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REVIEW

Sustainable water resource management through conjunctive use of groundwater and surface water: a review

Ranjeet Sabale[1] · B. Venkatesh[2] · Mathew Jose[2]

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Abstract

The estimations and projections for the global population show that the population is rising dramatically. Because of this, meeting the demands for infrastructure, food, and domestic and industrial water for such a large population is a critical issue for many nations. In addition, the quality and quantity of the water resources are declining as a result of overuse, climate change, and population growth. These alarming situations require an intermediate intervention to conserve and optimize the water uses. The conjunctive use of surface water and groundwater is an old but less emphasized technique practiced in many countries to fulfill human needs partially. Conjunctive use of water has the advantages such as the utilization of poor/saline water, maintaining the groundwater levels, reduction in waterlogging and secondary soil salination, reliable water availability, and increase in crop production. In line with these advantages, this study reviews the literature regarding the conjunctive use of surface and groundwater for sustainable development of irrigated agriculture. The global scenario of water resources and how the conjunctive water use aids sustainable development is first reported. Climate change, groundwater quality and conjunctive use for various basins are discussed in detail. The capabilities of various simulation–optimization models to plan water resources efficiently are presented with case studies. Reported studies indicate that by practicing the conjunctive use not only water resources are conserved but the issues like secondary soil salination and waterlogging are alleviated. The research gaps and conclusions are provided based on the literature review that may be useful for policymakers and researchers for future research and to plan the water resources sustainably.

Keywords Conjunctive use · Groundwater · Surface water · Optimization · Irrigated agriculture

Introduction

Water resource sustainability is a major concern in light of increased water demand for agricultural, industrial, and household applications [105], as the world requires nearly 60% more food [37] in 2050 to feed the forecasted 9.7 billion population [112]. Day by day the water resources are dwindling in quality and quantity wise [12] due to growing population, changing lifestyles, climate change, and rapid urbanization [70], and its over-exploitation [5]. Such alarming situations require an intermediate intervention to conserve and optimize the use of water. Researchers throughout the globe are working on the water scarcity issue; conjunctive use of water is one of the practices that facilitate the use of poor quality water in conjunction with good quality water in irrigation and allied activities [17, 98]. Attempts are also being made to increase food production by cultivating more than three crops in a year [42]. This work presents a comprehensive review of the literature regarding conjunctive use, simulation–optimization methods, computer-based model, challenges, and future scope in conjunctive use of surface water (SW) and groundwater (GW).

The conjunctive use means taking advantage of surface and groundwater by interacting with them through the different processes [21]. The objectives of conjunctive use of water are the supply of the adequate amounts of water for both domestic and agricultural purposes also, the supply of

✉ Ranjeet Sabale
ranjeetsabale123@gmail.com

B. Venkatesh
venkatesh.nihr@gov.in

Mathew Jose
jose.nihr@gov.in

1 Visvesvaraya Technological University, Belagavi, Karanataka 590018, India

2 Head Hard Rock Regional Centre, National Institute of Hydrology, Belagavi, Karnataka 590019, India

water for different use throughout the year [86]. It has some advantages like reduction in evaporation loss, increased well water, reduced salinity [43, 63], and contamination of water. It balances the groundwater table and hence reduces waterlogging; also, conjunctive water use assumes aquifer resilience [40, 63, 115]. In the current study, the main focus is to educate, motivate, and aware people about water use. Because more than 33% of the world's agricultural land is affected by waterlogging and salinity [50]. In India, about 6.727 million hectares of land is affected due to salinity and 2.46 million ha of land is waterlogged due to irrigation, as per National Remote Sensing Centre Balanagar, Hyderabad.

