

Implications Of Farming And Cropping Systems On Groundwater Resource In Berambadi Watershed, Karnataka- A Systematic Review

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Abstract: *The Berambadi watershed, known for its extensive irrigation practices, plays a crucial role in sustaining agricultural growth. However, the cumulative impact of farming practices, cropping systems, and farm typology has led to a significant alteration in the groundwater gradient, subsequently affecting both water supply and demand in the study area. This systematic review aimed to analyze the repercussions of cropping and farming systems on groundwater resources within the Berambadi watershed. The findings highlight that 60% of households in the watershed have access to groundwater, which has resulted in a substantial increase in groundwater-based irrigation practices. Specifically, the study reveals that irrigation coverage in the Berambadi watershed increased to 15.8% during the Summer, 16.5% during the Kharif, and 13.9% during the Rabi season in 2015-2016, compared to 6.3%, 9.2%, and 15.7% respectively in 2014-2015. Moreover, the percentage of irrigated cropland witnessed a notable transformation, rising from 4% in the upstream, 6% in the middle stream, and 4% in the downstream during the 1990s to 51% in the upstream, 24% in the middle stream, and 19% in the downstream during the 2015 Rabi season, reflecting the evolving cropland patterns within the watershed. Technological advancements and the pursuit of profitable cash crops have spurred intensive groundwater abstractions, leading to a significant decline in the water table by up to 30 meters. The decisions and management strategies employed by farmers have played a crucial role in shaping cropping systems and farm typology, further highlighting the reliance on groundwater irrigation. Therefore, comprehensive investigations are imperative to assess the actual potential effects and the extent of the impact on groundwater resources.*

Keywords: *Farming systems; Cropping systems; Groundwater levels; Berambadi Watershed.*

1. INTRODUCTION

It is understood that protecting water resources is essential to maintain the ecological system. The essential concerns of the environment's changes effects on how water responds must be identified to effectively manage and prepare for water resources (Malekzadeh et al. 2019; Evan et al. 2020). In India, groundwater irrigation has dramatically risen over the years from 20Mha to 60Mha with a net irrigated area growth from 22Mha to 75Mha (Marion et al. 2017; Bhaduri et al. 2012), securing crop yield in semi-arid areas. Groundwater resources have been overexploited, and their quality and quantity have been depleted over time (Varouchakis et al. 2022; Buvaneshwari et al. 2016; Fishman et al. 2011). Numerous studies are conducted on the relationship between irrigation and poverty, all of which point to the development of irrigation as an effective strategy for reducing poverty (Lipton et al. 2003; Kijne et al. 2003; Castillo et al. 2007; Hussain et al. 2004) by improving the economic condition of the rural households (Giordano et al. 2019; Namara 2010; Shah et al. 2004; Saleth et al. 2003). The effect of agricultural production on the use of water resources in India has been studied from a variety of angles and using different approaches. These include measuring crop-livestock water productivity, analysing how much more water is used in agriculture, looking into how water is becoming increasingly scarce in arid places, and performing water resource auditing and modelling at the watershed level (Bekele et al. 2017; Ariyama et al. 2019; Saravanan et al. 2020). According to research findings, crop production has already been negatively impacted by groundwater depletion, resulting in lower yields. A further decline in cropping intensity and overall agricultural output is anticipated as a result of this trend in the future (Jain et al., 2021). Additionally, it

is anticipated that the effects of climate change would compound these issues, amplifying the detrimental effects on agriculture (Zaveri and Lobell, 2019). According to Marion et al. (2017) and Nagano et al. (2015), almost 95% of farmers in India have parcels of land that are less than or equal to 1 ha. Therefore, it is crucial to keep an eye on these tiny irrigated croplands to determine how much water is being used for irrigation (Lobell et al. 2008, 2011). As a result of factors such as the rising global population, income growth, urbanization, and development policies, farming systems are undergoing rapid transitions on a global scale (Bhavana et al. 2023). Growing crops like rice, sugarcane, and bananas with high water consumption is prohibited in arid and semi-arid regions because excessive groundwater pumping causes groundwater levels to decline and become detached from the surface, which causes rivers to dry up (Javeed et al. 2009; Barik et al. 2016; Paul et al., 2016). Categorization of irrigated crop types, irrigation source and intensity, and unambiguous monitoring of irrigated farmland are the important problems with small fields (Sharma et al. 2018; Thenkabail et al. 2009). Monitoring farmland that is irrigated with groundwater and identifying places with intensive cropping are the two main steps to combat the global water resource shortage (Thenkabail et al. 2009; Shiklomanov 2000).

In Southern India, crop classification is a difficult problem since optical satellite images are sporadic throughout the monsoon season due to cloud cover and small croplands with various crops (Mangiarotti et al. 2018; Marion et al. 2017). There is currently little knowledge on the precise effects of groundwater depletion on the production of diverse food crops, each of which has different water requirements. Understanding these effects on specific crops is essential, though; since it can assist identify those that are most at risk and need interventions or regulations to maintain their production. We can put targeted measures into place and protect agricultural productivity in the face of water resource issues if we have a thorough grasp of how groundwater depletion impacts various food crops (Nishan et al. 2021). There is a need to synthesise the results of the numerous empirical studies that have examined the relationship between diverse crop rotations and water use. This synthesis would be a useful tool in educating policymakers about possible tactics to improve agricultural sustainability. Policymakers can apply practises that maximise water usage and support sustainable crop production by using the findings from these studies to inform their decisions (Xiaolin et al. 2021). Sharma et al. (2018) claim that the only source of irrigation with noticeable regional variation in the Berambadi watershed is groundwater. The water resources in the watershed are significantly impacted by frequent multiple cropping, which causes the water table to drop dramatically (by more than 50 m) (Amit et al. 2018). The ecology was more significantly impacted by the rivers' loss of base flow and the more pronounced groundwater level reduction in the valleys. The goal of this investigation is to look at the variations in farming methods, cropping patterns, and farm features within the Berambadi watershed and assess how these affect groundwater resources. The gathered data offers important insights for a more precise evaluation of the potential impacts of agricultural and water management strategies on both farmers' livelihoods and the groundwater table in the Berambadi Watershed. Such an evaluation is essential for the efficient management and planning of water resources, assuring the long-term viability of agricultural practises and the welfare of nearby people.

