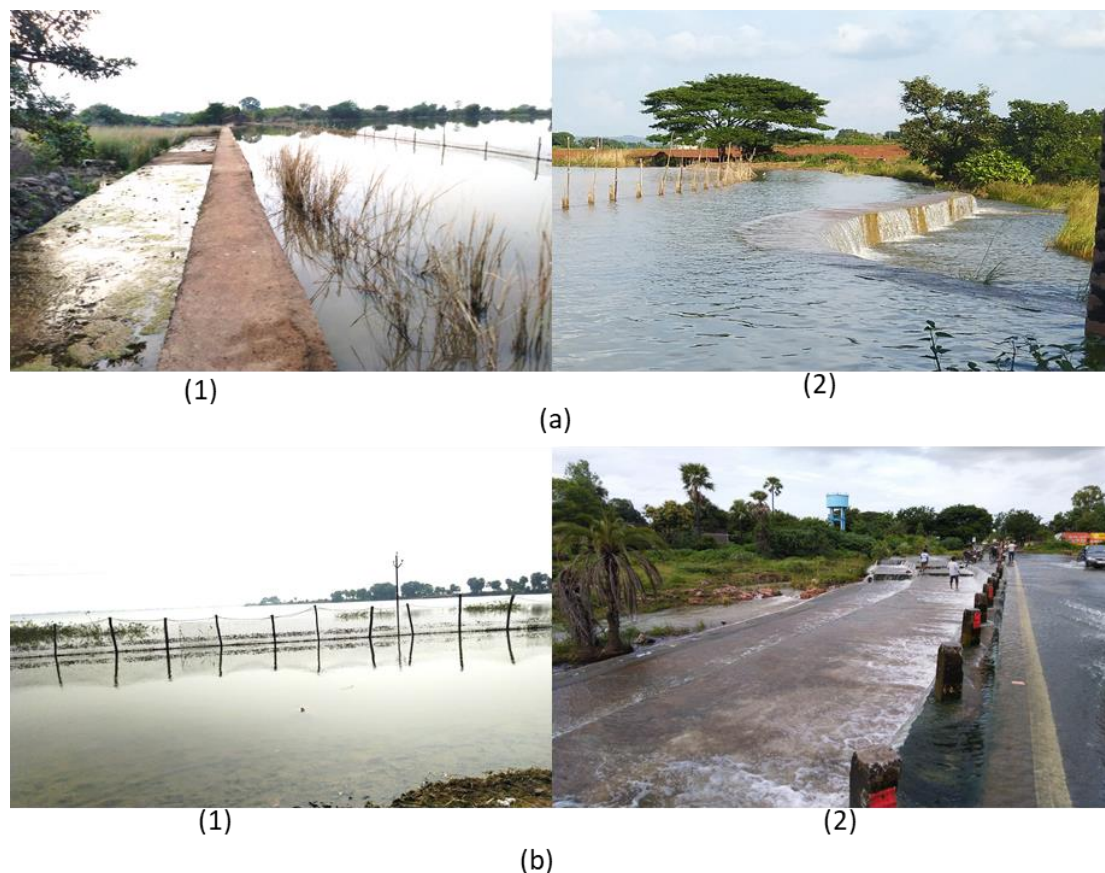
Figure 2. The condition of tank overflow section (**1**) during full storage, (**2**) during flood events of (**a**) Mallampalli tank and (**b**) Katakshapur tank.

To determine the influence of tanks, the Salivagu watershed flow simulation was run with and without tanks. In addition, the KTCS (Katakshapur Tank Cascade System) (Figure 1b) was chosen to compute the tank volume using the TCS's water balance. The KTCS is located on the Pedda bodaru vagu (stream), which runs for 13 km from the uppermost tank to the lowermost tank. It is made up of eleven interconnected tanks, seven of which are quite small and have a capacity of less than 0.1 Mm^3, and were therefore excluded from the water balancing study. At Ramchandrapur, Mallampalli, Dharmaraopalle, and Katakshapur, the KTCS water balance was accomplished. There are no further tanks or canals in the cascade's most upstream tank. Table 1 lists the various tanks' catchment and command areas.

Table 1. The catchment and command area details of KTCS tanks.

S. No	Name of Tank	Catchment Area (km^2)	Command Area (Acres)
1	Ramchandrapur	14.29	230
2	Mallampalli	32.5	550
3	Dharmaraopalle	12.4	120
4	Katakshapur	19.51	1500

The topmost tank, Ramchandrapur, draws streamflow from a 14.29-km^2 catchment area. This tank serves as a storage tank, and when it fills up, the excess water spills over into the Mallampalli catchment's downstream tank. The Mallampalli tank gets streamflow from a 32-km^2 catchment area, which is supplemented by flow from the

upstream Ramchandrapur tank. The water from this tank is released through two sluices into a 550-acre command area via the alluvial canal.

Dharmaraopalle tank is situated on a tributary of the Pedda Bodaru vagu and collects water from a catchment area of 12.47 km^2. The water from the tank is released through two sluices to irrigate 120 acres. Katakshapur tank is the KTCS's lowest tank, receiving water from tiny tanks in a 19.51 km^2 catchment region, as well as spill-over water from Mallampalli (Figure 2a) and Dharmaraopalle tanks. The water is released from the Katakshapur tank through four sluice gates to irrigate a 1500-acre command area, where the excess water flows downstream (Figure 2b) and into the Salivagu stream. During the monsoon season, all of the water in the tanks is used to meet the agricultural needs of the Kharif season (July–October) which is the first crop season following the onset of the southwest monsoon. If there is any remaining water in the tanks at the end of the season, it will be used in the rabi season (December–April).

3. Data and Methodology

3.1. Data

The Salivagu watershed is in a semi-arid zone, and the Salivagu river only has flow for six months of the year, during the monsoon. The streamflow gauge station on the Salivagu river near Ankushapur hamlet was erected in 2017, hence data on observed discharge is only available for the last three years (2017 to 2019). In the Salivagu watershed, there are various tank cascade systems, but KTCS was chosen for a complete water balance evaluation. Among the neighbouring KTCS tanks, only four tanks have substantial size and capacity and are ungauged. In the absence of observable data, the surface area and volume of tanks extracted from satellite imageries serve as the best equivalent. Waterbody Information System (WBIS) [31] was used as geospatial data in this work, which is available in the Bhuvan platform, which was created by the National Remote Sensing Centre (NRSC). Since 2012, the WBIS has collected data on water surface area and volume of water bodies for the entire country. Using multi-sensor satellite data, the tank water spread area and volumes were estimated. Water pixels and sensor-specific automated water bodies using extraction algorithms were used to estimate the surface area. The size of the tank determines the temporal resolution of the data. If the water body area is greater than 50 ha, the temporal resolution is 15 days, greater than 2 ha, once per month, and greater than 0.025 ha, once per season [32]. The volume was calculated based on the water spread area and the tank's approximate water levels. When an anomaly in Bhuvan data was discovered, the NRSC recommended field verification. Table 2 lists important features such as tank depth, which was personally measured in the field, and the water surface area and capacity of the tank, which were received from the Bhuvan portal. The tanks' hydraulic conductivity (K) was estimated with soil sample taken from the tank's bottom using a lab test of falling head permeability method. The soil strata under the tank bottoms in the Ramchandrapur and Mallampalli tanks are the same, and the tank's hydraulic conductivity is 12 mm/day. The soil layers of the Dharmaraopalle and Katakshapur tanks are comparable, and the ponds' hydraulic conductivity was calculated to be 4.8 mm/day. The water output from the tanks was estimated using the volume to time relationship for each tank in the KTCS and a sump tank at the end of the sluice gate as described in Table 2.

Table 2. Important attributes of observed and satellite-derived data of the KTCS tanks.