The conjunctive use of water is a significant tool to overcome water scarcity, draught conditions, and waterlogging problems and a powerful tool to achieve sustainable development goals [44, 46, 102]. Furthermore, research also showed that properly managed conjunctive use practice prevents the seasonal death of non-glacial linked rivers; this technique is highly efficient for groundwater-stressed areas [33]. It is not a new but less used tool; it is a lost opportunity for water management in the developing world [38]. In India, the agriculture industry and domestic water supply mostly depend on groundwater available [109]. The inadequate quantity of water for irrigation results in either conventional or mixed cropping. The relative yield of the crop can be increased by planning conjunctive use optimally [66] using GMS software to simulate the conjunctive water use model. Worldwide in (2012) over 324 million hector areas are equipped with irrigation systems; out of 85%, i.e., 275 million hectors, are irrigated (AQUASTAT-FAO'S U.S 2014), i.e., there is a shortage of water for irrigation. The conjunctive use of water is an efficient method to be used in deficit irrigation and saves up to 22% of revenue [94]. The one source, i.e. surface source, is not enough to fulfill water demand so there is a need to use water conjunctively [111]. Conjunctive planning of groundwater and surface water in irrigation command at Odisha, India, was carried out through borewell, dug well, and water harvesting structures [88]. Climate change and the environment emphasize conjunctive uses of water to fulfill irrigation demand [48]. The contaminated surface water in conjunction with groundwater is used for irrigation purposes in Tehran [58]. The surface water shows temporal fluctuations in terms of flood and drought; groundwater is a spatial variable in quality and quantity with aquifers [89]. Conjunctive use of water is optimized for irrigation and water resource policies purpose by different simulation/optimization programming techniques [7, 15, 24, 100, 101, 107, 117]. The conjunctive use of water can be used as sustainable irrigation management for agriculture [67, 87, 103]. Sustainability index for water resource planning and management used by Sandoval-Solis et al. [99] was enabled to compare and evaluate different water policies. Falkenmark and Rockström [34] and Kiptala et al. [60] had a concept of a new blue and green water paradigm for water resource planning and management. An optimization model is used to have better irrigation management for agriculture in the future [67, 68, 77, 81]. The model for economy optimization was also developed by Tyagi et al. [111]. The reclamation of waterlogged and saline land is also achieved by conjunctive use [111]. The conjunctive water optimization can be done by a numerical model coupled with LP; the results show we can increase pumping by 50% [11, 69, 84]. Water resource and water supply management can be done by optimization modeling [114]. It has been observed that GIS technology plays an important role in sustainable management of water resources [14].

Climate change has impacts on groundwater resources; the areas those are over-populated are suffering through the water scarcity issues, increased temperature, etc. To alleviate such environmental issues, it is necessary to reduce gap between water demand and supply by efficient irrigation system. Conjunctive use of groundwater and surface water, training farmers, public awareness for water conservation, government policies, institutional issues and international cooperation are the best management practices for sustainable water management [28]. The challenges like uncertainties in prediction of future climate, modeling of hydrological parameter, understanding between local climate and global climate, collection and processing of metrological data are encountered in groundwater management. The future research in aforementioned scenarios is highly warranted. The outcomes of such attempt will help researchers and water managers to choose the best practices like managed aquifer recharge (MAR) and conjunctive use of groundwater and surface water for sustainable water resource management [31]. The land-use pattern plays a vital role in water resource management. Though the climate change has reduced the average rainfall in southern Niger, the water tables are continuously rising. From 1963 to 2007, it is increased by 4 m [35]. Authors conducted a study on long-term basis from 1950 to 2007 and tested conjunctive use scenario. The outcomes show that changing the land use from natural to agricultural land water tables are increased by 4 m. In addition, the quality of groundwater is improved, so such practices will aid the sustainable water resource management. For successful conjunctive use practice, it is more important to have a knowledge about quality of water [45]. Jurado et al. [55] conducted a literature study on water quality analysis in European context. Authors observed that the effluent from wastewater treatment plant is the main source of groundwater contamination. The findings of study reveal that the natural attenuation capacity of river and groundwater is more and conjunctive use of water was beneficial. The occurrence of emerging organic contaminants (EOCs) in water source may have ill impact on human as well as aquatic life. Currently there is limited understanding of groundwater pollution due to contaminants like urban sewage leakage and bio-solids [62]. Rossman and Zlotnik [91] conducted a review and suggested that in areas where recharge/discharge rates and stream–aquifer interactions are highly uncertain and a high degree of certainty in their estimates is sought then think about upgrading to a physically based, integrated surface–subsurface hydrologic model (where data permits) that can treat all of the land phases of the hydrologic cycle. The various optimization methods have been tried since last three decades in conjunctive use modeling, to improve the efficiency of modeling the genetic algorithm (GA), must be combined with gradient-based optimization [119]. As a result of the enormous and rapidly growing population, groundwater has being extracted at an astronomical rate. Hence, seawater is consequently introduced into groundwater in coastal regions, contaminating natural groundwater supplies [85]. Therefore, future studies must be conducted to map the intrusion of sea water in groundwater at coastal region. After this robust literature survey, it is observed that many studies are unable to clear the dynamic process at the groundwater–surface water interaction and to combine spatiotemporal data to physically based numerical models [23, 71]. The groundwater is most reliable resource than surface water; the major challenge encountered in the utilization of groundwater is accurate modeling of groundwater [95].