2. MATERIALS AND METHODS

Study Area

A river basin tributary to the Kaveri, the Berambadi watershed (89 km²) is located in the South Gundal basin (816 km²), which is a portion of the Kabini River basin (about 7050 km², southwest Karnataka state) (Sekhar et al. 2011; Ruiz et al. 2016) as shown in Fig.1. Weather stations, flux towers, COSMOS (Cosmic-ray Soil Moisture Observing System) (Barik et al. 2016), and rain gauges are only a few examples of the real-time ground-based equipment that is available in the watershed. The salient features of the watershed and aquifer characteristics are as shown in Table.1 and Table.2.

The watershed comprises of crops (52%) and forest reserves (35%) occupy 87% of the watershed, while diverse land uses, including habitations, water features, roads, and wasteland, account for the remaining

13% of the total area. The watershed is used as a location of calibration for numerous satellite missions, including Radarsat-2 and RISAT-1, as part of the continuous project, Assimilation of Multi-satellite at Berambadi watershed for Hydrology and land Surface Research. The Indo-French Cell of the Water Science Cell in Bangalore has been building the site as a research observatory since 2002 (<https://mtropics.obs-mip.fr/>). Approximately 35% of the annual precipitation falls during the SW monsoon and 36% falls during the NE monsoon, totalling 734 mm per year with the growing seasons lasting 90 to 120 days. The Berambadi watershed has a tropical sub-humid climate due to its location in the eastern Kabini basin, with an average yearly rainfall and PET of 900 mm and 1200 mm, respectively (Sharma et al., 2019). With roughly 900 mm of yearly precipitation upstream (in the west) and less than 800 mm of annual precipitation downstream (in the east), the watershed exhibits a moderate east-west rainfall gradient. The spatial distributions of several monitoring locations in the watershed are as shown in Fig. 2. <<http://ambhas.com/study-area/berambadi/>>.

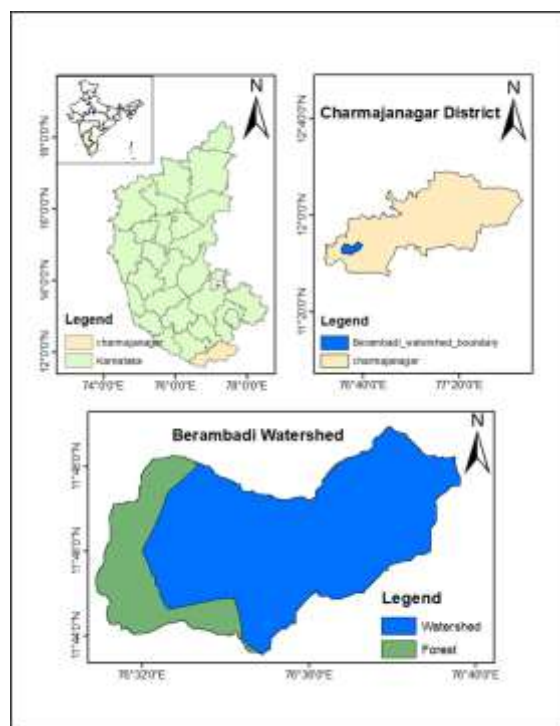


Fig. 1 Location of Berambadi Watershed

The watershed is classified as AWh (Equatorial, Desert/arid, Dry) based on the Köppen-Geiger updated world climate classification.. The cropping systems are controlled by three seasons: the south-western monsoon season of Kharif (June to September), where practically all plots are farmed and either totally or partially rainfed; the northeast monsoon or winter season of Rabi (October to January), where most of the plots are cultivated through irrigation; and the hot/dry season of summer (February to May), where only a few irrigated areas are grown (Sharma et al., 2019).

Table. 1 Salient features of Berambadi Watershed

Parameter	Description
Watershed Details	
Area	89 km ²
Elevation	830 - 940 m above MSL

Annual Temperature	23.7 °C
Annual Precipitation	734 mm downstream; 900 mm upstream
Aridity Index (P/PET)	0.7
PET	1200 mm
Geological Formations	Granite and Genesis
Moisture & Temperature regime of Soil	Ustic & Isohyperthermic

METHODS AND DATA ANALYSIS

The Berambadi watershed was the subject of a systematic study based on peer-reviewed research that were gathered from well-known databases including Mendeley, ScienceDirect, Springer, and Scopus using simple keywords like "Berambadi Watershed," "Farm Typology," "Crop Classification" and "Impact on Groundwater Resources". All in all, 17 articles that incorporated crop classification, farm typology, and groundwater irrigation estimation out of which 6 papers were chosen which provided sufficient information on farm typology, crop classification, and overall accuracy statistics as represented in Table. 3. Studies also covered the watershed's significant variety of crop kinds and crop management techniques. The selected six representative articles on Cropping and Farming Systems (Marion et al. 2016, 2017; Amit et al. 2018, 2019, 2021; Mangiarotti et al. 2018) were used to extract farm structure, farm practices, cropping systems and impact on groundwater resources. Cloud-free images from a variety of optical satellite systems are used in many papers since cloud cover is the most difficult hurdle to track agricultural growth. Next, to validate these images, the kappa coefficients are utilized, which vary from +1 (perfect agreement) to 0 (no agreement above that expected by chance) to 1 (total disagreement). Support Vector Machine (SVM) was one of the most commonly adopted classifier methods to identify the intensively irrigated cropland with the use of Normalized Difference Vegetation Index (NDVI) to optimize vegetation model and crop irrigation. The literature employed various techniques to detect farm characteristics, crop management and impact on groundwater resources in the watershed.

