



# Plant Archives

Journal homepage: <http://www.plantarchives.org>

DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-1.418>

## DEVELOPMENT AND RECLASSIFICATION OF WATER ACCOUNTING LAND USE (WALU) MAPS FOR BHIMA LOWER SUBBASIN, KARNATAKA INDIA

Shwetha G.<sup>1\*</sup>, Srinivasa Reddy<sup>2</sup>, Shirahatti M. S.<sup>1</sup>, Maheshwara Babu<sup>2</sup>, Mallikarjuna M. D.<sup>2</sup>,  
Ajayakumar M. Y.<sup>2</sup> and Santhosh C. P.<sup>2</sup>

<sup>1</sup>Department of Agricultural Engineering, UAS Dharwad, Karnataka, India

<sup>2</sup>University of Agricultural Sciences, Raichur, Karnataka, India

\*Corresponding author e-mail id: [shwethag13512@uasd.in](mailto:shwethag13512@uasd.in)

(Date of Receiving : 29-11-2025; Date of Acceptance : 30-01-2026)

### ABSTRACT

Land use and land cover (LULC) affect the water balance as well as the benefits and services for society and for the environment. Spatially distributed LULC information is a key to Water Accounting Plus (WA+). WA+ is a water accounting framework that provides explicit spatial information on water depletion and net withdrawal processes in complex river basins. A key differentiating factor in this framework is that it explicitly describes the influence of land use and landscape evapotranspiration on the water cycle by defining land use groups with common characteristics. An existing LULC map of the Bhima lower sub basin (K6) developed by NRSC was used for this study as a reference map, to develop WALU. A total of 18 LULC types were incorporated in the WALU map from 12 types in NRSC. These LULC classes are further arranged into four major water management categories (WMC), namely "Protected Land Use" (PLU), "Utilized Land Use" (ULU), "Modified Land Use" (MLU), and "Managed Water Use" (MWU). PLU shares 1 WMC-based LULC types- protected forest out of the total 18 LULC types, covering 0.94% of the total basin area. The ULU, MLU and MWU accounts for 4, 5 and 8 WMC-based LULC types occupying 4.5% , 53.66% and 40.90% of the total area respectively. Among all the WMC-based LULC types, MLU (Rainfed Crops - Kharif) is dominant LULC class of the K6 basin with an average area of 6215.11 square kilometer.

**Keywords:** Water Accounting Land Use, Water accounting plus, Satellite data, GIS, River basin

### Introduction

Land use and land cover (LULC) play a critical role in regulating basin-scale hydrological processes, environmental quality, regional climate dynamics, and the provision of ecosystem services. Land cover refers to the biophysical attributes of the Earth's surface, while land use characterizes anthropogenic activities and management practices imposed on the land (Lambin *et al.*, 2001). Therefore, precise and temporally updated land use datasets are indispensable for the robust execution of WA+ water accounting analyses.

Water Accounting Plus (WA+), is a water accounting framework that provides explicit spatial information on water depletion and net withdrawal processes in complex river basins (Karimi *et al.*, 2013).

A key differentiating factor in this framework is that it explicitly describes the influence of land use and landscape evapotranspiration on the water cycle by defining land use groups with common characteristics. It is a multi-institutional effort from international institutions. The International Water Management Institute (IWMI) (Molden and Sakthivadivel, 1999), the UNESCO-IHE Institute for Water Education (now IHE Delft), the Food and Agriculture Organization of the United Nations (FAO) and the World Water Assessment Programme (WWAP) work together on global water-related research and policy initiatives.

The WA+ method provides a means to determine the output per unit of water effectively depleted without a need to account for all the flows related to this processes. This is done by explicitly providing

information on water depletion processes for every land use class.