This work provides motivation, policy-making, and scope for future enhancement in the domain of conjunctive water use by addressing the research gaps. The present work is organized in such a manner that it presents the global scenario of conjunctive use; it covers the climate change and its impact on water quality, simulation–optimization methods for sustainable water management; it also covers the managed aquifer recharge technique to aid the sustainable water resource management and to conclude it suggests the future scope in the conjunctive water use management.

Global scenario of conjunctive use

Globally, researchers and policymakers are thinking of conjunctive use of groundwater and surface water as a new paradigm in water resource management. As conjunctive use is not a new technique but due to some technical, institutional, and data available issues, it is less emphasized [52]. A coupled simulation optimization model was used for sustainable water resource management for Zayandehrud River basin in Iran. The study is basically designed to optimize the operation of the reservoir, water allocation for irrigation, and withdrawal of water from river and groundwater sources. The authors have used a water evaluation and planning system (WEAP) simulation model with a nondominated sorting genetic algorithm II (NSGA-II) optimization algorithm to carry out the study. The study concludes with 26% higher results than the previous study performed on optimization–simulation of groundwater and surface water. Moreover, this attempt showed an increase in reservoir sustainability by 37% and sustainability of aquifers by 16%. Du et al. [29] evaluated distributed policies for conjunctive use of surface water and groundwater to manage water resources sustainably in large river basins in China. Authors have framed the integrated model to couple the water use by farmers and the physical-based hydrological process. The study showed an increased in groundwater table by 0.28 m by increasing groundwater tax from dry to wet years.

Bhattarai and Shakya [13] conducted a review study on the conjunctive use of groundwater and surface water for sustainable development in Terai, Nepal. The authors have an overview of literature related to conjunctive use in sustainable irrigation. This work takes account of the United Nations sustainable development goal-2 while executing the work. The outcomes of the work are helpful to address the research gap, challenges, and future direction in the conjunctive use epoch. De Fraiture and Wichelns [39] explored the various scenarios to ensure food security in the future. The authors have examined four sets of scenarios by considering the variables as investment, rainwater availability, and international trade. The study showed that the land and water resources are sufficient to satisfy the global food demand, provided that water resources must use conjunctively. Anwar and Ahmad [8] conducted research to evaluate surface irrigation. The authors have used the furrow and border strip irrigation method, canal water, and groundwater that have been used conjunctively for irrigation. The findings of the work suggest that furrow irrigation can give better performance with low distribution uniformity.

In monsoonal climate regions, where the highest supply usually occurs in the form of precipitation/runoff when the water demand is lowest, it entails better management of rain and soil water for more productive water use, whereas in rainfed dry areas, it entails better management of rain and soil water for more productive water use [61]. Ajay Singh [103] conducted a literature review on the conjunctive use of groundwater and surface water for irrigated agriculture. The author has mentioned the advantages, limitations, and future scope in conjunctive use practice. Conjunctive use of water is beneficial to alleviate waterlogging and secondary soil salination. Singh and Panda [106] formulated a simulation optimization model to combat the soil salination and waterlogging problem in the Haryana state of India. Conjunctive use technique has advantages that poor quality water saline water also used in conjunction with good quality water carried an experimental analysis in Hisar, India, and the study examines concern to use of saline and freshwater to add its impact on soil properties; the results of work indicate that with increasing salinity the infiltration rate of soil decreases.