Table.2 Berambadi watershed – Aquifer Characteristics

Parameter	Description	Spatial Distribution	Source
Weathering Profile			
Bedrock	Horizontal Fractures: 1 to >13 m in length	More intense fractures in shear zones	Geological Observations
	Vertical Fractures: <1 m in length		
Saprolite	1-4 m thick (<0.4 m on slope)	Thin on slopes & thick in valleys	Geological Observations
Saprock	1- 4 m thick	Always present	Geological Observations
Hydrodynamic Properties			

Specific Capacity	0.9 - 48 m ² /day	Spatially Variable	Sarah et al. 2020
Transmissivity	1-60 m ² /day	Spatially Variable	Sarah et al. 2020
Specific Yield	~0.1-0.4%		Legchenko et al. 2006

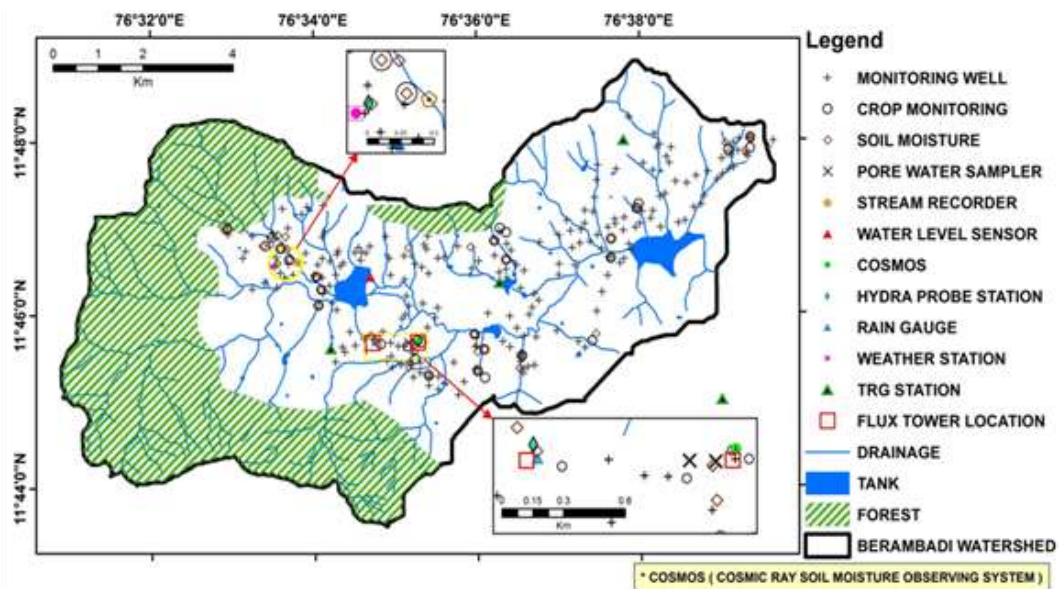


Fig. 2 Spatial distribution of monitoring locations in Berambadi Watershed from AMBHAS, accessed 5 May 2023, <http://ambhas.com/study-area/berambadi/>

Table. 3 Information of 6 articles: data acquisition, software used for crop classification and farm typology, overall accuracy

Over all Acc urac y and Kap pa coeff icien t	-	Right detection (>60%) for corn, beets, chillies, beans, sorghum, and turmeric, middling scores (between 40% and 50%) for bananas and onions, and poor scores (30%) for marigold and sunflower	-
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Cro ppin g Syste ms/ Prac tices	Sorghum, maize, sunflowers, and marigolds are not irrigated during the Kharif season; however, turmeric, onions, garlic, and bananas are. Sorghum, millet, and pulses are sub cropped on 20% of the total crop land. Maize, horse gram, and (irrigated) during the Rabi season. 90% of the cropland is fallow throughout the summer. Cropping strategy based on weather, market price, labour source, and machinery.	The following are the percentages: marigold (4-9%), sunflower (18-35%), sorghum (17-24%), turmeric (16-19%), maize (1-4%), and banana (1-2%). The representativeness of the next four crops, onion, beetroot, bean, and chilli, is lower (0.5% each).	Large diversified and productivity farms. Small and marginal rainfed farms, and Small, irrigated marketing farms
Soft ware Use d for Clas sific atio n	Conceptual Model Numerical Assessments with Models of Agricultural Systems integrating Techniques and Economic (NAMASTE)	Operational Land Imager (OLI) Sensors from Landsat-8 platform https://landsat.usgs.gov/landsat-level-1-standard-data-products	Multivariate analysis (including Multiple Correspondence Analysis and Agglomerative Hierarchical Clustering) and descriptive statistics Environment and language for statistical computation in R
Data Acq uisit ion (Yea r)	2014 and 2015	Kharif season of years 2006, 2007 and 2008	2016 684 farms
Aut hor	Marion et al. 2016	Mangiarotti et al. 2018	Marion et al. 2017

Over all Acc urac y and Kap pa coeff icien t	Kappa coefficient greater than 0.9	Irrigated double croplands are 6.22 km ² (13.4%), 16.14 km ² (34.7%), and 9.58 km ² (20.6%) in size, with kappa coefficients of 0.84, 0.74, and 0.94	Kappa coefficients: 0.81-0.96 for 2014- 2015; 0.62-0.89 for 2015-2016, 1.00 for summer 2016
Cro ppin g Syste ms/ Prac tices Far m Stru ctur e/Pr actic es	1990: 5% irrigated cropland clustering 1994: 16% irrigated cropland clustering 2004: 14% irrigated cropland clustering 2008: 21% irrigated cropland clustering 2015: 31% irrigated cropland clustering 2016: 14% irrigated cropland clustering	Nearly 21.7% of the total cropland is covered by the 10.1 km ² of the kharif cropping season. Rabi season irrigation covers 10.5 km ² , or roughly 22.6% of the watershed's farmland	2014-2015: No. of intensively irrigated fields-182, other croplands - 446 2015-2016: No. of intensively irrigated fields-218, No. of other croplands - 513 2016: o. of intensively irrigated fields-152, No. of other croplands - 452

Software Used for Classification	Landsat satellite images Support Vector Machine (SVM) classifier	Microwave Remote Sensing C-band polarimetric Synthetic Aperture Radar (SAR) time series images Support Vector Machine (SVM) classifier	Cloud-free images from multiple optical satellite platforms Support Vector Machine (SVM) classifier
Data Acquisition (Year)	1990 - 2016	Kharif and Rabi season of 2013	2014, 2015, 2106
Author	Amit et al. 2018	Amit et al. 2019	Amit et al. 2021

Table. 3 Information of 6 articles: data acquisition, software used for crop classification and farm typology, overall accuracy