The WA+ framework classifies LULC into broad groups of 80 possible classes. These LULC classes are further arranged into four major water management categories (WMC), namely “Protected/Conserved Land Use” (PLU), “Utilized Land Use” (ULU), “Modified Land Use” (MLU), and “Managed Water Use” (MWU) (Karimi *et al.*, 2013 and Bastiaanssen *et al.*, 2015). These four Water Management Classes (WMC) classes were developed based on common management characteristics of LULC classes and their degree of influence on natural ‘hydrologic cycle’, WMC as defined below:

**Protected Land Use (PLU)** refers to areas designated for conservation because of their ecological, cultural, or hydrological significance. These zones often include national parks, nature reserves and wetlands of international importance, biodiversity hotspots and other legally protected landscapes. Human activities are either strictly limited or completely restricted. Water systems within PLU areas are expected to remain in a near-pristine state, with minimal disturbance to natural hydrological processes such as runoff generation, groundwater recharge and habitat-supporting flows.

**Utilized Land Use (ULU)** covers areas where land is used lightly and human influence on the landscape is minimal. Examples include extensive rangelands, low-intensity forestry and traditionally managed agricultural lands without significant water infrastructure. The hydrological cycle in ULU zones remains predominantly natural: water is neither diverted nor heavily regulated and river flows, soil moisture patterns and groundwater recharge occur with little anthropogenic alteration.

**Modified Land Use (MLU)** describes landscapes where land cover or soil properties have been deliberately altered through activities such as intensive

agriculture, mechanized farming, forestry operations, or urban expansion without direct manipulation of surface water flows. Although water is not diverted or stored through major structures, human activities modify the unsaturated zone. These modifications influence core physical processes including infiltration rates, soil storage capacity, evapotranspiration patterns, root-zone water uptake and percolation, which collectively impact the vertical soil-water balance and often lead to measurable hydrological shifts.

**Managed Water Use (MWU)** refers to areas where water flow is actively controlled, distributed, or manipulated by human systems. These include irrigated agricultural zones, urban water supply networks, drainage and sewer systems, hydropower channels, managed wetlands, reservoirs, ponds and other hydraulic infrastructure. In MWU areas, human intervention directly alters timing, quantity and spatial distribution of water, often transforming natural hydrological regimes to meet agricultural, industrial, domestic, or environmental objectives.

By structuring land use into these four clusters, WA+ shifts the perspective from conventional land-cover classification to a hydrologically relevant framework that links land, water management practices and consumptive use, thereby offering deeper insights into the trade-offs between natural ecosystems, agriculture and human-modified landscapes, an especially useful approach in basins, where rainfed farming, large-scale irrigation and urban expansion coexist and compete for limited water resources.

## Materials and Methods

### Datasets collections

The dataset consists of RS imageries of Bhima lower sub basin maps from 2017-18 to 2023-24, obtained from NRSC. These images were clear of cloud cover. Table 1. Shows the Sensor and Date/time of the scene acquisition from IRS.

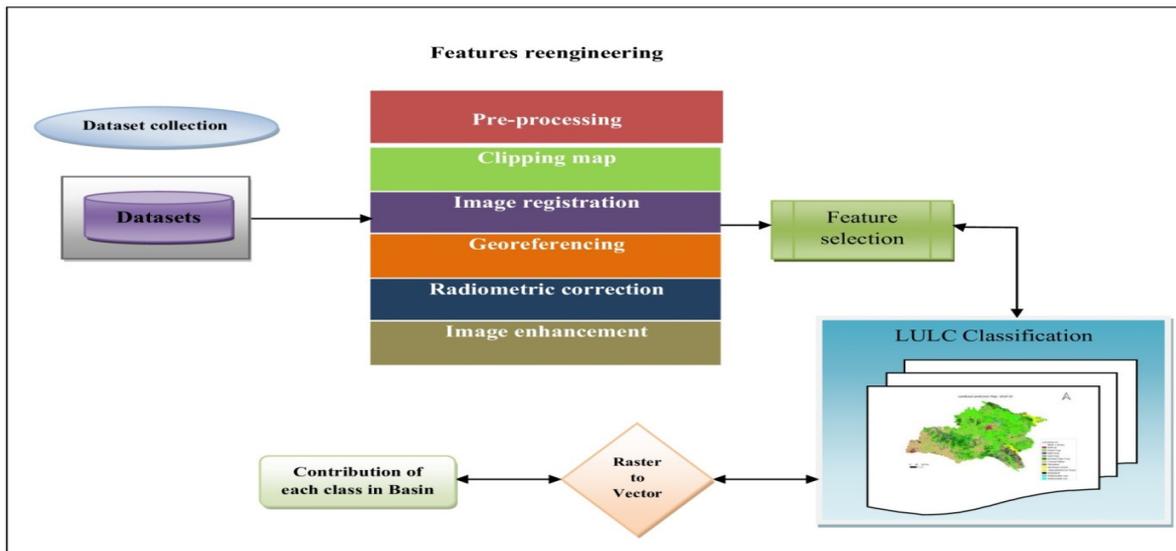
**Table 1:** Detail of data sources used for analysis of LULC in the study.