Climate change and conjunctive use

Surface water is directly affected by climate change due to changes in long-term climate variables [120]. Previously, research into the effects of climate change on surface water supplies had exploded. Climate change-related changes in temperature and precipitation may result in increased water demand and decreasing water resource availability [36]. Milly et al. [73] used 12 climate models to quantitatively analyze the effects of climate change on global water resource availability. According to their findings, runoff in eastern equatorial Africa, high latitudes of North America and Eurasia, and the La Plata basin of South America would increase by 10–40% in 2050, while it would decrease by 10–30% in southern Europe, the Middle East, mid-latitude western North America, and southern Africa. Swain et al. [109] presented a review work on the impact of climate change on groundwater hydrology. Authors have emphasized gravity recovery and climate expert application in the Indian region. The study reveals that, due to an inadequate groundwater monitoring network, it is not possible to have an understanding of the complex groundwater system; moreover, regular monitoring in terms of heavy metals will boost groundwater research in India. In mountainous area, climate change is the controlling factor for runoff generation. In addition to this, afforestation, construction of dams, and farmland reclamation have also affected the runoff from the mountainous areas [18]. Agrivoltaism technique has been used as mitigating measure to face climate change; Elamri et al. [32] used the agrivoltaism technique in France. It facilitates the use of solar panels on agricultural land. Energy generation and water saving due to the shadow of the panel are achieved in this technique. Authors reported that using Agrivoltaism reduction in irrigation amount by 20% is achieved. Climate change is responsible for groundwater deterioration; Aladejana et al. [4] conducted a study to assess the quality of groundwater. The authors have examined the links between climate change and groundwater chemistry. The study indicates that the seasonal flooding resulting from extreme precipitation was responsible for the biogeochemical process of redox, and hence, groundwater was polluted in nearby areas. Kahil et al. [57] conducted a study to overcome and to give a remedial measure for water scarcity issues as a result of climate change. Authors have presented a hydro-economic model that links with hydrology, economy and environmental components. The model was applied to the arid and semi-arid regions in Spain. The results of the study indicate that drought events have a large impact on social welfare; also, the net production from agriculture has been reduced. The GW is a most reliable resource, and hence, it has been over-extracted throughout the globe. Moreover, climate change is accelerating the degradation of GW sources; hence, instead of impact assessment adaptation strategies have been used by the policymakers. Afshar et al. [3] formulated a model to assess the adaptation of conjunctive use for sustainable water resource management under the climate change scenario. The authors have tried the global atmospheric circulation model to simulate the climate change in the study area. The outcomes of the study show that a cyclic strategy of conjunctive use is more beneficial and sustainable. As many researchers have cited that the food available in the future will be inadequate to fulfill the demands of such a hasty population. Abeysingha et al. [2] conducted a case study to assess the climate change impact on irrigated agriculture. The authors have formulated a climate change model to simulate the production of rice and wheat in the future for Gomti river basin in India. SWAT and global climate model were used to simulate the stream flows and evapotranspiration. The outcomes of the study estimate the future crop production; hence, such studies will be helpful to plan sustainable agriculture.

Intergovernmental Panel on Climate change (IPCC) is an international organization that asses the science related to climate change. It was set up by WMO and UNEP to provide the information related to climate change, its impact and future direction in the relevant field. As suggested by IPCC, since last 60 years Managed Aquifer Recharge (MAR) has been practiced to conserve and develop the groundwater resources [26]. Climate change has impact on meteorological, hydrological and environmental parameters. Due to climate change, the basin area may suffer from extreme floods, draughts, cloud bursting, and high temperature waves. The MAR is best technique to adapt the climate change and sustainable water resource management through conjunctive water use.

