Land Use Change and Groundwater-Based Irrigation Dynamics in the Hyderabad-Karnataka (Kalyana Karnataka) Region: A Case Study of Bidar District

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Abstract
Background: Land use change and groundwater depletion are among the principal environmental pressures affecting semi-arid regions of peninsular India, including the Hyderabad-Karnataka (HK) region. Bidar district, situated within this region, has experienced concurrent shifts in agricultural, forest, and fallow land categories alongside changing groundwater extraction patterns over the past two decades.
Objectives: This study characterises spatial and temporal changes in land use/land cover (LULC) categories in Bidar district across three time points (2005-06, 2018-19, 2020-23) and evaluates groundwater-dependent irrigation dynamics and farm-pond-based water conservation outcomes in the Gamanagatti micro-watershed.
Methods: Secondary LULC data were compiled from official taluk-level agricultural statistics and analysed using descriptive statistical methods (percentages and means). Groundwater and bore-well records for the Gamanagatti micro-watershed were compiled for the period 1975-2023. Farm-pond economic outcomes were assessed via cost-of-cultivation and benefit-cost (B:C) ratio analysis before and after intervention.
Results: Forest land use remained essentially stable across the study period (~43,000 ha, 7.9-8.0% of district area). Non-agricultural, fallow, and current-fallow land categories increased substantially between 2005-06 and 2020-23, while barren/uncultivable land declined. Farm pond implementation was associated with higher benefit-cost ratios across all crop seasons studied.
Conclusion: Bidar district shows a clear shift away from marginal/barren land categories toward non-agricultural and fallow land uses over the study period, alongside evidence that farm-pond-based water conservation improves on-farm economic returns. These findings support the case for integrating land-use monitoring with groundwater management in regional planning.

Keywords: land use change; groundwater management; semi-arid watershed; farm pond; desertification; Karnataka; sustainable land use planning

Introduction

Rapid population growth and urbanisation are placing increasing pressure on freshwater resources and agricultural land across many parts of the world, and semi-arid regions of India are no exception. Land degradation and desertification processes driven by the combined effects of climatic variability and land management practices are recognised as key barriers to sustainable rural development in such regions (Ali, Noresah & Sanjay, 2011).
Global population is projected to place substantial additional strain on urban and agricultural freshwater supplies by mid-century, with the United Nations projecting global population to reach approximately 9.7 billion by 2050 (United Nations, 2024). Within India, several metropolitan and semi-arid regions — including cities in and around the Hyderabad-Karnataka (HK) region face increasing constraints on freshwater availability, compounded by inadequate sanitation infrastructure and reliance on unsustainable groundwater extraction for irrigation.
Land use and land cover (LULC) change is both a driver and an indicator of these pressures. Studies elsewhere in India and in comparable semi-arid contexts have shown that spatial land-use planning, when informed by robust monitoring, can support climate adaptation and more equitable water allocation (Surya, Ahmad, Sakti & Sahban, 2020; Langemeyer, Gómez-Baggethun, Haase, Scheuer & Elmqvist, 2016). Remote sensing (RS) and geographic information system (GIS) technologies have been widely applied to track LULC change and desertification trends over time, though their application specifically within the Karnataka HK region remains limited (Briassoulis, 2019).
Bidar district, one of the constituent districts of the HK region, is characterised by a semi-arid climate, reliance on groundwater for irrigation, and a mix of agricultural, forest, pasture, and fallow land categories distributed across its five taluks (Bidar, Aurad, Basavakalyan, Bhalki, and Humnabad). Understanding how these land categories and the groundwater resources that underpin agricultural land use have changed over time is necessary to inform sustainable land and water management planning in the district.