3. RESULTS AND DISCUSSIONS

3.1. Cropping Systems and its Implications on Groundwater Resource

As 60% of the households have access to groundwater, irrigation practices have led to extensive use of groundwater. The Berambadi watershed has significant annual actual evapotranspiration values that are higher than annual rainfall (Sekhar et al. 2016; Eswar et al. 2016). During kharif (monsoon, mid-May to mid-September), rabi (post-monsoon, mid-September to mid-January), and summer seasons (pre-monsoon, mid-January to mid-May), farmers commonly used drip, sprinkler, and flood irrigation methods (Sharma et al. 2018, 2019; Mangiarotti et al. 2018; Ruiz et al. 2016). Sunflower, maize, beans, marigolds, sorghum, and finger millets are some of the non-irrigated crops planted during the kharif season (Rainfed) with farmers partially relying on irrigation systems and groundwater availability during periods of low rainfall. Based on the availability of groundwater, annual crops like banana and sugarcane, as well as cash crops like onion, cabbage, beetroot, and chillies, are planted throughout the kharif season (Sharma et al. 2018; Mangiarotti et al. 2018). Crops that require intensive irrigation are grown such as turmeric, chillies, bananas, sugarcane, garlic, beets, cabbage, tomatoes, and beans during Rabi season. Irrigated crops such as beets, bananas, sugarcane, vegetables, and tomatoes are grown during the summer season. Due to intensive water use, the watershed's dug wells and open wells have vanished since the groundwater level has decreased to about 50 m below the surface. Various datasets, including seasonal crop types, irrigation techniques, sowing and harvest times, and irrigation water sources, showed that the farmers used an unplanned partial irrigation system during crop growth. Farmers moved water from downstream tanks to upstream fields because of the clayey soil with high water-holding capacity in the downstream portion. Most farming techniques during the kharif monsoon season rely on rainfall from the SW monsoon as

monthly rainfall varies between the cropping seasons. Table.4 represents the harvest calendar of the watershed.

Farmers relied heavily on groundwater irrigation during the early crop seasons due to rainfall deficits, which led to a 40-50 m reduction in groundwater levels in the downstream watershed areas. The two main causes of groundwater depletion in the watershed were extensive irrigation with groundwater and a bad monsoon season during the summer, kharif, and Rabi harvesting seasons in the years 2014-2015 and 2015-2016. More than 400 mm of rainfall recharged groundwater in kharif and summer seasons during the year 2014-2015, which encouraged farmers to implement irrigation in the summer cropping season of 2015, as can be seen in Fig. 4 and Fig. 5. It demonstrates that the total area that was irrigated in 2014-2015 was 6.3%, 9.2%, and 15.7% correspondingly and the overall percentage of area that was irrigated for the summer, kharif and Rabi seasons, respectively, was 15.8%, 16.5%, and 13.9% for the years 2015-2016 as shown in Table. 6. With adequate groundwater recharge due to SW and NE monsoons, spatial distribution of intensively irrigated croplands was observed in 2016 as shown in Fig. 6. According to studies by Sharma et al. (2018) and Ruiz et al. (2016), irrigation practises began downstream and steadily moved upstream through time, resulting in assemblages of irrigated croplands with a considerable number of operable borewells in the upstream portion of the watershed (Marion et al. 2017). Using SVM classification and a variety of satellite pictures, the overall classification accuracy for the cropping seasons achieved 83%.

Table.4 Harvest Calendar of Berambadi watershed (Amit el al. 2018)

Non-Irrigated Crops			
	Summer Season	Kharif Season	Rabi Season
Jan - May			
May - Sept		Maize	
		Country Beans	
		Marigold	
		Finger Millet	
Sept - Jan			Maize
			Country Beans
			Chickpea
			Groundnut
Irrigated Crops			
	Summer Season	Kharif Season	Rabi Season
Jan - May	Onion		
	Beetroot		
	Watermelon		
	Cabbage		
	Tomato		
May - Sept		Onion	
		Beetroot	
		Chilli	
Sept - Jan			Tomato

		Garlic
		Beetroot
		Solar Beans
		Cabbage
		Turmeric (8 - 9 months)
		Sugarcane (annual crop)
		Banana (annual crop)

Table. 5 Crops name, Crop density (m^{-2}) and Percentage of regional surface representativeness in Berambadi watershed (Mangiarotti et al. 2017)

Crop	Density (m^{-2})	% in Berambadi
Sunflower	9	18-36
Marigold	9	4-8
Turmeric	6	16-19
Beetroot	9-12	<0.5
Onion	16	<0.5
Chilli	6	<0.5
Beans	6	<0.5
Banana	1	1-2

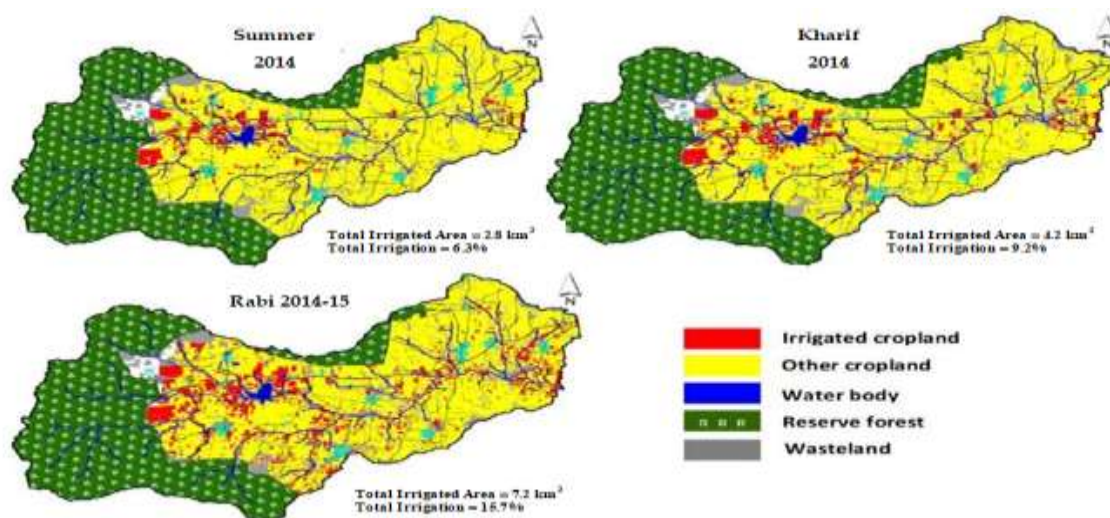


Fig. 4 Classification of seasonal intensively irrigated cropland for 2014-2015 (Amit et al. 2021)