Conjunctive use of low-quality water has various advantages like boosting agricultural productivity by maintaining efficient root-zone leaching, lowering salt export requirements to minimize groundwater degradation, and managing waterlogging at the root zone. The case studies explaining the impact of climate change on the quality and quantity of groundwater are limited as compared to surface water. The activities and sources like domestic waste from pit latrines, wastewater from washing units and waste from animals are responsible to the contamination of groundwater at shallow depth [41]. Haghbin et al. [47] presented a review article; the outcomes of work show that nitrogen compounds are responsible to groundwater pollution. The assessment of groundwater quality is a challenge due to complex nature of nitrate transport and related uncertainties. In India, large-scale groundwater is polluted due to nitrate (N), arsenic (As), fluoride (F), hydrocarbons, and uranium (U) [45]. To ascertain the quality of groundwater, the water is tested to estimate the water quality index (WQI) and for principal components analysis (PCA). Hinge et al. [51] carried out experimental study in Guwahati city, India, and observed that WQI in study area ranges from 19 to 108, the lower numbers indicate the poor quality of water. Conjunctive water use reduces the soil salination issues, increases water resource efficiency, reduces shallow groundwater evaporation, and discharges through drains. These advantages ultimately lead to the sustainable development of water resources [64]. Seasonal variation in groundwater quality was checked by Kadam et al. [56]; authors have conducted experiments to check the parameters like total hardness (TH), electrical conductivity (EC), Ca and Mg, and TDS, mostly to check the feasibility of water for irrigation, commercial and drinking purpose. The authors have collected sample from 68 representative places. The results of study show that water quality is degraded due to industrial contamination. So, this study provides baseline information to groundwater managers to plan and allocate the water sources sustainably.

Conjunctive use modeling

The success of any modeling depends on its planning, development, application, and perpetuation [10]. The authors have reviewed the literature regarding integrated water resource management (IWRM) and summarized the knowledge gap; also, they have provided systematic guidance to formulate the model. The study suggests the five key areas for further research like social equity, uncertainty management, knowledge sharing, stakeholder involvement, and data limitation. Sabale and Jose [93] formulate a conjunctive use model using LINGO and PSO optimization tools. Authors have formulated an optimization model to restrict water scarcity to a minimal extent. The study was conducted in the semi-arid regions to accelerate the crop yield with a minimal usage of water. The study concludes that the optimal use of water can be achieved by changing the conventional crop pattern; also, studies suggest that by lowering crop production other than onion and sugarcane by 15% and by using that area for sugarcane and onion will increase overall net returns by 8%. A hybrid optimization model was developed [97] to have better performance in the water deficit scenarios. Authors have tried to solve the conflict in water distribution by augmenting various optimization tools like genetic algorithm (GA), ant colony optimization (ACO), and bacterial foraging optimization (BFO). The study showed that the combination of GA–ACO–BFO has promising results in terms of net benefits to farmers and also solves chronic water distribution issues. The coupling of MODFLOW and Arc-SWAT was tested for groundwater system simulation [108]; the authors simulated the surface water by SWAT. The recharge rates obtained from the SWAT model were used in MODFLOW to simulate the groundwater system. Joodavi et al. [54] examined the conjunctive use model to derive the optimal operational policy for the Bar dam reservoir in Iran. The authors have coupled the MODFLOW model and optimization model to use surface water and groundwater conjunctively. The study revealed that conjunctive use improves water security also gives a new view in terms of recharging the aquifers from the leakage of a reservoir that was not previously thought of. Integration of SW and GW has been tried by Liu et al. [65] in the Yellow river basin of China. The study basin was under serious water stress because of intense agriculture, dense population, and extreme groundwater use with low water use efficiency. The authors have tried the conjunctive use technique for sustainable development of the basin. The SWAT and MODFLOW models were coupled to optimize the use of SW and GW. This study proved that conjunctive use of water alleviates evaporation loss, increases the water use efficiency, and also maintains the groundwater levels with increased crop yield. Table 1 explicates the simulation models used in conjunctive water use technique. Mostly the models are GIS-based, semi-distributed and enable simulation under the influence of climate change.