Satellite	Sensor	Resolution (m)	Path/row	Acquisition date	Season
Resourcesat-2 / IRS	LISS-IIIIRS AWiFS	~23.5	~95/59+96 /59 region	Cycle 2017–18 To 2023-24	Annual

### Reclassifying NRSC LULC maps into water accounting land use maps

Reclassification of the NRSC maps was done using the scheme given by Karimi *et al.*, 2013a. The workflow diagram of this study is illustrated in Figure. 1. The diagram illustrates the steps followed to compile

process and categorize spatial LULC data into the four water-use categories (PLU, ULU, MLU and MWU). It provides a clear overview of how raw land-cover information is interpreted, refined and organized to create a consistent LULC dataset that supports subsequent water-accounting analyses.



**Fig. 1:** Flow diagram for LULC maps development

Data pre-processing is an essential part of LULC classification, as it affects the accuracy of the resulting classification outputs. The standard pre-processing was done including clipping maps, image registration, georeferencing, radiometric correction, image enhancement, band composition, and layout preparation. These steps collectively improved image clarity, reduce noise, and prepare the dataset for accurate analysis (Abdulbasit *et al.*, 2023). Reclassification of the NRSC maps was done using the scheme given by Karimi *et al.*, 2013.

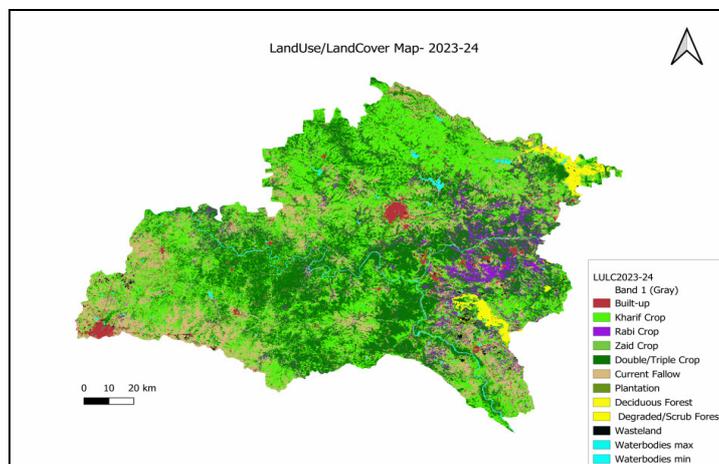
Three existing sources of data to create a time series of seven land use maps for the analyzed sub-basin used are:

- 1) NRSC time series maps (2017-2018 to 2023-2024), 0.0005 degrees obtained from NRSC.

- 2) Shape file of command areas obtained from ACIWRM
- 3) Shape file of protected areas developed by WDPA ((UNEP-WCMC & IUCN, 2019)) and downloaded from Protected Planet (<https://www.protectedplanet.net/>)

The following assumptions were made for creating the land use maps for K6: (a) all pixels within the command areas are irrigated, (b) all pixels classified as double/triple crops are irrigated. As a result, irrigated areas outside the command areas might not all be identified. All input maps are resampled at 0.0025 degrees before aggregation.