S. No	Tank Name	Depth (m)	Maximum Water Surface Area (ha)	Volume (Mm^3)	Hydraulic Conductivity of Tank (mm/day)	Water Release from Tank (Mm^3/day)
1	Ramchandrapur	2.45	70	1.28	0.5	No release
2	Mallampalli	3.65	80	5.254	0.5	0.058
3	Dharmaraopalle	2.23	47	0.9	0.2	0.005
4	Katakshapur	5.5	320	18.91	0.2	0.085

In the Salivagu watershed, a stream network was generated using a 30 m resolution Digital Elevation Model (DEM) from the SRTM (Shuttle Radar Topography Mission). The LULC (Land Use land Cover) (Figure 3b) of 2017 and 2018 with 1:250,000 scale developed by NRSC was used in the present study. The Salivagu watershed covers 73.2% agricultural (AGRL) area, 8.5% of barren land (BARR), 7.63% of water surface area (WATR), 6.1% of urban area (URBN), 3% of wetland area (WETN) and 1.57% of forest area (FRST). The soil map of ISRIC (International Soil Reference and Information Centre) world soil data with 1 km resolution was used in the study. In the command regions of the KTCS, there is a combination of black cotton and red soil, with paddy being the most planted crop in the Kharif season. Cotton, chilly, and maize are also grown in the tank systems based on crop time and water availability. The study used 0.25° resolution gridded data from IMD (Indian Meteorological Data) for observed precipitation, maximum and lowest temperatures. Table 3 lists the various types of data and their sources in detail.
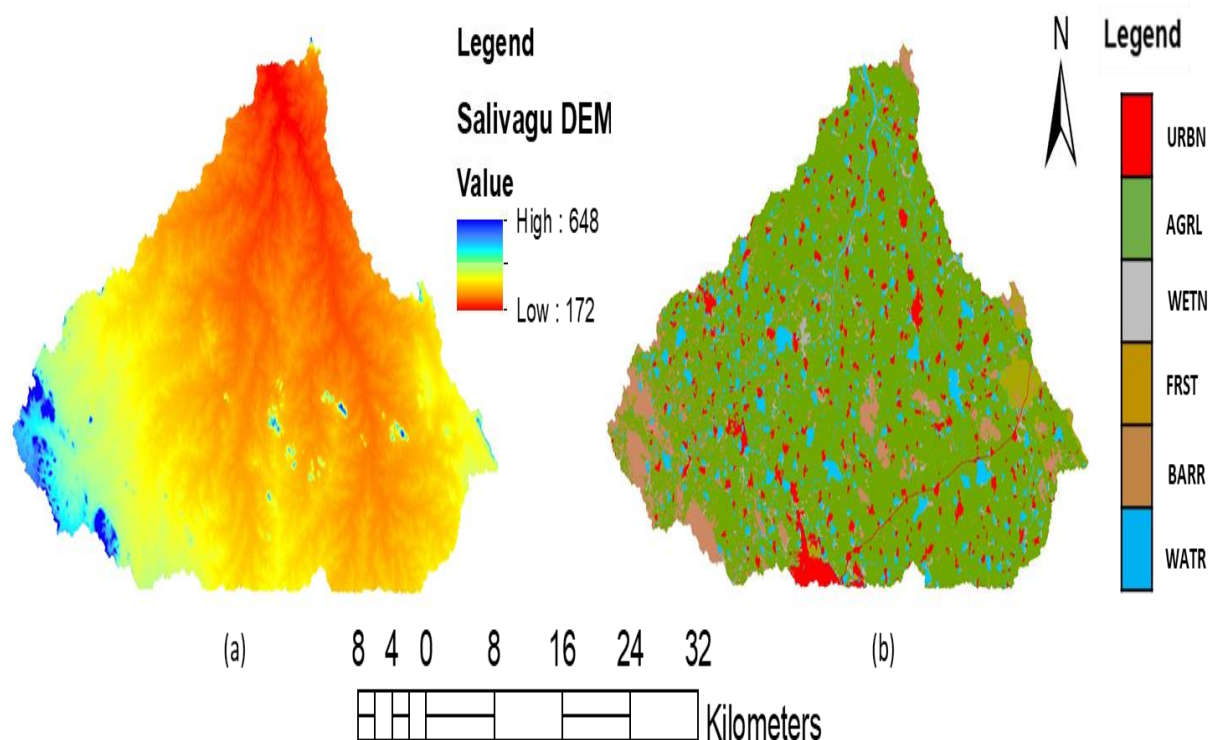
Figure 3. (**a**) Digital elevation model and (**b**) land use land cover of the Salivagu watershed used for SWAT modelling.

Table 3. The data types and sources used in the study.

S. No	Data Type	Data Resolution	Data Source
1	DEM	30 m	https://earthexplorer.usgs.gov (accessed on 2 May 2021)
2	LULC	56 m	https://www.nrsc.gov.in/EO_LULC_Portals https://bhuvanapp1.nrsc.gov.in/thematic/thematic/index.php (accessed on 15 June 2021)
3	Soil	1 km	https://www.isric.org/ (accessed on 20 June 2021)
4	Metrological data (precipitation, temperature)	0.25 Degree	https://www.imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html (accessed on 10 December 2020)
5	Observed streamflow	-	CWC Hyderabad
6	Surface area and volume of tanks	-	https://bhuvan-wbis.nrsc.gov.in/ (accessed on 21 July 2021)

3.2. Methodology

3.2.1. Hydrological Modelling in the SWAT Model

There are numerous challenges in modelling hydrological components for ungauged tank systems. The goal of this research was to use the SWAT model to simulate flow in the Salivagu watershed with and without tank systems and examine water balance in the tank cascade system. SWAT is a physical-based semi-distributed and continuous model [33] used for small-scale catchments to river basin scale to simulate the quality and quantity of surface and groundwater. The watershed is separated into sub basins, which are subdivided further into HRUs (Hydrological Response Units). The SWAT model enables easy visualization of water fluxes at the sub-basin and HRU scales [24]. SWAT is similar to other hydrological models but the major difference is the spatial scale, i.e., semi-distributed, which has the flexibility with input data and process-based to simulate the hydrological processes [34,35]. SWAT computes the surface and subsurface flow by simulating the hydrological process using soil equations (Equation (1)) (Neitsch et al., 2005) [36].

$$SW_t = SW_0 + \Sigma_{i=1}^t \left(R_{day} - Q_{sur} - E_a - W_{Seep} - Q_{gw} \right) \tag{1}$$

where SW_t is the soil water content at time "t", SW_0 is initial soil water content, R_{day} is precipitation on day (i), Q_{sur} is the surface runoff on day (i), E_a is the evapotranspiration on day (i), W_{seep} is the amount of the water seep to the vadose zone from soil profile on day (i), Q_{gw} is the amount of return flow on day (i). R_{day}, E_a, W_{seep} are the vertical flow and Q_{gw}, Q_{sur} are the horizontal flow water budget components respectively. The evapotranspiration from the moist soil and water surfaces are various based on land cover, crop rotation and surface temperature. The E_a fluxes are estimated using Penman–Monteith method (Monteith, 1965; Allen, 1986) on the basis of potential evapotranspiration. The seepage through the soil surface is based on the permeability of the soil layer and it is controlled by infiltration. The infiltration is the entry of water into a soil profile from soil surface. The initial infiltration is based on the soil moisture while the final is equivalent to saturated hydraulic conductivity of soil. The amount of water enter due to infiltration is calculated by the difference of precipitation and surface runoff on daily basis. A portion of the infiltrated water within the permeable layer which returns to the nearby waterbody in the form of recharge flow is called return flow. In SWAT, ground water divides into two aquifer systems, one is shallow and unconfined while the other is deep and confined which contributes return flow in the watershed and outside the watershed. The surface runoff occurs along the sloping surface through daily precipitation. The SWAT simulates the surface runoff volume for each HRU and it is estimated using SCS curve number approach (USDA-SCS,1972). In the present study, SWAT model was applied for the simulation of catchment hydrological processes in two approaches; firstly, the SWAT model was setup for the entire Salivagu watershed, taking into account all of the tanks. The observed discharge was used to calibrate and validate the simulated flow at the Ankushapur gauge station. The SWAT fitted parameters for the aforementioned conditions were used to simulate the flow in the Salivagu watershed without taking into account any tanks. This is to investigate the impact of tank systems in the watershed for the same set of parameters. In addition, to compute the water balance in the KTCS, the WBIS time series data of tank surface area and volume at normal and emergency spill levels are used since observed data is not available for the tanks.