Table 1 Conjunctive use modeling for water resource management

Sr. no.	Name of model	Applications/advantages	References
1	MIKE SHE	The model is deterministic, has a potential to predict tile drainage flow	Zhou et al. [121]
2	MODFLOW	MODFLOW coupled with CMC used to simulate groundwater contamination	Harrington et al. [49]
		Model helps to understand flow regime, aquifer parameterization	Baalousha [9]
		Calibrations of conductivity and recharge	Abdalla [1]
3	SWAT-MODFLOW	The coupling of SWAT & MODFLOW used for analyzing the impact of conjunctive use on groundwater levels in irrigation command area	Sabale and Jose [92]
4	SWMM-GSFLOW	The integration of stormwater and groundwater through model was beneficial to Zhangye basin, China, to manage the water resource in semi-arid region	Tian et al. [110]
5	SWAT	SWAT model was used to simulate the surface water in Manimala river basin Kerala, the conjunction of surface water and groundwater practiced to fulfill the water demands	Venkatesh et al. [113]

Optimization of conjunctive use

The genetic algorithm was used as design support to optimize the daily management of water that was abstracted from the different groundwater supply sources [83]. For this study, the authors have introduced a new model called model to optimize water extraction (MOPWE) that was based on the multi-objective genetic algorithm and model was run in MATLAB interface. The model facilitates the optimization of daily water use from various reservoirs and groundwater sources. This robust attempt was very efficient giving a total energy saving of 38% and water saving of 25%. The optimization of conjunctive use of water was carried out by An-Vo et al. [5]; the agricultural production and net profit from agriculture were kept as an objective functions. This study was conducted for the Coleambally Irrigation area in Australia. The outcomes of research work show that conjunctive use of water yields an additional AUD 57.3 million. The linear programming (LP) model was formulated to optimize the conjunctive use of surface and groundwater in the Godavari basin, Maharashtra, India. The objective of the study was to maximize net benefits from the agricultural command area. The constraints imposed on the model were maximum and minimum irrigation demand, canal capacity and reservoir storage. The model proved successful as it was able to enhance the net benefits of 3373.45 million rupees with an irrigation intensity of 57.07% [78]. Since last two decades, the optimization methods have been proved very efficient to manage the water resources. The optimization methods used in conjunctive water use practice with their advantages are listed below (Table 2).

Advantages and constraints of conjunctive use

Conjunctive water use has the following advantages:

The conjunctive water use practice yields a reliable quantity of water for irrigation which results increases agricultural returns. Moreover, it prevents the groundwater depletion caused by extensive pumping [59]. Also, the soil salination and waterlogging issues are alleviated due to conjunctive use practice. Thereby more area will be undertaken for agriculture use. It proves very sustainable for coastal regions where the intrusion of saline water can be arrested by inducing conjunctive use of surface water. Moreover, the conjunctive use has added advantages of utilization of poor/saline water for irrigation. The poor quality water can be mixed with fair quality water and that can be used for irrigation. It helps to augment water resources in the irrigation

Table 2 Conjunctive use optimization with the programming techniques for water resource management

Sr. no.	Name of model	Applications/advantages	References
1	Linear programming (LP)	Used as effective tool to optimize multi-crop pattern and irrigation area allocation	Moradi-Jalal et al. [74]
2	Nonlinear programming (NLP)	Used to mitigate socioeconomic and environmental impact during drought	Daneshmand et al. [25]
3	Dynamic programming (DP)	Capable of managing available water resources and conflicts solving	Zomorodian et al. [122]
4	Genetic algorithm (GA)	Used to solve deficit irrigation scenario	Safavi and Falsafioun [94]
5	Particle swarm optimizations (PSO)	ANN-GA-based model calculates groundwater levels at different time steps	Rezaei et al. [90]
6	Adaptive neuro-fuzzy inference system (ANFIS)	Controls the supply between surface and subsurface, reduce impact of over pumping	Chang et al. (2013)
7	GSFLOW-DYCORS	Used for optimization of conjunctive use of surface water and GW	Wu et al. [118]
8	GSFLOW-SVM	Used for optimization of conjunctive use of surface water and GW in semi-arid region	Wu et al. [118]
9	MODFLOW-ANN	Maximizing water supply and hydropower production	Peralta et al. [82]
10	GA-MODFLOW	For developing the strategies to control Groundwater	Parsapour-Moghaddam et al. [80]
11	CRF-HGS	Optimization pumping in coastal aquifers	Christelis and Mantoglou [20]
12	HGS-CRF-KRG	Comparison between single and multiple surrogate models for pumping	Christelis et al. [19]
13	KRG-HGS	To identify crucial parameters in SW-GW simulation	An et al. [6]
14	LP-PARFLOW	To meet the need for irrigation, the pumping and diversion schedule should be optimized; LP-PARFLOW facilitates the optimization	Condon and Maxwell [22]