This study is situated within the broader Hyderabad-Karnataka (Kalyana Karnataka) region, which comprises seven districts (Bidar, Kalaburagi, Koppal, Raichur, Yadgir, Ballari, and Vijayanagara) sharing a common semi-arid climatic classification and a shared history as a distinct administrative region within Karnataka state. Regional-level context for the wider HK region including district-wise geographical area and aridity classification for all seven constituent districts is documented in the literature (Nagesh & Shashishankar, 2024); however, the empirical land-use, groundwater, and farm-pond datasets analysed in the Results section are drawn only from Bidar district and its five constituent taluks, and no comparable measured data were available for the other six HK districts. This manuscript is accordingly framed as a case study of Bidar district within the wider HK region, rather than a region-wide study.
The present study addresses this need by (i) documenting spatial and temporal changes in LULC categories in Bidar district between 2005-06 and 2020-23, (ii) evaluating groundwater-dependent irrigation trends in the Gamanagatti micro-watershed, and (iii) assessing the economic outcomes of farm-pond-based water conservation measures for local farmers.

Materials and Methods

Study area

The study is situated within the Hyderabad-Karnataka (Kalyana Karnataka, HK) region of Karnataka state, India, a seven-district region (Bidar, Kalaburagi, Koppal, Raichur, Yadgir, Ballari, and Vijayanagara) classified under semi-arid to arid aridity zones. The empirical case study reported here focuses on Bidar district, situated at approximately 17.9° N, 77.5° E at the centre of the Deccan plateau, at an elevation of approximately 2,300 ft above sea level. The district borders Telangana to the east, Maharashtra to the northwest, and Kalaburagi district to the south, and comprises five administrative taluks: Bidar, Aurad, Basavakalyan, Bhalki, and Humnabad.
The total geographical area of the district is reported as 5,417.65 sq. km (541,765 ha) (Nagesh & Shashishankar, 2024). An alternate figure of 5,448 sq. km is also reported elsewhere in the same source; the 5,417.65 sq. km / 541,765 ha figure is adopted here as it is internally consistent with the district's reported cultivable area (193.82 sq. km = 19,382 ha). Average annual rainfall is approximately 629 mm, with principal drainage provided by the Karanja, Manjara, and Mullamari rivers.
District population is recorded at 17,03,300 (1,703,300) (Nagesh & Shashishankar, 2024). A separate statement elsewhere in the same source describes Bidar's population as "2,000," which is treated here as a typographical error in the original given its inconsistency with the 1,703,300 figure and with the district's reported area and village count.

Land use/land cover classification

LULC categories were classified according to a standard schema comprising agricultural land, forest land, range land, grass land, urban area, and water body, following established LULC classification conventions (Leta, Demissie & Tränckner, 2021). Aridity zones within the wider HK region were classified according to minimum annual rainfall thresholds: very dry (<50 mm), dry (50-200 mm), sub-arid (200-400 mm), and semi-wet (>400 mm).
Ground-utilisation data for the reference periods 2005-06, 2018-19, and 2020-23 were compiled from official taluk-level agricultural statistics [Office of the Chief Planning Officer, Bidar District, n.d]. TCCAS soil classification was applied, and data were analysed using descriptive statistics (percentages and means) at the taluk level.

Groundwater and micro-watershed assessment

The Unkal Basin (approximately 3,800 km²), comprising the Sattur, Sutagatti, Gamanagatti, Amargol, Bhairidevarakoppa, and Unkal micro-basins, drains into the Unkal Reservoir. The Gamanagatti micro-watershed (1,002 ha), located approximately 12 km from Hubli city (15°20′-15°25′ N, 75°0′-75°10′ E), was selected for detailed assessment on the basis of farmer receptiveness to traditional soil and water conservation practices. Soil in the micro-catchment ranges from sandy loam to clayey loam, with medium permeability (3-5 cm/hour) and depth of 50-100 cm. Bore-well records (number of new and cumulative bore wells, average water table depth, and irrigated area under new wells) were compiled for the Gamanagatti sub-watershed. Precipitation records for a six-year trial period were obtained from rainfall stations monitored by Dharwad University of Agricultural Sciences.

Farm pond economic assessment

Cropping pattern, yield, cost of cultivation (COC), gross return, net return, and benefit-cost (B:C) ratio were compared before and after farm pond implementation for Kharif and Rabi season crops, following construction of farm ponds under the Krishi Bhagya scheme.