3.2.2. Modelling of Hydrological Process with Tanks in the Watershed

In SWAT modelling, the tanks are classified as ponds with major input pond parameters (.PND) being PND_PSA (surface area of the pond when water filled to principal spillway level) PND_PVOL (volume of water stored in the pond when water filled to principal spillway level), PND_ESA (surface area of the pond when water filled to emergency surface area) and PND_EVOL (volume of water stored in the pond when water filled to emergency spillway level). The full reservoir level and the maximum water level in the

tank are denoted by the principal spillway and emergency spillway levels, respectively. The maximum recorded volume of the tank and the corresponding area were used to calculate the emergency spillway level volume and area. The principal spillway level area and volume were calculated by subtracting 10% from the emergency spillway level area and volume. The PNDEVCOEFF (pond evaporation coefficient) was calculated using the Penman-Monteith equation (Linacre 1977) and maximum and minimum temperatures within the tank's buffer zone, as well as field estimated pan evaporation data from [24]. Table 2 shows the PND K (hydraulic conductivity through pond bottom) of all tanks calculated from the lab test. The sub-basins were given the (.PND) parameters to allow tank storage in the sub-basin. The sub basin routing was carried out in order to create a cascade mechanism between the tanks.

3.2.3. Water Balance

The flow is simulated using tank routing in the watershed, and the water balance is performed in KTCS using Equation (2) [36] to assess water availability in each tank.

$$V_t = V_s + V_{PCP} + V_{In} - V_{EVP} - V_{SEEP} - V_{IRR} - V_{OUT} \tag{2}$$

The total water balance is based on the surface area of the tank and impounded volume of the water. V_t is the volume of water available in the tank at the end of the time "t" (m^3), vs. is the volume of water stored in the tank at the beginning time step (m^3). V_{PCP} is the volume of water falling on the tank from precipitation (m^3) and is estimated based on the surface area (ha) of the tank and precipitation depth (mm) in a given day. V_{In} is the volume of water impounded in the tank (m^3) from SWAT simulated runoff. V_{EVP} is the volume of water loss from the tank due to evaporation (m^3), estimated with evaporation coefficient, potential evapotranspiration for a given day (mm) and surface area (ha) of the tank. V_{SEEP} is the volume of water lost in the tank due to seepage (m^3), estimated using hydraulic conductivity (K(mm/hr)) of the pond bottom and surface area of the tank. V_{OUT} is the volume of water flow out from the tank at the end of the day (m^3). V_{IRR} is the volume of water withdrawn from the tank for irrigation and these details were given in water use data (.WUS) for each sub-basin.

The amount of water released from the tank for irrigation was determined by the amount of rainfall and the type of crop grown in the region. Paddy is cultivated in this region during the Kharif season, so the crop required less water during its initial stage, i.e., from sowing to transplanting (approximately 15 to 30 days), and then the crop required a large amount of water until harvesting. Local farmers operate the tank water releases for small tanks, and a local gate operator operates the medium to large tanks via manually operated sluice shutters. Local operators regulate the amount of water released based on crop water requirements; the water releases quantified for each tank in KTCS are shown in Table 2.

3.2.4. Model Performance and Evaluation

The SWAT simulated flow results were calibrated and validated using observed discharge through SWAT-CUP (SWAT Calibration and Uncertainty Program). The model was parameterized to local conditions during the calibration process, reducing prediction uncertainty. The first step in calibration is to use sensitivity analysis to select sensitive parameters in the watershed. The Sequential Uncertainty Fitting (SUFI-2) algorithm was used to identify the basin's sensitive hydrological parameters. The SUFI-2 has a plethora of performance indicators for evaluating model results. The Nash–Sutcliffe (NS) (Nash and Sutcliffe 1970) Equation (3) was used as a major objective function for calibration and validation of model predictions as it determines the residual variance between simulated and observed data. The coefficient of determination (R^2) measures correlation between simulated and observed streamflow using Equation (4). PBIAS (Gupta et al., 1999) [37] uses Equation (5) to calculate the average tendency of simulated flow compared to field

data. Additional criteria for model evaluation included the Kling-Gupta efficiency (KGE) (Gupta et al., 2009) [38] Equation (6).

$$NS = 1 - \frac{\sum_{i=1}^{n}(Q_m - Q_S)i^2}{\sum_{i=1}^{n}(Q_{m,i} - \overline{Q}_m)^2} \tag{3}$$

$$R^2 = \frac{\sum_{i=1}^{n}\left[(Q_{m,i} - \overline{Q}_m)(Q_{s,i} - \overline{Q}_s)\right]^2}{\sum_{i=1}^{n}(Q_{m,i} - \overline{Q}_m)^2 \sum_{i=1}^{n}(Q_{s,i} - \overline{Q}_s)^2} \tag{4}$$

$$PBIAS = 100 \times \frac{\sum_{i=1}^{n}(Q_m - Q_s)_i}{\sum_{i=1}^{n} Q_{m,i}} \tag{5}$$

$$KGE = \sqrt{(r-1)^2 + (\alpha - 1)^2 + +(\beta - 1)^2} \tag{6}$$

where, Qm is observed discharge; $\overline{Q}_m$ is mean of observed discharge; Q_s is simulated discharge; $\overline{Q}_s$ = mean of simulated discharge; i is the ith measured and simulated variable; n is the total number of observations; r is the regression coefficient between measured and simulated variables; $\alpha = \frac{\sigma_s}{\sigma_m}$ $\beta = \frac{\mu_s}{\mu_m}$, σ_s, σ_m are the standard deviations of simulated and observed variables, respectively; μ_s, μ_m are the mean of simulated and observed variables, respectively. Model calibration was performed with select sensitive parameters to simulate the streamflow and these were compared with the observed streamflow at a gauge station. In validation, the streamflow was simulated using the best calibrated parameters to check the model prediction capability. The streamflow prediction results were compared with observed streamflow which was not used in the calibration process. The SUFI-2 accounts for all sources of uncertainty in the observed data, conceptual model, parameters and driving variables [39]. The model prediction uncertainty is estimated using two statistical indicators r-factor and p-factor [39,40]. The p-factor is the percentage of observed data that is surrounded by the 95PPU (Percentage Prediction Uncertainty) model outcome, which runs from 0 to 1, with larger values indicating reduced uncertainty. The r-factor represents the thickness of 95PPU envelope, where a low value indicates less uncertainty [39].

4. Results

The simulation of hydrological processes in the Salivagu watershed was done using QSWAT and the QGIS (Quantum Geographical Information System) interface. The 1879-square-kilometer watershed is divided into 139 sub-basins, each with a 7-square-kilometer threshold, and the sub-basins are further classified into HRUs based on topography and soil characteristics. To begin, the runoff from the Salivagu watershed was modelled without taking into account any of the watershed's tanks. The mean monthly simulation was run from 2010 to 2019, with the first seven years (2010–2016) serving as a warmup period for the model to reach equilibrium [27]. The second method involved incorporating one tank in each sub-basin into the entire Salivagu watershed and simulating the flow after sub-basin routing. SWAT CUP employed the SUFI-2 algorithm for calibration and the uncertainty process. For the years 2017 through 2018 and 2019, the simulated streamflow was calibrated and confirmed against observed discharge at the Ankushapur gauge station. Table 4 shows the SWAT sensitive parameters of the Salivagu watershed. From the results it was observed that, CN2, GW_REVAP, ESCO and CH_K1 are the most sensitive parameters of the basin. Table 5 shows the simulated model performance and model uncertainty statistics during calibration and validation. The SWAT model performance indices in terms of NS, R^2, PBIAS and KGE without tanks are 0.42, 0.47, −31.5, and 0.47 for calibration and 0.45, 0.78, −29.7, and 0.48 for validation, respectively. As per Moriasi et al., 2007 [12] recommended R^2, NS & KGE > 0.5 and PBIAS ± 25% as acceptable ranges for the monthly streamflow performance assessment. The R^2 value of 0.74 indicates a reasonable correlation, but for the best simulation, the values of R^2 & NS must be in an acceptable range. The model

uncertainty statistics of p-factor, r-factor of without tanks are 0.38, 3.02 and 0.45, 2.34, respectively during the calibration and validation.