The NRSC Land Use Land Cover (LULC) raster dataset, which classifies land based on thematic land cover classes using integer codes, was used as the base data for reclassification (Figure 2).



**Fig. 2:** LULC map generated for K6 using NRSC satellite image for the year 2023-24

To extract meaningful subsets of this dataset relevant to the study's objectives, a reclassification process was carried out to separate the raster into two distinct thematic layers: one representing irrigated regions and the other representing protected areas. Each land cover type, such as irrigated agricultural land, barren land, forest, built-up area, or water body was assigned a unique class code in the raster attribute table. Based on this classification legend, the specific class codes corresponding to irrigated agricultural areas (e.g., "irrigated cropland" or "double/triple crop areas") were identified for the irrigated region raster. Similarly, class codes associated with protected regions, such as reserved forests, national parks, sanctuaries, or conservation zones, were identified for the protected region raster.

During the reclassification and raster analysis stages of the study, several important considerations were addressed to ensure the accuracy and consistency of results, especially when working with multiple raster layers in QGIS. These considerations include the handling of NoData values, aligning raster extents, and standardizing pixel sizes all of which are critical for avoiding unexpected errors or inconsistencies in raster-based outputs. To overcome this, NoData pixels in all input rasters were replaced with meaningful background values using QGIS's raster processing tools, ensuring consistent pixel participation in calculations (Olaya, 2004; QGIS Documentation, 2023).

Secondly, raster extent alignment was carefully managed. When performing calculations involving multiple rasters, QGIS computes the output raster extent based on the minimum overlapping area among input layers. While this avoids extrapolation, it can unintentionally exclude valid data located outside the overlap. To mitigate this, all rasters were resampled or clipped to a common extent, typically defined by the full study area boundary, ensuring full spatial coverage in analysis (Jenson & Domingue, 1988; QGIS Documentation, 2023).

Thirdly, the pixel size or resolution of input rasters was standardized before analysis. Input data from different sources often have varying resolutions. QGIS automatically resamples these to a common resolution using the nearest neighbor method a technique suitable for categorical data like LULC. However, mismatches in resolution can introduce edge distortions or classification artifacts. Therefore, all rasters were preprocessed to match a uniform pixel size—typically the coarsest resolution dataset using resampling tools available in QGIS or GDAL (Congalton & Green, 2019; QGIS, 2023).

The separation process was performed using the Raster Calculator tool in QGIS, which allows for pixel-wise logical operations across raster layers (QGIS Documentation, 2023). The reclassification and merging approach follows best practices in spatial data standardization, as recommended in land accounting literature (FAO & IHE Delft, 2018; Bastiaanssen *et al.*, 2014). It ensures consistency in land use categorization and supports comparative analysis across temporal and spatial scales.

After obtaining WALU map for seven year period from 2017-18 to 2023-24, all the seven maps were further analysed for grouping classes in each map into four categories of water accounting as PLU, ULU, MLU and MWU. The workflow encompasses the processing of seven annual WALU maps 2017-18 to 2023-24, each reclassified into the four Water Accounting Plus (WA+) categories, Protected Land Use (PLU), Utilized Land Use (ULU), Modified Land Use (MLU) and Managed Water Use (MWU), to produce both spatial and statistical outputs. First, data compilation involves collecting WALU maps for each year and harmonizing them in terms of projection, resolution and classification scheme auxiliary datasets (Singh *et al.*, 2022). Next, in the preprocessing phase, all WALU layers are standardized to a common coordinate system and pixel resolution and class codes across all years were consolidated using a unified lookup table. For mapping to WA+ categories, a consistent lookup table was developed to align WALU class codes to PLU, ULU, MLU, or MWU, guided by WA+ definitions, PLU includes protected forests and conservation zones; ULU encompasses savannahs, natural grasslands and wetlands; MLU covers rainfed cropland and urbanized areas; and MWU refers to irrigated agriculture, reservoirs and canal systems (Bastiaanssen *et al.*, 2015). During annual reclassification and analysis, each pixel in the WALU map for each year (2017-18 to 2023-24) is reclassified into one of the four WA+ categories as per the lookup table; these yields yearly classified maps and allow computation of area statistics measured in square kilometers or as percentages for each category. Finally, temporal aggregation and dynamics involves compiling a time-series table that tracks area changes across WA+ categories over the seven-year period, visualizing trends through line or bar charts to reveal land-use management shifts and optionally conducting change-detection mapping (e.g., transitions like ULU → MLU) to identify spatial hotspots of land-use conversion. This structured and repeatable methodology aligns seamlessly with the WA+ framework's emphasis on spatially explicit, transparent water accounting using remote sensing and open-access datasets.