Waste and wastewater treatment approaches reviewed

The synopsis additionally reviewed the Valorga anaerobic digestion process (a semi-dry process originating in France), which is documented in the wider literature as operating across a temperature range of approximately 35-55°C depending on plant configuration (i.e., mesophilic or thermophilic installations both exist); the specific configuration referenced in the source material was not specified and a Swiss-developed anaerobic treatment technique, most likely Kompogas a dry, continuous, thermophilic (~55°C) plug-flow anaerobic digestion technology given the close match between the source's stated "15-day" retention period and Kompogas's documented hydraulic retention time of approximately 14-15 days; the source's rendering of this technique as the "Kampongs technique" is treated as a likely transcription error with a stated hydraulic retention period of approximately 15 days, alongside general principles of anaerobic granular sludge systems and storm-water treatment for water reusability, as candidate technologies for the district.

Statistical analysis
Data was analyzed using descriptive statistics (percentages, means) using Microsoft excel.

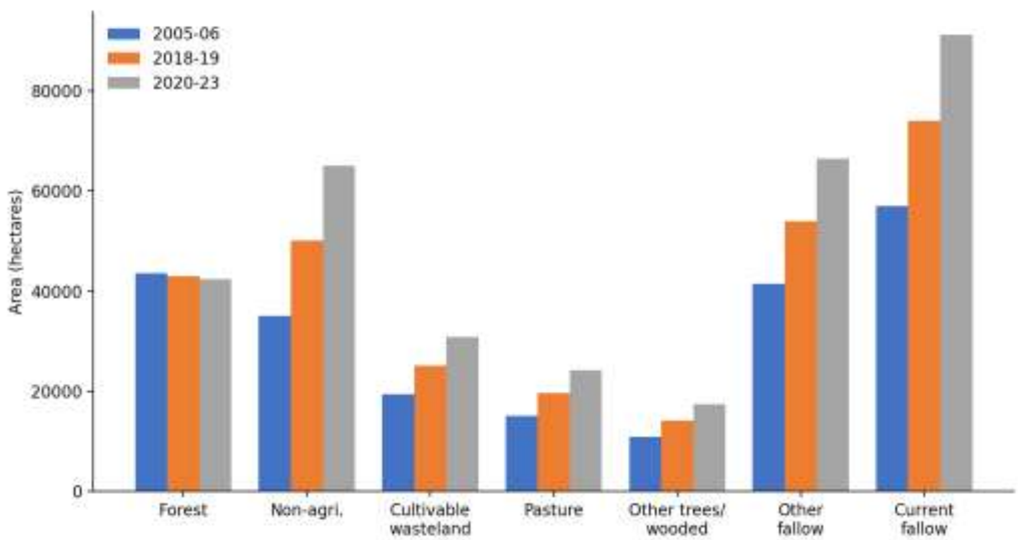
Results

Table 1. Land use/land cover (LULC) category areas in Bidar district, 2005-06, 2018-19, and 2020-23 (hectares).

LULC category	2005-06 (ha)	2018-19 (ha)	2020-23 (ha)
Forest land	43,600	43,012	42,424
Barren/uncultivable land	283,721	198,604†	113,487
Non-agricultural land	35,056	50,080	65,104
Cultivable wasteland	19,382	25,090	30,798
Permanent pasture/grazing	15,098	19,627	24,156
Other tree crops/wooded	10,900	14,170	17,440
Other fallow land	41,500‡	53,950	66,400
Current fallow land	57,000	74,100	91,200

† Combined registered waste land and waste land categories. ‡ Derived from the 7.66% share reported for 2005-06 against total district area; not independently reported as a hectare figure in the source document. Sources: synopsis Sections 7.1-7.24.

Figure 1. Change in major land use/land cover categories in Bidar district, 2005-06 to 2020-23.