Table 4. The list of sensitive SWAT parameters used in the calibration and validation process in the order of low to high sensitivity.

| Parameters (Method of Change)	Name of Parameter	Given Range (Default Value)	Fitted Value
GWQMN.gw (a)	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	−300 to +300 (1000)	231.3
CH_N2.rte (v)	Manning's "n" value for the main channel	0.01 to 0.3 (0.014)	0.048
LAT_TTIME.hru (v)	Lateral flow travel time	20 to 60 (0)	33.139
ALPHA_BF_D.gw (v)	Deep Baseflow alpha factor	0 to 1 (0.01)	0.847
REVAPMN.gw (a)	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	−750 to 250 (750)	−537.25
RCHRG_DP.gw (a)	Deep aquifer percolation fraction	−0.05 to 0.05 (0.05)	−0.046
CH_K2.rte (v)	Effective hydraulic conductivity in main channel alluvium	0.01 to 50 (0)	36.228
SOL_AWC(..).sol (r)	Avail. water capacity of soil layer	−0.05 to 0.05 (0.1136)	−0.03
ALPHA_BF.gw (v)	Baseflow alpha factor	0.3 to 1 (0.048)	0.708
GW_DELAY.gw (a)	Groundwater delay (days)	−30 to 90 (31)	72.54
ESCO.hru (v)	Soil evaporation compensation factor	0.3 to 0.75 (0.95)	0.654
CH_N1.sub (v)	Manning's "n" value for the tributary channels	0.01 to 0.1 (0.014)	0.077
CH_K1.sub (v)	Effective hydraulic conductivity in tributary channel alluvium	0.01 to 50 (0)	28.729
GW_REVAP.gw (v)	Groundwater "revap" coefficient	0.08 to 0.2 (0.02)	0.131
CN2.mgt (r)	SCS runoff curve number	−0.1 to 0.1 (83 to 87)	−0.035

a-Absolute, v-Replacement and r-Relative methods to change to existing value.

Table 5. Summary of model performance and uncertainty indices of calibration and validation.

Process	NS	R^2	PBIAS	KGE	p-Factor	r-Factor
			Without tanks			
Calibration	0.42	0.74	−31.5	0.47	0.38	3.02
Validation	0.45	0.78	−29.7	0.48	0.45	2.34
			With tanks			
Calibration	0.84	0.85	−6.1	0.9	0.5	1.14
Validation	0.93	0.95	16.3	0.83	0.45	0.52

The SWAT model performance indices in terms of NS, R^2, PBIAS and KGE with the tanks are 0.84, 0.85, −6.1, and 0.9 for calibration and 0.93, 0.95, 16.3, and 0.83 for validation, respectively. The results shows that the flow simulations with tanks agreed well with the observed flow data. When the tanks are taken into account, the model simulated results are within an acceptable range and demonstrate good agreement with the observed streamflow. The model uncertainty statistics of p-factor, r-factor of with tanks are 0.5, 1.14 and 0.45, 0.52, respectively during the calibration and validation. The seasonality in the flows was visible in the simulated flow with tanks, which peaked between August and October (Figure 4). The size of the flow grew in a straight line as the proportion of precipitation increased by

15% in 2018 and 41.2% in 2019 compared to 2017. The baseflows and peak flows were well simulated by the SWAT model.
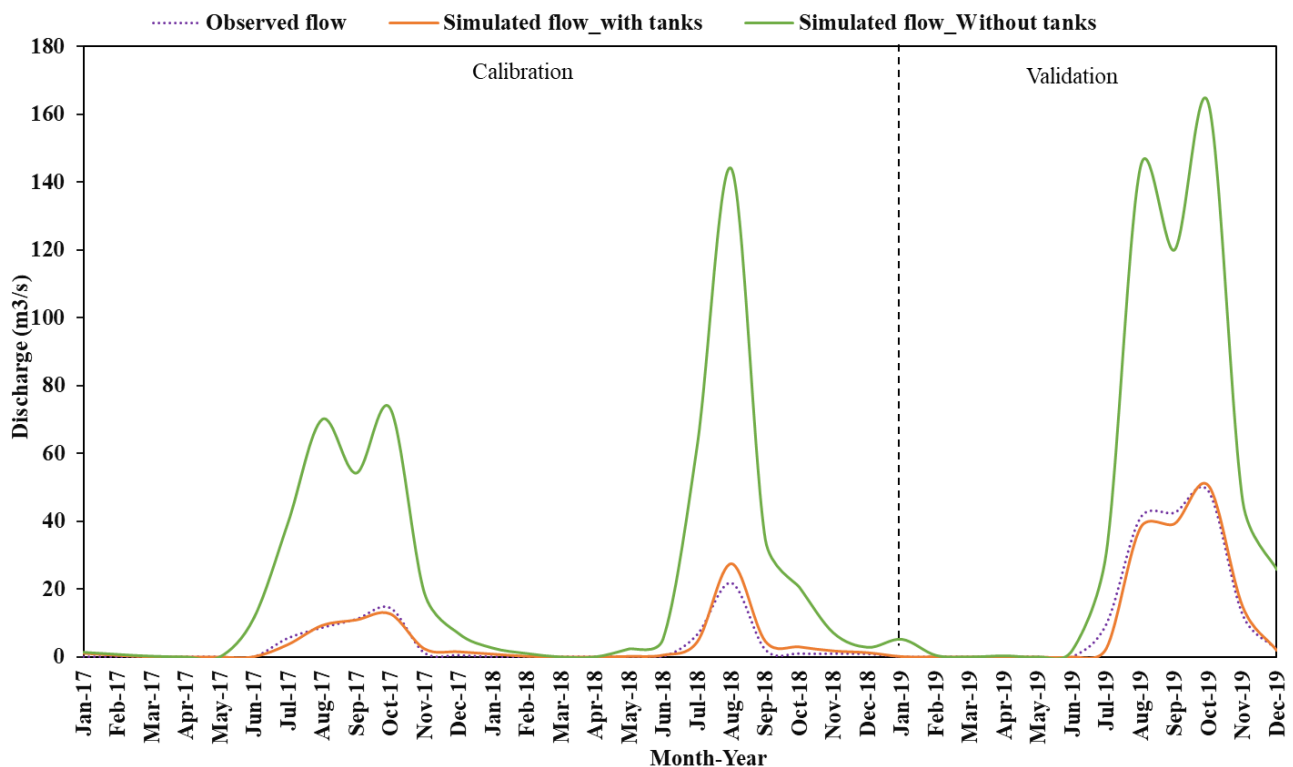
Figure 4. Simulated and observed streamflow at Ankushapur in the Salivagu watershed with and without tanks during calibration and validation.

Water Balance in SALIVAGU Watershed and KTCS

The Salivagu watershed has greater number of small and medium size irrigation tanks which play a major role in the hydrological regime of the catchment. Figure 5 depicts the Salivagu watershed's annual water balance and ratios. Precipitation, evapotranspiration, and percolation have all increased in three consecutive years, resulting in increased surface runoff and soil water. The increase in water budget is owing to a 15% increase in precipitation in 2018 and a 41.2% percent increase in 2019 as compared to 2017. From 2017 to 2019, the yearly Q/P (Surface Q to Precipitation) ratio increased as precipitation increased, resulting in more surface runoff in the watershed. As ET grew less constrained with more water available, the ET/P (evapotranspiration to precipitation) ratio declined as precipitation increased. The vertical moment of water that percolates past the bottom of the soil profile in a watershed is known as percolation. In comparison to 2017, the PC/P (percolation to precipitation) ratio slightly declined in 2018 and climbed in 2019. In 2018, the percentage increase in precipitation did not have much of an impact on percolation as opposed to a considerable increase in 2019.