## Results and Discussion

### Analysis of NRSC Land Use Land Cover (LULC) maps

Time-series LULC maps were generated for the study region from 2017-18 to 2023-24 using NRSC LULC datasets. The classified maps revealed clear temporal variations across agricultural, built-up and fallow categories. The LULC classes considered included: *kharif* crop, *rabi* crop, double/triple crop, fallow, built-up, forest, water bodies and others. The area of each LULC class was extracted and quantified annually.

The analysis showed that *kharif* crop consistently dominated the agricultural landscape, occupying the largest share of land use throughout the study period (Table 17). This reflects the monsoon-dependent farming system in semi-arid India, where rainfall availability drives crop choice and sowing intensity. Similar findings were reported by Singh *et al.* (2022) in the Betwa basin, where *kharif* agriculture contributed over 60% of total cultivated area.

The proportion of land under double and triple cropping systems increased gradually between 2017-18 and 2023-24. This intensification is attributed to the expansion of irrigation infrastructure and adoption of high-yielding varieties. A comparable trend was observed by Ray *et al.* (2020), who highlighted that cropping intensity in India has been steadily rising due to groundwater extraction and canal irrigation support.

A notable change was the continuous increase in built-up areas, particularly around peri-urban and semi-rural settlements. Between 2017-18 and 2023-24, built-up land expanded at the cost of agricultural and fallow land. This observation aligns with the findings of Jat *et al.* (2017), who reported that urbanization is one of the major drivers of land conversion in semi-arid watersheds of India. Such transitions have long-term implications for water accounting, as urbanization generally reduces infiltration and increases surface runoff.

Fallow land peaked in 2018–19, indicating reduced agricultural activity during that year. This anomaly may be linked to rainfall variability, delayed monsoon onset, or socio-economic constraints. Pathak *et al.* (2021) similarly documented high inter-annual fluctuations in fallow land in central India, associating them with climate variability and farm-level risk management practices.