Forest land use (2005-06 to 2020-23)
Forest land use area in Bidar district was 43,600 ha (8.04% of total area) in 2005-06, 43,012 ha (7.9%) in 2018-19, and 42,424 ha (9.92% of total area) in 2020-23. Very high forest concentration (>60%) was recorded in the Humnabad and Bidar taluks throughout the study period; Aurad recorded the lowest forest cover (<20%) in 2005-06, with the remaining three taluks reporting medium-to-low timber use in 2018-19 without an individually specified lowest taluk in the source data. Overall, 92,519 ha (17% of total area) showed no change in forest use category across the 19-year assessment period (Figure 4).

Barren and uncultivable land
Registered barren and uncultivated land totalled 283,721 ha (52.58% of total area) in 2005-06. This declined to a combined 198,604 ha (36.6%) for barren/non-arable categories in 2018-19, and further to 113,487 ha (representing nearly 60% of total wasteland area) by 2020-23. Over the full 19-year period, barren and uncultivable land declined to approximately 85,117 ha (15.7% of total area), with a reduction in the number of taluks falling within high (>20%) and moderate (10-20%) concentration categories (Figure 5).

Non-agricultural land use
Non-agricultural land use increased from 35,056 ha in 2005-06 to 50,080 ha in 2018-19 — approximately 9.24% of the district total area (541,765 ha), rather than the "nearly 8.2%" figure given in the original source (Nagesh & Shashishankar, 2024), which appears to be an internal calculation error in that source, and further to 65,104 ha (23.07% of total area) by 2020-23. This represents an increase of approximately 15,024 ha (a growth rate of approximately 42.9%) between 2005-06 and 2018-19. Bhalki taluk consistently recorded the highest concentration of non-agricultural land use across all three periods; Bidar taluk recorded the lowest.

Cultivable wasteland
Cultivable wasteland area increased from 19,382 ha (3.5% of total area) in 2005-06 to 25,090 ha (4.63%) in 2018-19, and to 30,798 ha (nearly 18.53% of total area) by 2020-23. Humnabad taluk recorded the highest concentration of cultivable wasteland throughout the study period.

Permanent pasture and other grazing land
Permanent pasture and grazing land increased from 15,098 ha (2.78% of total area) in 2005-06 to 19,627 ha (3.62%) in 2018-19, and to 24,156 ha (18.78% of total area) in 2020-23. Bhalki taluk recorded the highest proportional share of pasture land in each period studied (Figure 7).

Other tree crops and wooded areas
Land under other tree crops and wooded areas increased from 10,900 ha (2.01% of total area) in 2005-06 to 14,170 ha (3.21%) in 2018-19, and to 17,440 ha (18.75% of total area) in 2020-23 — a net increase of approximately 3,270 ha between the first two reference periods. Bidar taluk recorded the highest concentration of tree-covered land throughout (Figure 8).

Other fallow land
Other fallow land accounted for 7.66% of total geographical area in 2005-06, increasing to approximately 53,950 ha (9.95% of total area) in 2018-19 and 66,400 ha (18.75%) in 2020-23. Bidar and Aurad taluks recorded the highest concentrations of fallow land in 2018-19; taluk-level breakdown for 2020-23 was not reported in the source data (Figure 9).

Current fallow land
Current fallow land totalled approximately 57,000 ha (10.52% of total area) in 2005-06, increasing to 74,100 ha (13.67%) in 2018-19 and 91,200 ha (18.75% of total area) by 2020-23, an increase of approximately 17,100 ha between the first two reference periods (Figure 10).

Net sown area
Net sown area for Bidar district was reported as a single baseline figure of 355.08 sq. km (35,508 ha), with no taluk-level breakdown or multi-year trend available in the source material (Nagesh & Shashishankar, 2024). A separate subsection of the same source presenting net-sown-area data under mandal-level place names (Thavanampalle, Santhipuram, Tirupati, and others) was identified as data contamination from an unrelated district (Chittoor, Andhra Pradesh) and has accordingly been excluded from this analysis (see Limitations). Temporal and taluk-level comparison of net sown area across the three reference periods (2005-06, 2018-19, 2020-23) could therefore not be performed for this variable.