Table.6 Classification accuracy of intensively irrigated cropland for the years 2014-2015 and 2015-2016 (Amit et al. 2021)

Cropping Season	Irrigated Area (km^2)	Irrigation Area (%)	Kappa Coefficient	Overall Efficiency (%)
Summer 2014	2.8	6.3	0.9	94.8
Summer 2015	7.2	15.8	0.7	86.7
Summer 2016	5.8	12.8	1	100
Kharif 2014	4.2	9.2	0.9	95.6
Kharif 2015	7.4	16.5	0.8	92.2
Rabi 2014-2015	7.2	15.7	0.8	94.6

Rabi 2015-2016	6.4	13.9	0.8	88.3
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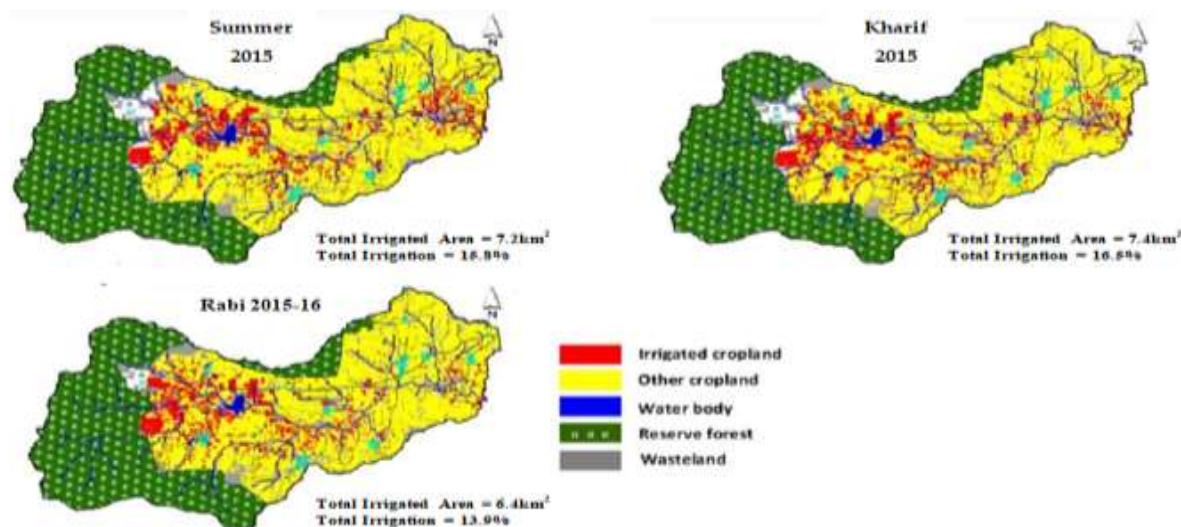


Fig. 5 Classification of seasonal intensively irrigated cropland for 2015-2016 (Amit et al. 2021)

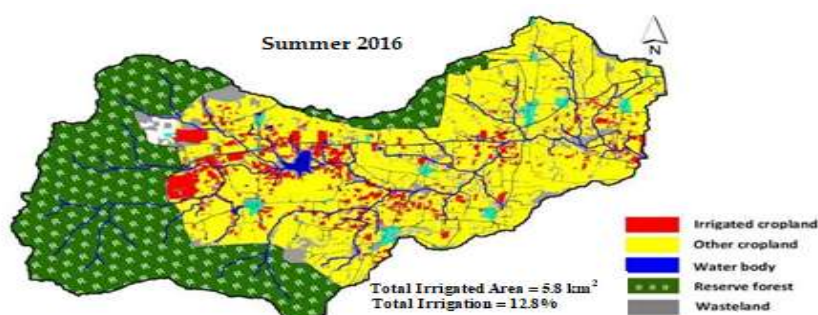


Fig. 6 Classification of seasonal cropland that is heavily irrigated in 2016 (Amit et al. 2021)

3.2. Farm Structure/Practices and its Implications on Groundwater Resource

There are 5461 farmhouses spread out among 12 communities in the Berambadi watershed. Because of intensive groundwater pumping, the watershed has an unusual groundwater level gradient, which was supported by low-cost pumping and irrigation equipment subsidies, with a shallow groundwater table upstream and a deep groundwater table downstream. This pattern change is also influenced by the geographic distribution of soil types, the accessibility of groundwater, farming techniques, market awareness, and government assistance. Farm structure, cropping system, farming practices, water management for irrigation, and farm economic performance are among the parameters were used to investigate farm typology in the watershed. The watershed's farms range in size from 0.01 to 9.3 hectares, with the typical farm measuring 1.3 hectares. Most farms are marginal (33% have 0.7 hectares) or small (46% have 0.7-2 hectares). 4% of farms have more than 4 hectares, compared to only 16% of farms with more than 2 hectares. 46% of farmers have just one jeminu, while 25% have two, 14% have three, and 15% have more than three (A jeminu is a farm made up several agricultural plots cultivated by the same farmer). One crop per season or multiple crops can be grown on the entire jeminu. In the water-shed, crop plot sizes range from 0.01 to 2.5 hectares on an average, but the crop yield varies among the fields. In the watershed, 60% of farms have access to irrigation. Compared to non-irrigated farms, irrigated farms typically have more jeminus with access to groundwater irrigation. During Rabi season 2015, the percentage ratio of total irrigated cropland has increased to 51% in the upstream, 24% in the middle

stream and 19% in the downstream from 4% in the upstream, 6% in the middle stream and 4% in the downstream in 1990's, representing the cropland evolution in the watershed as shown in Fig. 7. Cropland evolution in summer season 2016 compared to Rabi season 2015 is about 19% in the upstream, 14% in the middle stream and 9% in the downstream as represented in Fig. 8.