The mean monthly water balance at watershed scale (Figure 6) demonstrates that the SW monsoon increased precipitation from June to October, whereas the NE monsoon increased precipitation in December. In August, the maximum mean monthly precipitation and surface runoff were 327 mm and 149 mm, respectively. The maximum of mean evapotranspiration and percolation were 114.24 mm and 52.573 mm in the month of April and August, respectively. The considerable loss of water after irrigation was due to evaporation, which was especially noticeable in April and June. The decrease in evapotranspiration in May and June was caused by the lands being left fallow for crop rotation. Percolation is also vital for increasing the amount of water in the soil and recharging the groundwater in

the basin. As a result, due to the southwest monsoon, greater percolation was recorded primarily from July to November.
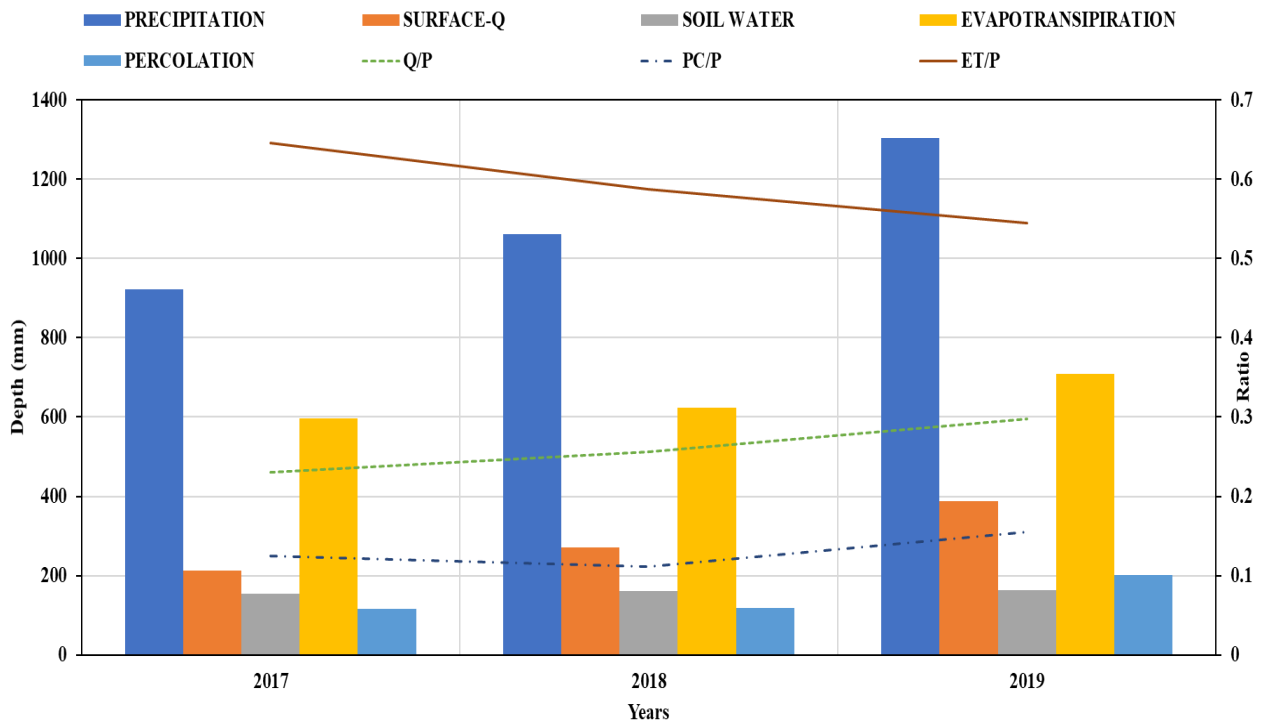

Figure 5. Yearly water balance of Salivagu watershed.
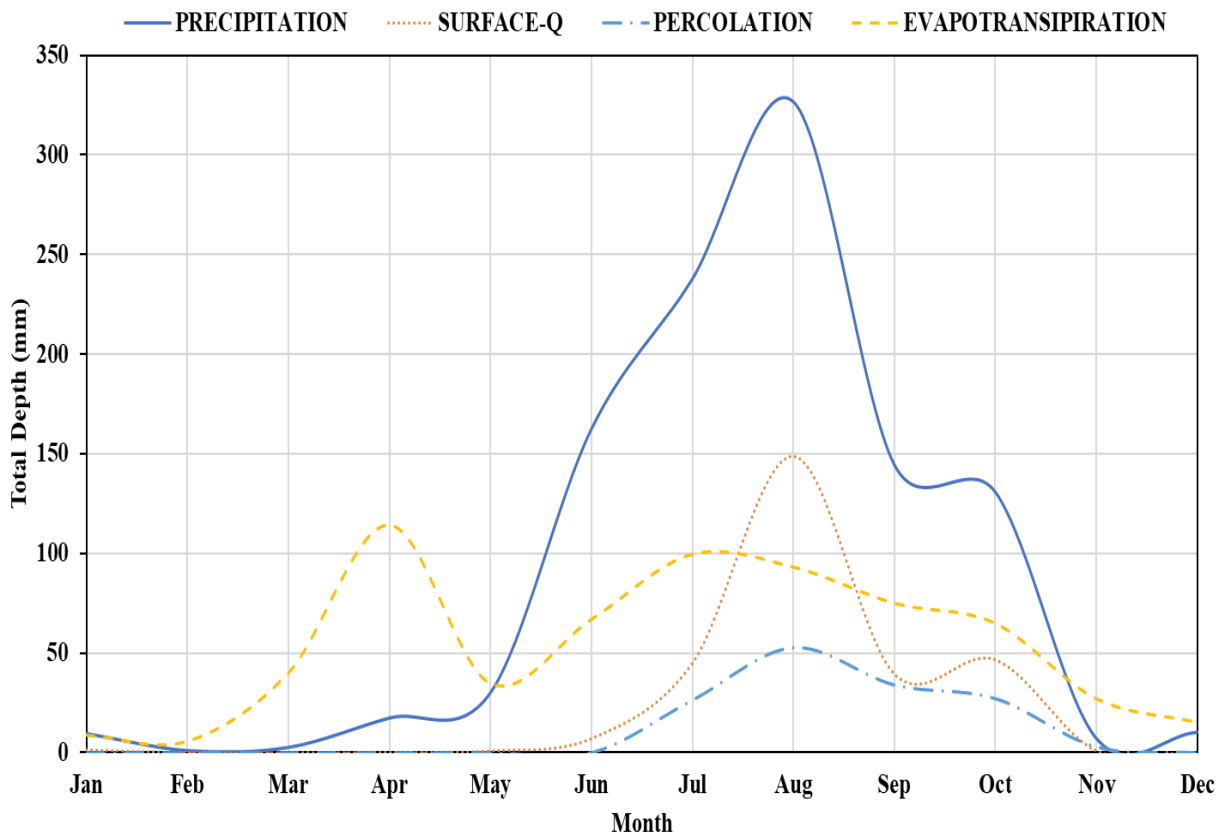

Figure 6. Mean monthly water balance of Salivagu watershed.