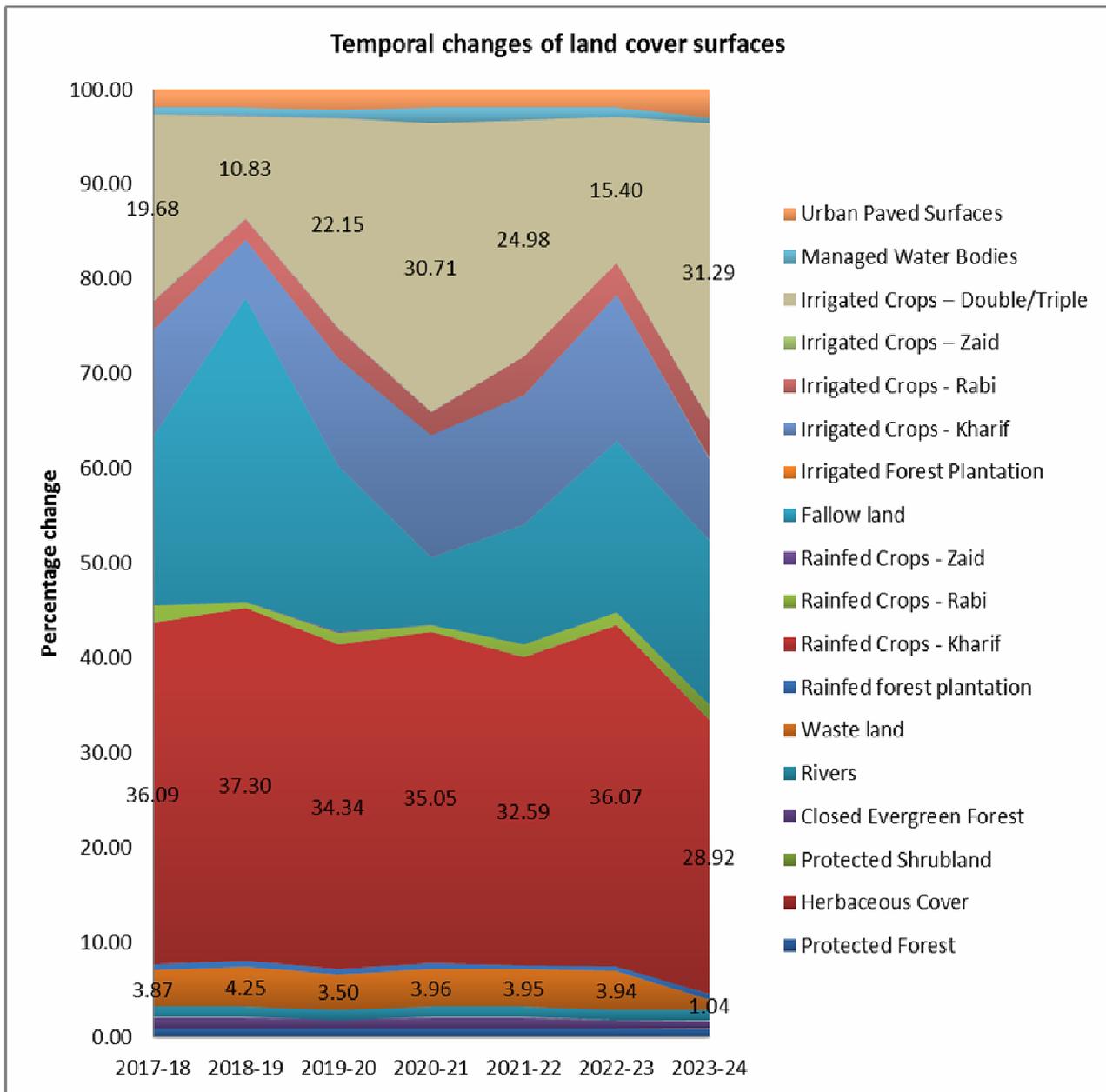
### Reclassifying NRSC LULC maps into WA+ LULC maps

The results shows the temporal changes from the year 2017-18 to 2023-24, the average area under rainfed crop-*kharif* (34.34%) is more compared to irrigated crop-*kharif* (11.35%) by 60%. A sharp decline in wasteland (-70%) was observed over the study period, which suggests that previously uncultivated or degraded areas have been progressively converted into cropland or built-up. Such reclamation of wastelands has also been reported in other parts of India, often driven by agricultural expansion and rural development programs (Pathak *et al.*, 2021). Conversely, irrigated double and triple crops increased by 15%, reflecting intensification of agriculture facilitated by irrigation (Figure 3). Similar increases in cropping intensity due to canal irrigation and groundwater exploitation were highlighted by Ray *et al.* (2020), who linked such trends with rising water stress in semi-arid regions. The shift in cropping patterns is analyzed in terms of water availability fluctuations in drought years in this water accounting study.

The WALU map revealed that Protected Land Use (PLU) included only one WMC class (protected forest), occupying just 0.94% of the total basin area (Table 2). This reflects the limited ecological conservation zones in the basin. Similar low PLU shares were reported by Gao *et al.* (2020) in the Yellow river basin, where anthropogenic land uses dominate the landscape. Utilized Land Use (ULU) accounted for four WMC types (4.5% of the basin), mainly representing natural lands such as grassland and grazing areas.