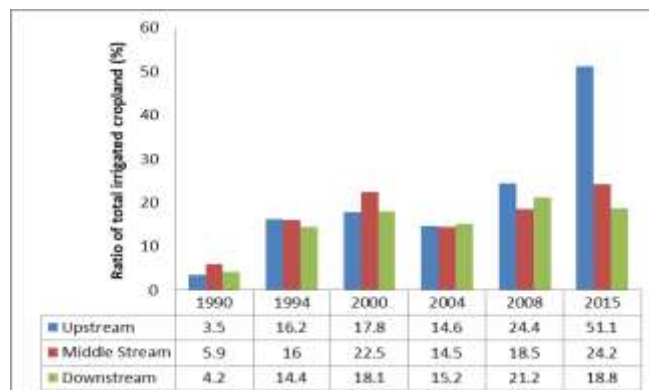


Fig. 7 Rabi Season Irrigated Cropland Evolution (Amit et al. 2018)

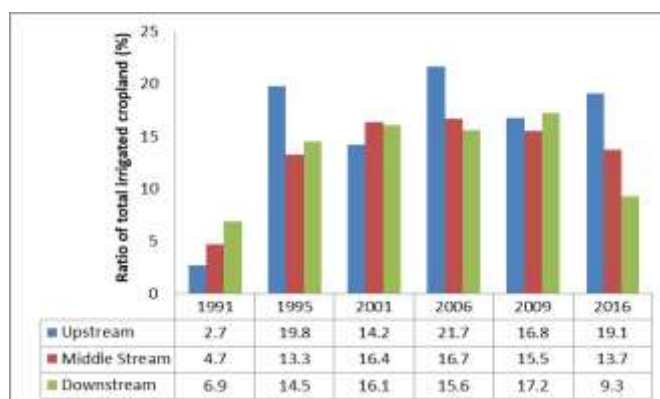


Fig. 8 Summer Season Irrigated Cropland Evolution (Amit et al. 2018)

The ratio of total dual irrigated cropland has evolved drastically to 14% (2015-16) in the upstream of the watershed, compared to 1% during 1990-91 as can be seen in Fig. 9. Technology has made it possible to dig deeper wells in addition to allowing for an increase of borewells represented in Fig. 10. While 18% of the borewells drilled between 1995 and 2010 were deeper than 160 m, the maximum depth of wells drilled prior to 1995 was 160 m. The deepest borewell, which was bored at a depth of 280 metres, was one of the 214 drilled after 2010. Along with sprinkler and drip irrigation, furrow irrigation is by far the most widely used irrigation technique in the watershed. The number of cropland evolution with respect to the area interval in the watershed is as shown in Fig.11.

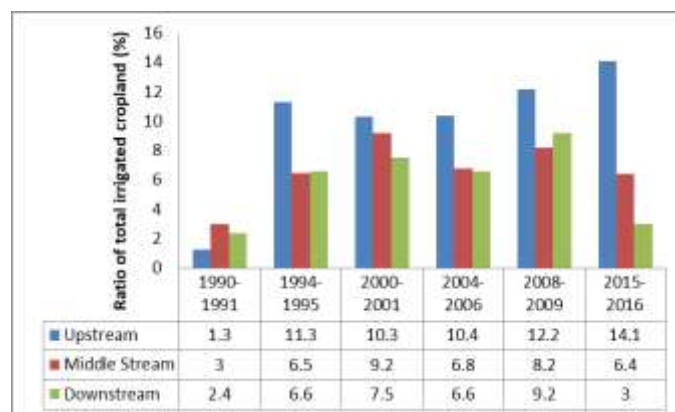


Fig. 9 Dual Irrigated Cropland Evolution (Amit et al. 2018)

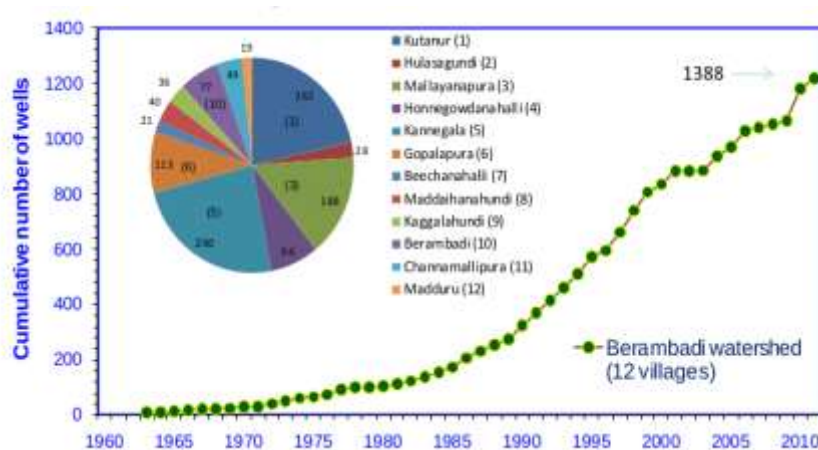


Fig. 10 Drastic increase in number of borewells in the watershed, spread across 12 villages AMBHAS, accessed 5 May 2023, <http://ambhas.com/study-area/berambadi/>

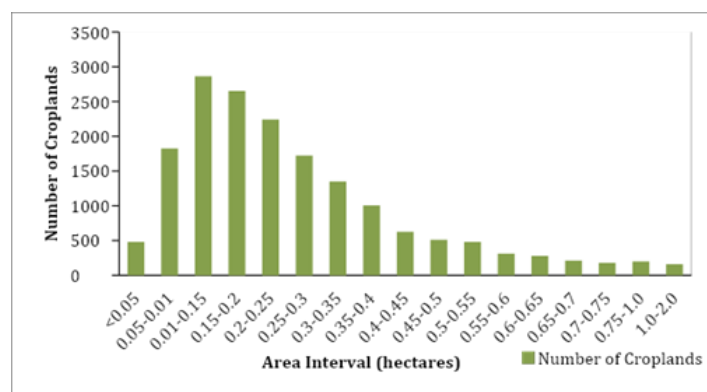


Fig. 11 Distribution of cropland in the Berambadi watershed (Amit et al. 2018)

There are three sorts of farms; Farm Type 1: Huge, productive farms with a variety of land uses that are primarily found in the watershed's core and have more than 2 hectares of farmland. These farms use one or more borewells to irrigate 98% of their land. Farm practices are diversified with mixed cropping systems (rainfed crops mixed with irrigated crops). Farm Type 2: Small and Marginal Rainfed Farms, which are located at the centre and western part of the watershed with 90% of these farms having less than 2 hectares

of cropland which do not have access to irrigation and minimal usage of borewells. As there is no access to irrigation, farmers face difficulty in growing crops during Rabi season. These farms have the lowest farming expenditure. Farm Type 3: Irrigable Small Marketing farms which are located in the eastern section of the watershed have fewer than 2 hectares of farmland, and at least one borewell present. Diversified cropping systems provide for the balance of medium to high expenses with medium to high profits from the sale of cash crops.