Using SWAT simulated flow through the Ramchandrapur, Mallampalli, Dharmaraopalle, and Katakshapur tanks of the Salivagu watershed, the water balance in KTCS was determined at tank scale. The tanks were flooded by streamflow, which was approximated using the SCS-CN approach as inputs to the tanks. Outflows are the water releases from the tanks for irrigation, which were approximated on a daily basis. Table 2 shows the evaporation and seepage losses calculated using the pan evaporation coefficient from Perrin et al. (2012) and the saturated hydraulic conductivity of tanks. Based on the surface area of the tank in a day, the corresponding amount of water loss was determined. On a daily basis, the water balance of all tank inflows, losses, and outflows at KTCS size was done (last day in the month). The water balance components for KTCS were compared to the volumes provided by WBIS-Bhuvan-NRSC for each tank, as they provide tank volumes on the last day of each month. As per SWAT simulated water balance and WBIS- Bhuvan-NRSC volumes, all the tanks in KTCS have adequate water from the month of June to December. In KTCS tanks, low water storage was observed from January to May except in Katakshapur tank. The correlation between SWAT simulated volume and WBIS-Bhuvan-NRSC volumes are 0.676, 0.81, 0.615 and 0.848 for the Ramchandrapur, Mallampalli, Dharmaraopalle and Katakshapur tanks, respectively. The simulated flow increased total water availability in all of the tanks in the KTCS. The results agreed well with the volumes provided by WBIS-Bhuvan-NRSC. The volume increase can be attributed to tank rejuvenation in 2016–2017 as well as an increase in annual precipitation.

Based on the WBIS-Bhuvan-NRSC and SWAT simulated volumes, the Ramchandrapur tank (Figure 7a) had a maximum capacity of 1.28 Mm^3 and 0.974 Mm^3 on 31 August 2019, the Mallampalli tank (Figure 7b) had a maximum capacity of 4.758 Mm^3 and 4.987 Mm^3 on 31 August 2019, the Dharmaraopalle tank capacity (Figure 7c) of 0.761. The difference in volume between the simulated and WBIS-Bhuvan-NRSC results may be attributed to depth variation caused by continuous water release from the tanks. The overflow from all tanks in KTCS is accumulated in the Katakshapur tank as a result of the tank cascading function. The decrease in capacity from 2017 to 2019 could be attributed to sediment accumulation or a difference in water release in the tank.
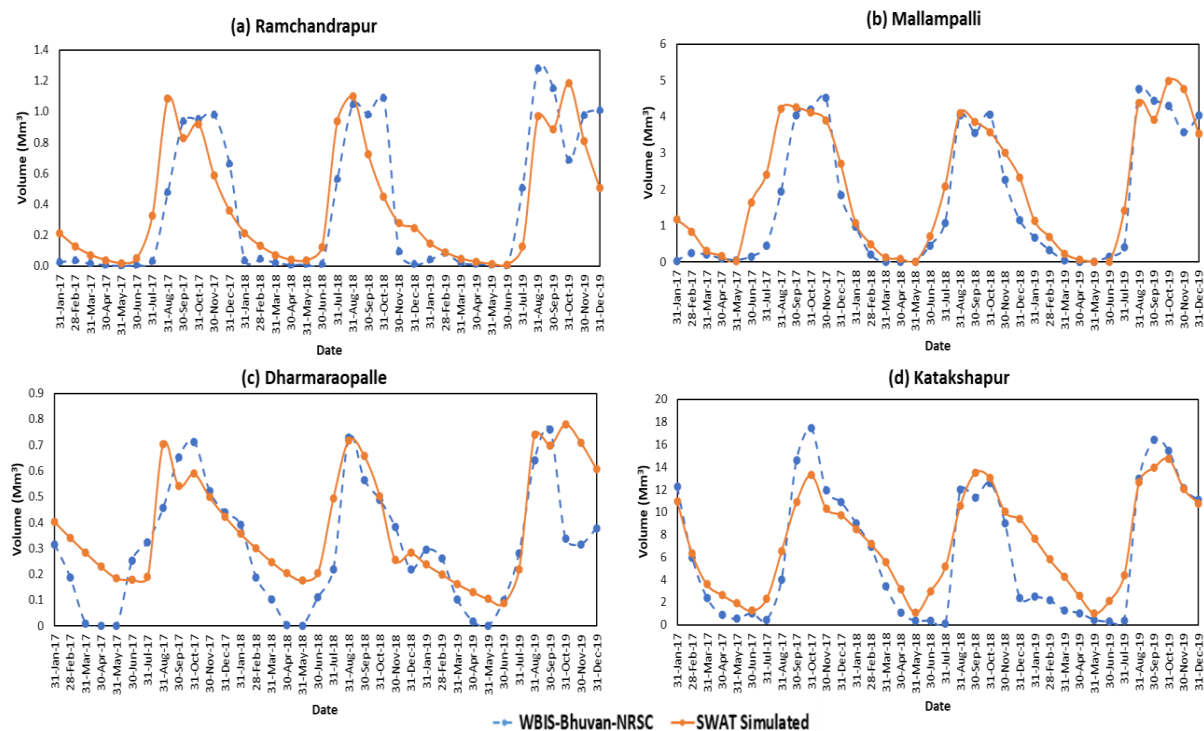
Figure 7. The simulated and WBIS-Bhuvan-NRSC observed volumes of (**a**) Ramchandrapur, (**b**) Mallampalli, (**c**) Dharmaraopalle, and (**d**) Katakshapur tanks.

5. Discussion

The SWAT model was applied to the study area with dense tank systems to simulate the flow difference in the watershed with and without tanks to analyze the water balance components in one of the TCS. The model was calibrated and validated using the observed streamflow at the gauge point. The streamflow was simulated without taking the tanks into account, and the results showed higher values of streamflow (Figure 4) as well as NS, KGE, and PBIAS indicating a poor fit between observed and simulated flow. However, all of the tanks in the Salivagu watershed with a total capacity of 324.52 Mm^3 were considered in the flow simulation. The resulting hydrograph (Figure 4) at the watershed outlet matched the observed streamflow. Krishnaveni et al. (2018) [9] found similar results in their TCS study in the semi-arid region of Tamil Nadu, India. The presence of tank systems in the watershed arrested the flow of water, causing the flow in the stream at the gauge point to be reduced. The estimated volume differences between with and without tank flow were significant in 2017, 2018 and 2019, with 606 Mm^3, 615.9 Mm^3 and 1011 Mm^3, respectively. The increase in streamflow of 27.7% and 82% in consecutive years is due to increase in precipitation from 15% to 41.2% between 2017 and 2019. The model captured the components and physical process of the tank cascaded catchment very well, demonstrating the importance of including surface water bodies in hydrological simulation because they have a large influence on water balance analysis. We simulated those higher flows in the watershed without taking tanks into account, but when we did, all of these tanks functioned as flood mitigating structures by storing the water in the tanks.

The water balance of the Salivagu watershed shown that, after precipitation, evapotranspiration was the second highest component in the watershed's water budget (Figures 5 and 6), as is typical in semi-arid environments [24]. The water balance in KTCS (Figure 7) revealed that the peak volume was observed in all tanks during the months of August and October due to the SW monsoon. The tank storages were also improved in part as a result of KTCS rejuvenation, which was completed in 2016–2017.

Katakshapur tank has the most capacity and is the last tank in the KTCS, allowing it to receive excess water from upstream tanks during the monsoon. The last tank in the cascade received all of the return flow benefits from the upper tanks, and the similar results were observed by [11,21]. For tank sizes larger than 0.8 Km^2, the SWAT model simulated results were satisfactory. Perrin et al. (2012) [24] and Dewandel et al. (2012) [41] also recommended an individual tank size (0.5–1 Km^2) for dominance of vertical ground water fluxes rather lateral ground water fluxes. The maximum volume of the Katakshapur tanks is 17.458 Mm^3 based on observed data, but the maximum capacity based on SWAT simulation is 14.73 Mm^3, with the difference possibly due to sediment accumulation and tank water release variation. Because the tank surface area was calculated using satellite imagery, the WBIS-Bhuvan-NRSC volume may be high during the monsoon season (August to November). The moist soil pixels in the tank periphery could have been misinterpreted as water pixels, resulting in more surface area and volume extraction in the tanks.