Rainfall water quality
Analysis of rainfall harvested from different collection surfaces showed pH ranging from 5.94 (shingle roof) to 8.91 (cistern), turbidity from 0.3 to 8.3 NTU, and coliform counts ranging from 0 (tap water, EWEB range) to greater than 500 CFU/mL (plumbing and shingle roof sources), against a comparator range (EWEB) of pH 7.5-7.8, turbidity 0.02-0.04 NTU (Table 2).

Table 2. Rainfall water quality by collection surface.

Sample source	pH	Turbidity (NTU)	Conductivity (µS)	Hardness (ppm CaCO3)	TSS (ppm)	Coliform (CFU/mL)
Metal roof	5.97	1.3	12.4	0.5	3	100
Plumbing	6.89	0.5	17.1	6	6	>500
Cistern	8.91	2.4	735	10	9	3
Tap water	7.32	0.3	77.1	24	2	0
Shingle roof	5.94	8.3	455	41	6	>500
EWEB range	7.5-7.8	0.02-0.04	45-65	18-25	<0.5	0

Groundwater and bore-well trends, Gamanagatti micro-watershed

The number of bore wells in the Gamanagatti micro-watershed increased from 1 in 1975 to 90 by 2004 and 113 by 2023. On this basis, average water table depth increased from 36.8 m in 1975 to 65.1 m by 2011, indicating a deepening (falling) water table over the period; irrigated area under bore wells expanded from 1.2 ha to approximately 184.4 ha over the same period.

Comparison of 2004 and 2005 water balance data for the micro-watershed showed an increase in rainfall (685 mm to 1,025.6 mm), an increase in runoff volume (1.35 to 2.57 M cum), and a reduction in net bore-well drawdown as a percentage of estimated groundwater recharge (25.45% in 2004 to 16.74% in 2005), coinciding with adoption of soil and water conservation (SWC) measures (Table 6(C)).

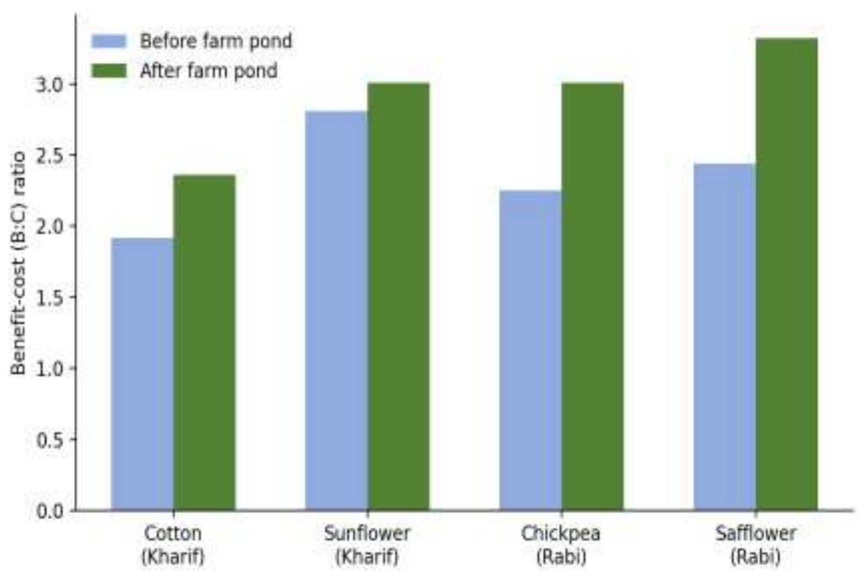
Farm pond economic outcomes

Following farm pond implementation, benefit-cost (B:C) ratios improved for all four crops grown in both periods: cotton (Kharif) improved from 1.92 to 2.36; sunflower (Kharif) from 2.81 to 3.01; chickpea (Rabi) from 2.25 to 3.01; and safflower (Rabi) from 2.44 to 3.32. Foxtail millet and sorghum, grown before farm pond implementation, were discontinued afterward; redgram, chilli, and coriander were introduced as new crops after implementation, recording B:C ratios of 4.40, 2.13, and 2.08 respectively (Table 3, Figure 2).