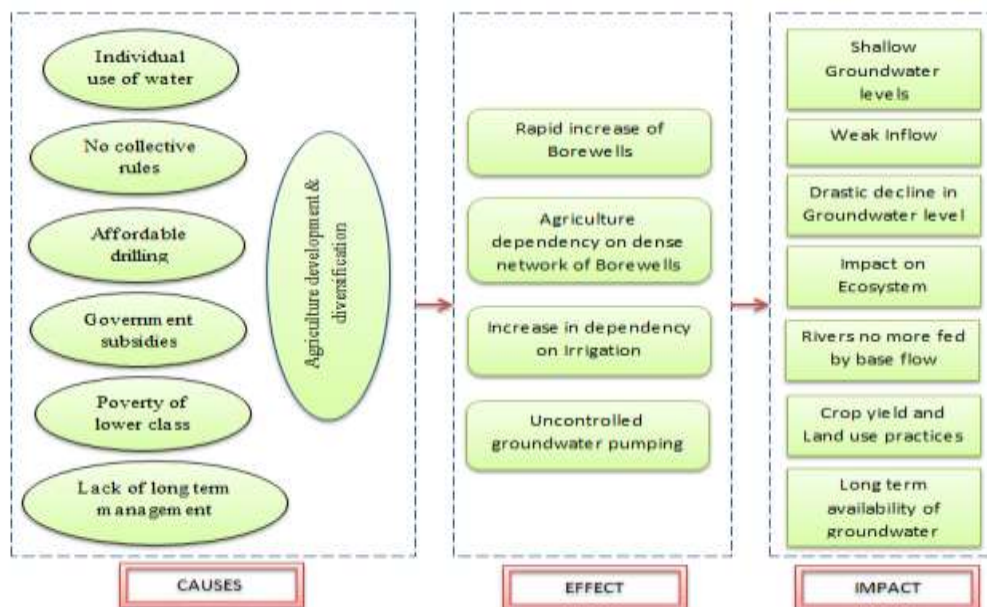


Fig. 12 Summary of causes, effect and impact of cropping and farming systems on groundwater resources

According to studies, over the past ten years, the watershed's technological advancements have caused the depth of its borewells to expand. Other elements like distances from the main road, local soil and groundwater conditions, accessibility to markets and crop outlets, crop selection, and farming methods also have a bigger impact on how specialised the farm typology is able to represent the variety of farms in the watershed. According to the farm typology in the watershed, farmers who have small, irrigated marketing farms grow cash crops and crops that require a lot of water. Small rainfed farms have been transformed into small irrigable marketing farms because of increased technological advancements, particularly in the western part of the watershed, according to farmers. Affordable drilling, Government subsidies, Lack of long term management of water resources with no collective rules are some of the causes led to rapid increase of borewells in watershed. With more increased agriculture dependency on dense network of borewells which led to uncontrolled groundwater pumping impacting on the groundwater resource of the watershed with weak inflow and drastic decline in groundwater levels impacting on the crop yield and land use practices. The summary of causes, effect and impact of cropping and farming system on the groundwater resources in the watershed is represented in Fig. 12.

3.3. Spatial Distribution of Groundwater Level and Groundwater Recharge

Groundwater level maps for the pre and post monsoon seasons of 2010 and 2015 shown in Fig. 13 indicates the seasonal variations in the groundwater levels which do not show drastic variation between the seasons. It is observed that during the pre-monsoon season in 2010 and 2015 have much deeper groundwater levels compared to post-monsoon season in 2010 and 2015. This pattern is may be due extensive irrigation with groundwater and a scanty rainfall during pre- monsoon seasons.