Modified Land Use (MLU) comprised five WMC types, covering 53.66% of the area, dominated by Rainfed *kharif* crops with an average extent of 6,215.11 km<sup>2</sup>. The dominance of MLU underscores the intensive utilization of land for agriculture, consistent with observations by Bastiaanssen *et al.* (2014), who emphasized that cropland-dominated basins exhibit high consumptive water use and limited ecological buffers.

Managed Water Use (MWU) represented eight WMC classes, occupying 40.90% of the basin. This category primarily includes irrigated crops and water-dependent land uses, showing the strong influence of irrigation infrastructure on land-water interactions.



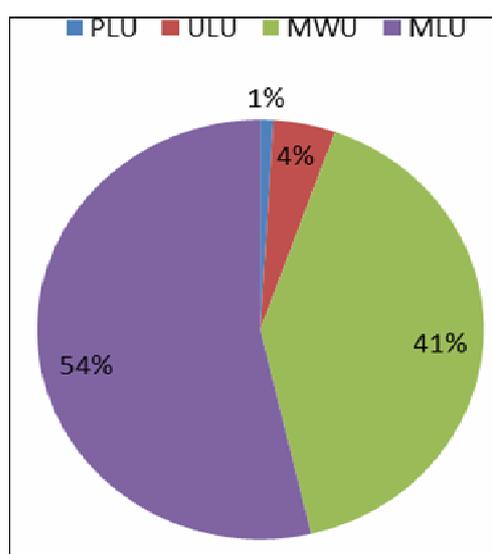
**Fig. 3:** Temporal changes of land cover surfaces in the analyzed sub-basin.

Spatially, the WALU distribution map (Figure 4) highlights that PLU contributes only ~1%, natural lands (ULU) about 4%, while MLU and MWU together cover ~95% of the basin. This heavy skew towards agriculture and water-managed land uses mirrors the findings of Singh *et al.* (2022), where MLU and MWU were the dominant land uses in a semi-arid river basin, significantly influencing basin water balances.

The temporal and WALU-based LULC analysis suggests that the basin is highly dependent on rainfed agriculture while showing signs of increasing cropping intensity in irrigated areas. This dynamic interplay reflects the influence of water availability fluctuations during drought years, which shifts in cropping patterns and land use transitions. As noted by Veldkamp *et al.* (2017), such fluctuations exacerbate water scarcity risks and necessitate integrated land-water accounting to support decision-making.

**Table 2:** The seven years average area wise distribution of WALU-based land use classes in K6.

Water Management Category (WMC)	LULC WA+	WALU code	Area in km <sup>2</sup>
Protected Land Use (PLU) (0.94%)	Protected Forest	PLU1	169.58
Utilized Land Use (ULU) (4.5%)	Herbaceous Cover	ULU7	1.23
	Protected Shrubland	ULU7	0.34
	Closed Evergreen Forest	ULU3	178.77
	Waste land	ULU21	633.76
Managed Water Use (MWU) (40.90%)	Rivers	MWU12	202.21
	Irrigated Forest Plantation	MWU1	1.34
	Irrigated Crops - Kharif	MWU3	2055.32
	Irrigated Crops - Rabi	MWU3	581.88
	Irrigated Crops – Zaid	MWU3	0.43
	Irrigated Crops – Double/Triple	MWU3	4008.86
	Managed Water Bodies	MWU12	170.48
Modified Land Use (MLU) (53.66%)	Urban Paved Surfaces	MWU21	383.35
	Rainfed forest plantation	MLU1	103.90
	Rainfed Crops - Kharif	MLU3	6215.11
	Rainfed Crops - Rabi	MLU3	222.54
	Rainfed Crops - Zaid	MLU3	1.95
	Fallow land	MLU13	3169.83
<b>Total Area</b>			<b>18100.88</b>

**Fig. 4:** LULC categories distribution in K6 (average of 2017-18 to 2023-24).

The underlying reason for framing these four land use categories is that their management options widely differ from keeping them pristine to planning hourly water flows. Information on water supply, water depletion process, beneficial and non beneficial depletion, biomass production, data on water and land productivity, along with water withdrawals and reuse, provides a comprehensive understanding of water resource management within river basins, in turn provides better water management strategies from the previous year's assessments.