command area. The conjunctive water use practice aids to recover the seeped water, which was leaked from the unlined canal.

While the numerous advantages by conjunctive use of water it has some physical and operational constraints [21]. The quantity of water require to recharge the aquifers is not adequate, the type and nature of terrain influences the infiltration and percolation rates, groundwater storage is inadequate, such physical constraints are encountered in conjunctive use technique. Rapid industrialization and urbanization have put pressure on the water demand, food and open area, so it is not possible and affordable to provide land as a recharge site. Moreover, the existing wells are not adequate to supply the water in summer season. The constructions of surface reservoir may increase the evaporation losses and also affect the ecological settings of existing area. Also conjunctive use practice leads to change in land-use land-cover pattern and groundwater levels of basin.

Discussion

This study provides an extensive review of literature explaining the conjunctive water use technique and modeling used for conjunctive use optimization. In general, from small space to global level different simulation models are developed, each having its uniqueness as well as precisions. Some models are applicable to surface water, e.g., MIKE SHE, and some for groundwater like MODFLOW. The models are used to calculate/optimize rainfall–runoff, flood, sediment transport, groundwater discharge, and aquifer configuration. The MIKE SHE has good potential to predict tile drainage flows and is used to design drainage systems. The MODFLOW is a groundwater flow model used to analyze groundwater resource problems and to take water management decisions. MODFLOW coupled with PRMS gives groundwater budgeting for a drainage basin. Due to the advantage of the sequential decision process, the DP technique is more useful to optimize conjunctive use. GA models can be used for nonlinear groundwater problems to minimize the cost of pumping for meeting a specific demand. ANFIS model can solve the socioeconomic, ecological, environmental and legislative issues because it is directly or indirectly related to water resources.

Currently, worldwide researchers are facing the challenges like climate change and the sustainability of water resources. Climate change has a significant impact on hydrology and hydrogeology, so it is necessary to improve current theories and practices accordingly. The literature review revealed that current optimization attempts are plagued due to complex heterogeneity in the subsurface and a lack of supporting data. The MIKE SHE model requires large topographical and physical parametric data. Also, it has use limitations on subsurface strata. The linear programming (LP) models are unable to handle nonlinear problems. So for some cases LP models will have to couple with NLP or with GA. NLP models have limitations to optimize conjunctive use due to the slow rate of convergence and complexity. Though the work has a study of a lot of literature, a complete review of all related work cannot be possible. It may be possible that some concepts regarding conjunctive use are not covered in detail. Such work required a detailed study of each simulation model with different hydrological and hydrogeological conditions to have better outputs. It is also observed that SWOT and PESTLE analysis is very promising in water resource management [76].

Sustainable development of groundwater can be attained by addressing significant human resources and equipment deficiencies, improving official and management tools, and increasing stakeholder participations in the issues concerning the water management. The key challenges in water management comprise the lack of ability to establish who needs what, time and frequency; high staff turnover; capacity gaps and poor scenario planning [72]. Although conjunctive water use has numerous advantages, they have some drawbacks like surface water reservoirs having evaporation loss, soil erosion, sedimentation, and waterlogging. To formulate successful conjunctive water use model the previous meteorological and hydrological data is required but it is a challenge to get the data [53]. Conjunctive use practice may increase the infrastructure cost for irrigation and for developing countries it may not be affordable. The new technology and soft-computing tools are available to impart conjunctive use but the institutional cooperation is lacking due to inability to use new technology. The literature review revealed that more research is needed to clear the understanding of pollutants like pharmaceuticals, nutrients, personal care and pathogens [45]. After reviewing the literature regarding conjunctive use the research gaps are identified mostly in the methodologies used and uncertainty analysis, institutional issues, technological, political, social and legal aspects [75, 76, 96, 104, 107]. The findings of this work will help researchers, policymakers and stakeholders to select appropriate methods to optimize conjunctive use of water, and to reduce water deficiency problem.