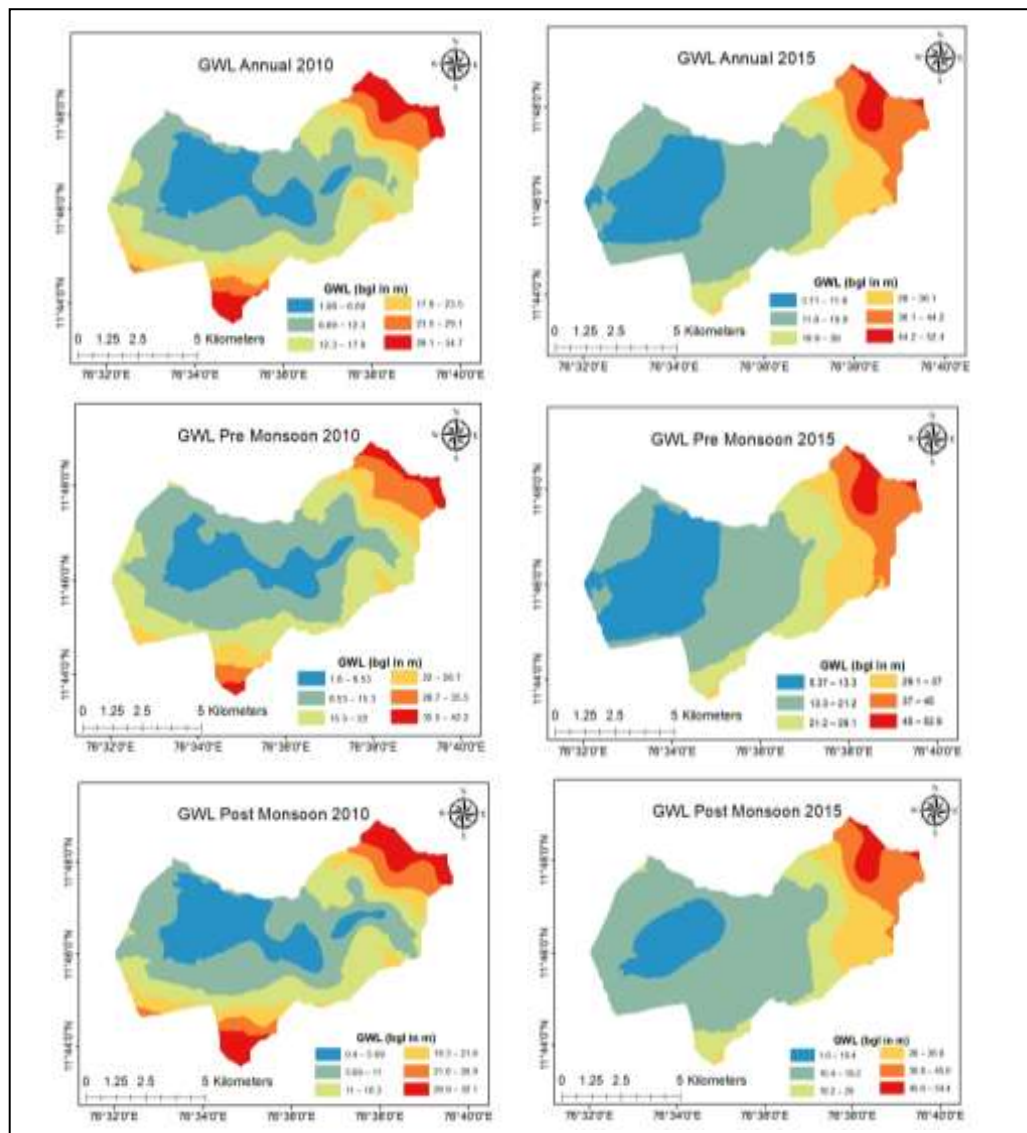


Fig. 13 Groundwater Level Map of Pre Monsoon and Post Monsoon seasons of 2010 and 2015, along with annual map (2010-2015) (Data Source: GWL's from ATREE)

Groundwater level rise is observed during post-monsoon seasons of 2010 and 2015 compared to pre-monsoon seasons of 2010 and 2015. As 80% of rainfall occur during the pre-monsoon period (June – September) each year, has the flourishing effect on the groundwater re-charge which leads to comparative rise in groundwater levels during post-monsoon periods. The spatial distribution of annual groundwater level depletion map shown in Fig.13 shows that the watershed has shallow groundwater levels in the western region compared to the north eastern part with much deeper groundwater levels showing groundwater depression upto 30-40 m.

The long term variations indicate that the groundwater levels have become much deeper during pre and post monsoon seasons in 2015 compared to in 2010. In pre and post monsoon seasons of 2010 the groundwater level in the watershed has varied from 1.8-8.53 m to 35.5-42.2 m bgl and 0.4-5.69 m to 26.9-32.1 m bgl, respectively. The groundwater level in the watershed in 2015 during pre and post monsoon seasons have varied from 5.37-13.3 m to 45-52.9 m bgl and 1.6-10.4 m to 45.6-54.4 m bgl, respectively. From the long-term groundwater level fluctuations, it can be observed that the whole watershed has shown

groundwater depression in both the seasons from 2010 to 2015. The north part towards the eastern half of the watershed display extreme variation and significant decline of groundwater level upto 30-40 m bgl. Fig. 14 highlights the extending groundwater depression upto 30 m in the watershed indicating the increasing stress on available groundwater resources in the watershed. Groundwater recharge, being a major factor maintaining groundwater resources in the watershed, should be carefully analysed in order to establish the quantities of water that are available for pumping without dangerously depleting groundwater reserves, but also to determine the groundwater vulnerability.

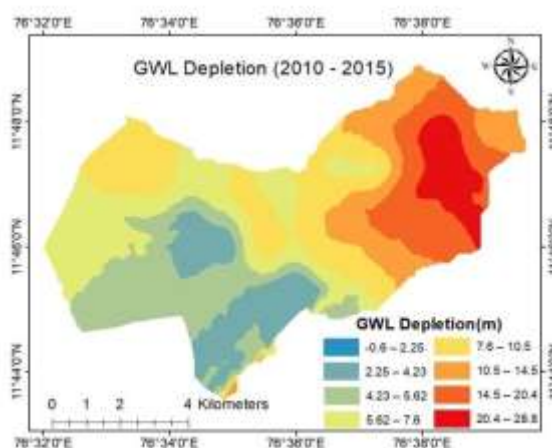


Fig.14 Groundwater Level Depletion Map (2010-2015)

5. CONCLUSIONS

This review study aimed to assess the impact of groundwater resources on farming practices and cropping patterns in the Berambadi watershed. The literature review revealed significant reliance on groundwater irrigation, leading to a unique groundwater gradient within the watershed. Farmers in the area prioritize irrigated crops over rainfed ones due to government incentives and affordable pumping options. To maximize profitability, farmers tend to cultivate high-water-demanding and cash crops on their small irrigated marketing farms. The shallow groundwater in the upstream region of the watershed has compelled farmers to extensively pump groundwater for meeting agricultural water requirements across multiple cropping seasons. Consequently, this extensive pumping has significantly impacted groundwater levels. In spite of the clear advantages of agricultural intensification, particularly in increasing overall food production, it is important to recognise that such intensification in water-scarce regions can have long-lasting social and ecological effects. According to our research, the region's current farming practises appear to be exceeding the natural rate of groundwater infiltration, which could result in groundwater depletion. This finding highlights the necessity of employing sustainable water management techniques to lessen the negative effects of intensive agriculture on the area's water resources and to promote long-term environmental and societal well-being. However, studies on the geographic distribution of groundwater and water irrigation management in the watershed are limited and inadequate. To gain a comprehensive understanding of the actual potential effects and the extent of the impact on groundwater resources, it is imperative to conduct thorough investigations. Such studies will contribute to improving the management of water irrigation and addressing the challenges associated with groundwater resources in the Berambadi watershed.

Author Contributions: The first draft of the manuscript was written by Madhushree C and all the authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding: Not applicable.

Data Availability Statement: The datasets generated during and/or analysed during the current study are available from Marion et al. 2016, Marion et al. 2017, Amit et al. 2018, Mangiarotti et al. 2018, Amit et al. 2019 and Amit et al. 2021. Groundwater Levels were collected from ATREE, Ben-galuru.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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