The tank storage was improved in part as a result of tank rejuvenation, but spill over water can be controlled with proper controlling structures and water management policies. Based on water availability in KTCS, simulated water balance and observed tank contents clearly revealed that the Ramchandrapur, Mallampalli and Dharmaraopalle tanks only meet irrigation water requirements for one cropping season (Kharif season-June to October). Fields near the Mallampalli tank use water from the tank to meet the early needs of the second cropping season in January and February (same condition is observed while interaction with local farmers at the time of field visit). The water in the Katakshapur tank is sufficient to supply the command area for two agricultural seasons. In TCS, spillover water flows downstream unregulated; therefore, if the impact of tanks in the watershed is not quantified, it may have a negative impact on public life and transportation [42]. These frequent spillovers may also make bund management difficult. As a result, the tanks must be considered in order to estimate the flow and impact in the watershed. This study aids in the accurate estimation of surface water resource potential, which is critical for better

water allocation, budget planning, and resource management for catchments that include intervening surface storage structures such as ponds, lakes, and reservoirs.

The study found that simulating flow in the watershed using a dense tank system controlled streamflow because the tanks regulate the flow. These tank systems have an impact on groundwater recharging as well. Similar findings were found in previous studies on tank systems [9,11,14]. In KTCS, tanks with a surface area of less than 0.8 km^2 did not accurately simulate flow, whereas tanks with a surface area of equal to or greater than 0.8 km^2 performed well in the simulation of hydrological processes. Similar results were reported by Dewandel et al. (2012) [41]. In terms of storage and groundwater recharge, the tank at the tail end of the cascade system benefitted the most. Similar results were found in studies undertaken in South Asia and India [9,11,14,21].

However, some limitations were observed in the application of the model. The water release from the tanks is given on a monthly scale (i.e., the average daily water removal from the pond is the same for the entire month) rather than daily scale, resulting in variation in storage volume at daily time step. As a result, the simulations were performed at a monthly scale, but the tanks spillover conditions could not be demonstrated at this time step. The uncertainty in satellite data, i.e., if the images are high resolution, the extracted information will be accurate as well. The observed data collection at local scale has a flaw; if the tanks were managed systematically by accounting all the releases and inflows, it would be relatively simple to manage the water in all the tanks optimally. Model simulations could be improved in future studies by using exact tank observations, and model calibration could be improved by using long-term discharge data. The findings from this study can be used to develop a decision support system for the sustainable management of the water resources in tank-rich watersheds of the semi-arid region with limited gauge observations.

6. Conclusions

The physically-based SWAT model can be effectively applied for hydrological flow simulation and water balance in the tanks that are in cascade systems. Data for tank surface area and volume provided by WBIS-Bhuvan-NRSC can be used as a secondary source proxy data in the absence of field data.

i. The SWAT model flow simulation for Salivagu watershed without tanks resulted in an overestimation of streamflow, and when the tanks were considered, the flow simulated results were agreed well with the observed flow data. The model captured the water balance components reasonably well. The estimated volume differences between the condition with and without tank flow were significant with 606 Mm^3, 615.9 Mm^3, and 1011 Mm^3 in 2017, 2018, and 2019, respectively.

ii. The increase in the streamflow of 27.7% and 82% in consecutive years is due to increase in precipitation of 15% and 41.2% from 2017 to 2019. In the catchment water budget assessment, evaporation is the second largest component after precipitation, which is typical for the semi-arid basins.

iii. In KTCS, improvements to the SWAT simulated volumes of Ramchandrapur and Dharmaraopalle tanks were modest due to the tank size less than 0.7 km^2 and having the capacity up to 1 Mm^3 storage. However, the Mallampalli and Katakshapur simulation results agreed well with WBIS-Bhuvan-NRSC as their tank sizes were greater than 0.8 km^2 and capacity more than 2 Mm^3.

The cascade function is very useful at the time of monsoon to manage the all overflows through the tank system. Katakshapur tank benefited due to the large size of the tank and the cascade effects (i.e., being the terminal tank in the cascade, it received more water transfer added with seepage benefits).

The stream flow in cascading tanks watershed is different from the uninterrupted terrain flow, as the routing to streams without including the tanks in the basin will not give any realistic estimates of surface flow. Therefore, with consideration of tanks in the watershed, the watershed hydrology and ground water recharge will improve at a

local scale. At present, local scale tanks need more attention to fulfill the requirement of irrigation water demand for at least two cropping seasons.

References

1. Palanisami, K. Sustainable Management of Tank Irrigation Systems in India. *J. Dev. Sustain. Agric.* **2006**, *1*, 34–40. [CrossRef]
2. Madduma Bandara, C.M. Catchment Ecosystems and Village TankCascades in the Dry Zone of Sri Lanka A Time-Tested System of Land and Water Resource Management. In *Strategies for River Basin Management*; Springer: Dordrecht, The Netherlands, 1985; pp. 99–113. [CrossRef]
3. Von Oppen, M.; Subba Rao, K. *Tank Irrigation in Semi-Arid Tropical India: Economic Evaluation and Alternatives for Improvement*; International Crops Research Institute for the Semi-Arid Tropics: Andhra Pradesh, India, 1987; RA-00121-ISBN 92-9266-121-6.
4. Kumar, M.D.; Bassi, N.; Kishan, K.S.; Chattopadhyay, S.; Ganguly, A. *Water Policy Science and Politics*; Elsevier: Amsterdam, The Netherlands, 2018; Volume 51, ISBN 9780128149034.
5. Kumar, N.; Singh, S.K.; Srivastava, P.K.; Narsimlu, B. SWAT Model calibration and uncertainty analysis for streamflow prediction of the Tons River Basin, India, using Sequential Uncertainty Fitting (SUFI-2) algorithm. *Model. Earth Syst. Environ.* **2017**, *3*, 30. [CrossRef]
6. Mission Kakatiya. Available online: https://missionkakatiya.cgg.gov.in/ (accessed on 21 November 2020).
7. Sakthivadivel, R. *Rehabilitation Planning for Small Tanks in Cascades: A Methodology Based on Rapid Assessment*; International Irrigation Management Institute: Colombo, Sri Lanka, 1997; ISBN 92-9090-345-0.
8. Jayakody, B.V.P.L.; Mowjood, M.I.M.; Gunawardena, E.R.N. Modifying and Testing of a Cascade Water Balance Model Using a Mini Cascade System with two Tanks. *Trop. Agric. Res.* **2004**, *16*, 159–170.
9. Krishnaveni, M.; Rajeswari, A. Flow Routing and Surface Water Balance Simulation of a Tank Cascaded Catchment Using Coupled MIKE SHE/MIKE 11 Modeling. *J. Inst. Eng. Ser. A* **2019**, *100*, 65–74. [CrossRef]
10. Glendenning, C.J.; Van Ogtrop, F.F.; Mishra, A.K.; Vervoort, R.W. Balancing watershed and local scale impacts of rain water harvesting in India-A review. *Agric. Water Manag.* **2012**, *107*, 1–13. [CrossRef]
11. Van Meter, K.J.; Steiff, M.; McLaughlin, D.L.; Basu, N.B. The socioecohydrology of rainwater harvesting in India: Understanding water storage and release dynamics across spatial scales. *Hydrol. Earth Syst. Sci.* **2016**, *20*, 2629–2647. [CrossRef]
12. Moriasi, D.N.; Arnold, J.G.; van Liew, M.W.; Bingner, R.L.; Harmel, R.D.; Veith, T.L. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *Trans. ASABE* **2007**, *50*, 885–900. [CrossRef]
13. Li, Q.; Gowing, J. A daily water balance modelling approach for simulating performance of tank-based irrigation systems. *Water Resour. Manag.* **2005**, *19*, 211–231. [CrossRef]
14. Kanagaraj, R.P.; Abraham, M.; Perumal, M.; Panneerselvam, V.; Sekar, S. Modeling and simulation of runoff from an irrigation tank watershed to evaluate the utilizable water. *Arab. J. Geosci.* **2021**, *14*, 16. [CrossRef]
15. Dessie, M.; Verhoest, N.E.C.; Pauwels, V.R.N.; Adgo, E.; Deckers, J.; Poesen, J.; Nyssen, J. Water balance of a lake with floodplain buffering: Lake Tana, Blue Nile Basin, Ethiopia. *J. Hydrol.* **2015**, *522*, 174–186. [CrossRef]
16. Gal, L.; Grippa, M.; Hiernaux, P.; Peugeot, C.; Mougin, E.; Kergoat, L. Changes in lakes water volume and runoff over ungauged Sahelian watersheds. *J. Hydrol.* **2016**, *540*, 1176–1188. [CrossRef]
17. Ovakoglou, G.; Alexandridis, T.K.; Crisman, T.L.; Skoulikaris, C.; Vergos, G.S. Use of MODIS satellite images for detailed lake morphometry: Application to basins with large water level fluctuations. *Int. J. Appl. Earth Obs. Geoinf.* **2016**, *51*, 37–46. [CrossRef]
18. Ogilvie, A.; Belaud, G.; Massuel, S.; Mulligan, M.; Le Goulven, P.; Malaterre, P.O.; Calvez, R. Combining Landsat observations with hydrological modelling for improved surface water monitoring of small lakes. *J. Hydrol.* **2018**, *566*, 109–121. [CrossRef]