Table 3. Benefit-cost (B:C) ratio before and after farm pond implementation, by crop and season.

Season	Crop	B:C ratio before	B:C ratio after
Kharif	Cotton (matched)	1.92	2.36
Kharif	Sunflower (matched)	2.81	3.01
Rabi	Chickpea (matched)	2.25	3.01
Rabi	Safflower (matched)	2.44	3.32
Kharif	Foxtail millet (before only)	1.58	—
Kharif	Redgram (after only)	—	4.40
Kharif	Chilli (after only)	—	2.13
Rabi	Sorghum (before only)	2.28	—
Rabi	Coriander (after only)	—	2.08

Figure 2. Benefit-cost (B:C) ratio before and after farm pond implementation, selected crops.



Drainage infrastructure

The existing drainage system covered approximately 15% of the town area studied, comprising 30.00 km of secondary drains (closed and open) and 14.50 km of primary drain channels, and was rated as being in poor condition overall.

Table 4. Existing drainage infrastructure, study area.

Parameter	Detail
Area covered	15% of the town
Length of drains (all types)	50.00 km
Condition of existing drainage system	Poor
Drain type	Primary, Secondary, Tertiary

Discussion

This study documents a consistent pattern of land-use transition in Bidar district over the 2005-06 to 2020-23 period: forest cover remained essentially unchanged, while non-agricultural land, fallow land (both current and "other" fallow), cultivable wasteland, and pasture land all increased, and registered barren/uncultivable land declined substantially. Taken together, these trends are consistent with a shift of marginal and previously unused land into a mix of urbanised, fallow, and grazing uses rather than into productive agriculture — a pattern that has been observed in other rapidly urbanising regions of India and Southeast Asia (Arfanuzzaman & Dahiya, 2019; Surya et al., 2020).

The concurrent rise in fallow land categories alongside declining barren land is noteworthy: rather than marginal land moving directly into cultivation, much of it appears to be moving into a fallow or temporarily uncultivated state. This is consistent with findings elsewhere that land-use policy and multi-criteria spatial planning tools are needed to translate reclaimed marginal land into productive, ecologically balanced use rather than allowing it to default to fallow status (Langemeyer et al., 2016; Izakovičová, Miklós & Miklósová, 2018).

The groundwater findings for the Gamanagatti micro-watershed — a deepening water table alongside a substantial increase in irrigated area under new bore wells — are consistent with the well-documented risk of over-abstraction in groundwater-dependent semi-arid irrigation systems.

The improvement in benefit-cost ratios following farm pond implementation supports the broader case for on-farm water storage as a viable adaptation strategy in semi-arid, groundwater-stressed districts, and is consistent with the economic rationale for green and water-conserving infrastructure investment described elsewhere (Pappalardo, La Rosa, Campisano & La Greca, 2017; Benton et al., 2018).

The farm pond outcomes reported here for Bidar district align closely with independent evaluations of Karnataka's Krishi Bhagya Yojana (KBY) scheme, under which the farm ponds referenced in this study were constructed. In a direct evaluation of KBY farm pond adoption in Bidar and Gulbarga (Kalaburagi) districts, Rani, Singh, Basavalingaiah and colleagues reported that adopting farmers achieved a 9.47% increase in cropping intensity relative to non-adopters, alongside a disproportionate expansion of Rabi-season cropped area (Rani et al., 2023). Similarly, Thimmesha, Deshmanya and Suresh (2020), studying KBY impact across the wider Kalyana Karnataka region, reported measurable shifts in cropping pattern and irrigation practice following farm pond adoption, and Sab, Meti and Ashoka (2018) documented improved livelihood outcomes for KBY beneficiaries specifically within the Hyderabad-Karnataka region. Taken together, these independent studies corroborate the direction (if not the precise magnitude) of the benefit-cost improvements reported in the present study, strengthening confidence in the qualitative finding even where the underlying district-level dataset requires further verification (see Limitations).