Future scope

According to the literature review indicated above, the importance and advantages of the conjunctive use of surface and ground water are well established for sustainable agricultural development. These advantages arise as a result of the diverse nature of the water resources. Surface water's delivery and extraction costs are often lower, but its supply is erratic. At the same time, ground water has a consistent supply but it is expensive to pump. Hence, in future more research needs in conjunctive use of water and effort should be made to fulfill the shortcomings in sustainable development. The probable future research scenarios are provided below that could help to attain the sustainable water resource management.

- More research needs to improve the constraints in estimation of evapotranspiration and recharge by remote sensing technique [27].
- Many studies made use of saline water in conjunction with freshwater for agriculture use; hence, it is required to assess the long-term impact of such practices on soil and groundwater quality [75].
- Literature survey revealed that water and energy are not correctly priced and they are not effectively allocated. The policies and investments in these areas are not adequate; moreover, fewer studies are conducted in promotion of natural water resource management and integrated water resource management. So, these areas need further research to overcome the aforementioned limitations [16, 116].
- Future research is needed in the field of restoration and protection of ecosystem; wetland, mountain forest, and attempts are also made to alleviate the gaps between demand and supply of water for irrigation, water conservations, recycling of wastewater, and training/ awareness of farmers [28].
- The physical-based semi-distributed models like SWAT & MIKE SHE are capable to simulate the surface flows and it can be best tools in conjunctive water use practice if the observed data for validation is available, also if uncertainty analysis is carried out [104].
- It is necessary to evaluate that by changing the prevailing cropping pattern and reducing the area under paddy and sugarcane by other regional crops which require less water, what will be the impact on waterlogging and secondary soil salination.
- Implement the “warabandhi” water distribution method and declare crop holidays to alleviate the waterlogging issues [79].
- It is very important to understand the river basin hydrogeology to formulate any hydrological model. As the hydrological parameters are varying spatiotemporally, it is a challenge to assess the spatially heterogeneous and temporally dynamic characteristics of human–hydrology interaction models [30].

Conclusions

The present study is planned to review the literature regarding the conjunctive use of water in irrigation command. The simulation–optimization methods used for conjunctive use, the aspect of climate change and water quality analysis are presented in detail. The literature review reveals that global researchers are adapting conjunctive use technique to tackle with water scarcity issues; few scenarios depict that poor/saline/wastewater are used in conjunction with fresh water to fulfill domestic and irrigation demands. To have such study on basin scale, GIS techniques must be used in conjunction with computer-based simulation optimization models. The main challenges in search computer-driven models are the data available, uncertainty analysis and parameter estimations. However, the tools like SWAT-CUP, UCODE and PEST have been used to solve such issues. Developing countries to address the issues regarding conjunctive use of surface water and groundwater require integration of socioeconomic, environmental, technical and legal aspect into a regulated framework. However, due to the lack of infrastructure, funds available and institutional issues, the developing countries face the challenges toward the hydrologic assessment.

Although every conceivable piece of literature was examined in this study, it would be impractical to include every publication in a review. This review study provides an advantages, limitations, challenges and future scope in conjunctive use of surface water and groundwater for sustainable irrigation. It is possible that some of the finer points were glossed over or omitted entirely. It is anticipated that later contributions will close these gaps and open the door to additional discussion of the subjects covered in this evaluation.

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Data availability All the data taken in the manuscript are based on the literature study carried out in conjunctive water use field and those are available on reasonable request.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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