19. Bishop, E.; Calder, I.; Batchelor, C.; Garratt, J.; Gosain, A. Development and application of the HYLUC-Cascade model for investigating the water resource impacts of rainwater harvesting structures in India. *Cent. Land Use Water Resour. Res. Newctle. Newctle. Univ.* **2009**, *61*, 11.

20. Jayatilaka, C.J.; Sakthivadivel, R.; Shinogi, Y.; Makin, I.W.; Witharana, P. *Predicting Water Availability in Irrigation Tank Cascade Systems: The Cascade Water Balance Model*; International Water Management Institute: Colombo, Sri Lanka, 2001; RR48-ISBN-92-9090-422-4.

21. Jayatilaka, C.J.; Sakthivadivel, R.; Shinogi, Y.; Makin, I.W.; Witharana, P. A simple water balance modelling approach for determining water availability in an irrigation tank cascade system. *J. Hydrol.* **2003**, *273*, 81–102. [CrossRef]

22. Bucak, T.; Trolle, D.; Andersen, H.E.; Thodsen, H.; Erdoğan, Ş.; Levi, E.E.; Filiz, N.; Jeppesen, E.; Beklioğlu, M.; Bucak, T. Future water availability in the largest freshwater Mediterranean lake is at great risk as evidenced from simulations with the SWAT model. *Sci. Total Environ.* **2017**, *581–582*, 413–425. [CrossRef] [PubMed]

23. Jayanthi, S.L.S.V.; Keesara, V.R. Climate change impact on water resources of medium irrigation tank. *ISH J. Hydraul. Eng.* **2019**, *25*, 1–12. [CrossRef]

24. Perrin, J.; Ferrant, S.; Massuel, S.; Dewandel, B.; Maréchal, J.C.; Aulong, S.; Ahmed, S. Assessing water availability in a semi-arid watershed of southern India using a semi-distributed model. *J. Hydrol.* **2012**, *460–461*, 143–155. [CrossRef]

25. Kang, H.; Sridhar, V. Improved Drought Prediction Using Near Real-Time Climate Forecasts and Simulated Hydrologic Conditions. *Sustainability* **2018**, *10*, 1799. [CrossRef]

26. Deckers, D.L.E.H.; Booij, M.J.; Rientjes, T.H.M.; Krol, M.S. Catchment Variability and Parameter Estimation in Multi-Objective Regionalisation of a Rainfall-Runoff Model. *Water Resour. Manag.* **2010**, *24*, 3961–3985. [CrossRef]

27. Setegn, S.G.; Srinivasan, R.; Dargahi, B. Hydrological Modelling in the Lake Tana Basin, Ethiopia Using SWAT Model. *Open Hydrol. J.* **2008**, *2*, 49–62. [CrossRef]

28. Sridhar, V.; Kang, H.; Ali, S.A. Human-induced alterations to land use and climate and Their Responses for Hydrology and Water Management in the Mekong River Basin. *Water* **2019**, *11*, 1307. [CrossRef]

29. Jaiswal, R.K.; Ali, S.; Bharti, B. Comparative evaluation of conceptual and physical rainfall–runoff models. *Appl. Water Sci.* **2020**, *10*, 48. [CrossRef]

30. Tegegne, G.; Park, D.K.; Kim, Y.O. Comparison of hydrological models for the assessment of water resources in a data-scarce region, the Upper Blue Nile River Basin. *J. Hydrol. Reg. Stud.* **2017**, *14*, 49–66. [CrossRef]

31. Bhuvan | Water Body Information System. Available online: https://bhuvan-wbis.nrsc.gov.in/#!/map/18.091033487001273,80.0738525390625@8z (accessed on 21 November 2021).

32. WBIS-HYDAS Water Bodies Information System (WBIS)-Hydrological Drought Services (HYDAS) Technical Details. Available online: https://bhuvan-wbis.nrsc.gov.in/resources/technical_details.pdf (accessed on 21 August 2021).

33. Srinivasan, R.; Ramanarayanan, T.S.; Arnold, J.G.; Bednarz, S.T. Large area Hydrologic Modeling and Assessment Part II: Model Application. *J. Am. Water Resour. Assoc.* **1998**, *34*, 91–101. [CrossRef]

34. Arnold, J.G.; Allen, P.M. Estimating hydrologic budgets for three Illinois watersheds. *J. Hydrol.* **1996**, *176*, 57–77. [CrossRef]

35. Borah, D.K.; Bera, M. Watershed-Scale Hydrologic and Nonpoint-Source Pollution Models: Review of Applications. *Trans. ASAE* **2004**, *4747*, 789. [CrossRef]

36. Neitsch, S.L.; Arnold, J.G.; Kiniry, J.R.; Williams, J.R. *Soil and Water Assessment Tool Theoretical Documentation Version 2005*; Texas Water Resources Institute: College Station, TX, USA.

37. Gupta, H.V.; Sorooshian, S.; Yapo, P.O. Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. *J. Hydrol. Eng.* **1999**, *4*, 135–143. [CrossRef]

38. Gupta, H.V.; Kling, H.; Yilmaz, K.K.; Martinez, G.F. Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling. *J. Hydrol.* **2009**, *377*, 80–91. [CrossRef]

39. Abbaspour, K.C.; Rouholahnejad, E.; Vaghefi, S.; Srinivasan, R.; Yang, H.; Kløve, B. A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. *J. Hydrol.* **2015**, *524*, 733–752. [CrossRef]

40. Arnold, J.G.; Moriasi, D.N.; Gassman, P.W.; Abbaspour, K.C.; White, M.J.; Srinivasan, R.; Santhi, C.; Harmel, R.D.; van Griensven, A.; van Liew, M.W.; et al. SWAT: Model Use, Calibration, and Validation. *Trans. ASABE* **2012**, *55*, 1491–1508. [CrossRef]

41. Dewandel, B.; Maréchal, J.C.; Bour, O.; Ladouche, B.; Ahmed, S.; Chandra, S.; Pauwels, H. Upscaling and regionalizing hydraulic conductivity and effective porosity at watershed scale in deeply weathered crystalline aquifers. *J. Hydrol.* **2012**, *416–417*, 83–97. [CrossRef]

42. Sujatha, E.R.; Sridhar, V. Spatial Prediction of Erosion Risk of a small mountainous watershed using RUSLE: A case-study of the Palar sub-watershed in Kodaikanal, South India. *Water* **2018**, *10*, 1608. [CrossRef]