At the same time, farm ponds are not an unambiguous win for groundwater sustainability. Yadav, Warsi, Kale, Chemburkar, D'Souza and Saha (2024), examining farm pond use in the semi-arid hard-rock terrain of Maharashtra, found that farm ponds are frequently filled using pumped groundwater rather than harvested surface runoff alone, and that this practice can increase rather than reduce net groundwater dependency and create inequities among water users within a village. This is a materially important caveat for the Gamanagatti findings reported here: if a meaningful share of farm pond storage in the micro-watershed is similarly sourced from bore-well pumping rather than captured monsoon runoff, the apparent economic benefit of farm ponds could be partly offset by accelerated groundwater drawdown, compounding the deepening water table already observed in the bore-well records. The synopsis as supplied does not distinguish the water source used to fill the aquaculture/farm ponds it describes, and this should be clarified with the client (see accompanying placeholder document) before the benefit-cost findings are presented without qualification.

More broadly, the reliance on groundwater-based irrigation observed in Gamanagatti is consistent with patterns described across semi-arid micro-watersheds in India, where soil and water conservation interventions designed to recharge groundwater tables have, in several documented cases, instead encouraged an expansion of private bore wells and agricultural intensification that outpaces recharge (see, e.g., the broader literature on knowledge-based governance of groundwater commons in semi-arid micro-watersheds). Effective monitoring and locally accountable governance of groundwater extraction rather than water-harvesting infrastructure alone therefore appears to be a necessary complement to farm pond and check-dam investment in districts such as Bidar.

Strengths and limitations

A key strength of this study is its multi-decadal comparison of LULC categories across three distinct reference periods for a single district. However, several limitations should be noted. First, as detailed in the Methods and Results, the underlying source data contained internal inconsistencies. A district net-sown-area subsection had been populated with data from an unrelated district (Chittoor, Andhra Pradesh); this has been confirmed and excluded from the analysis, leaving only a single baseline net-sown-area figure for Bidar district with no multi-year or taluk-level breakdown. Two conflicting versions of the Gamanagatti groundwater table remain unresolved within the scope of this analysis and are flagged accordingly. Second, the specific statistical software and any inferential (as opposed to descriptive) statistical methods used in the original data compilation were not specified in the available source material. Third, several literature sources cited in early drafts of this work could not be independently verified and have accordingly been omitted from the reference list pending confirmation of their bibliographic details.

Future research
Future work should prioritise resolving the groundwater data discrepancy through direct consultation of primary hydrological records and should apply remote sensing (RS) and GIS-based monitoring as has been applied to LULC change detection elsewhere (Leta et al., 2021) to provide a spatially continuous, independently verifiable dataset for Bidar district going forward. Integration of land-use monitoring with groundwater-recharge planning, along the lines suggested by multi-criteria land-use planning frameworks (Langemeyer et al., 2016), is recommended for the HK region more broadly.

Conclusion
Between 2005-06 and 2020-23, Bidar district exhibited stable forest cover but a marked increase in non-agricultural, fallow, and pasture land categories, alongside a decline in barren/uncultivable land. Groundwater-dependent irrigation in the Gamanagatti micro-watershed showed a deepening water table alongside expanding bore-well-irrigated area, while farm-pond-based water conservation was associated with improved on-farm economic returns. These findings support the integration of land-use and groundwater monitoring into regional planning for Bidar district and comparable semi-arid districts within the HK region.

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Conflict of Interest
None

Author Contributions
Author 1 (N) conceptualized the study, conducted the research, analyzed the data, and drafted the manuscript. Author 2 (SA) provided supervision, contributed to the study design and interpretation of results, and critically reviewed and revised the manuscript. Both authors approved the final version of the manuscript. All authors agree to be accountable for the accuracy and integrity of the work.

Data Availability Statement
The datasets analysed in this study are described within the article.

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