## Conclusion

The present study adopted an integrated framework combining remote sensing, GIS, hydrological modelling and water accounting to assess the spatial and temporal dynamics of water resources in the Bhima lower sub-basin (K6). NRSC LULC maps were downloaded, processed and customized for the K6 sub-basin to develop land use specific water consumption maps and water accounting land use classes. A seven-year time-series analysis was conducted to assess changes in land use and associated water use patterns within the sub-basin.

The reclassified WALU maps revealed that the proportion of land under double and triple cropping systems increased gradually between 2017-18 and 2023-24. This intensification is attributed to the expansion of irrigation infrastructure and adoption of high-yielding varieties. A notable change was the continuous increase in built-up areas, particularly around peri-urban and semi-rural settlements.

Rainfed *rabi* crops showed no significant change across the study period and it was consistent with their dependence on residual soil moisture and supplemental irrigation availability. This pattern suggests that while *kharif* agriculture is highly dynamic and rainfall-driven, *rabi* cultivation in the basin is relatively stable. The dominance of MLU (rainfed *kharif* crops) indicates that water consumption in the basin is primarily rainfall-driven ( $ET_{green}$ ), while the steady rise in MWU points to increasing  $ET_{blue}$  demands. The decline in wasteland suggests positive utilization of resources but also raises concerns over ecological

sustainability, given the minimal share of protected land.

### References

- Abdulbasit, A. D., Alhashmi, A. A., Almadani, A. M., Alanazi, A. K., & Sutantra, G. A. (2023). Development of a map for land use and land cover classification of the Northern Border Region using remote sensing and GIS. *Egyptian Journal of Remote Sensing and Space Science*, **26**, 341–350.
- Bastiaanssen, W. G. M., Karimi, P., Rebelo, L. M., Duan, Z., Senay, G., Muthuwatte, L., & Smakhtin, V. (2015). Earth observation-based assessment of the water production and water consumption of Nile Basin agro-ecosystems. *Remote Sensing*, **6**, 10306–10334.
- Bastiaanssen, W. G. M., Coerver, H. M., & Karimi, P. (2014). *WA+ for monitoring water productivity and water consumption at basin scale*. UNESCO-IHE Institute for Water Education.
- Congalton, R. G., & Green, K. (2019). *Assessing the accuracy of remotely sensed data: Principles and practices* (3rd ed.). CRC Press.
- FAO & IHE Delft. (2018). *Water accounting in practice: Fundamentals and lessons from case studies* (FAO Water Reports No. 43). Food and Agriculture Organization of the United Nations.
- Gao, H., Hu, H., Zhao, X., & Li, H. (2020). Integration of WA+ framework and remote sensing for land and water accounting in the Yellow River Basin. *Journal of Hydrology*, **585**(1), 124–137.
- Jat, M. K., Garg, P. K., & Khare, D. (2017). Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. *Environmental Monitoring and Assessment*, **189**(1), 1–15.
- Jenson, S. K., & Domingue, J. O. (1988). Extracting topographic structure from digital elevation data for geographic information system analysis. *Photogrammetric Engineering and Remote Sensing*, **54**(11), 1593–1600.
- Karimi, P., Bastiaanssen, W. G. M., & Molden, D. (2013). Water Accounting Plus (WA+): A water accounting procedure for complex river basins based on satellite measurements. *Hydrology and Earth System Sciences*, **17**(7), 2459–2472.
- Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., & Folke, C. (2001). The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change*, **11**, 261–269.
- Molden, D., & Sakthivadivel, R. (1999). Water accounting to assess use and productivity of water. *International Journal of Water Resources Development*, **15**(2), 55–71.
- Olaya, V. (2004). *A gentle introduction to GIS*. Open Source GIS: A GRASS GIS Approach.
- Pathak, P., Wani, S. P., & Sudi, R. (2021). Land degradation dynamics in semi-arid watersheds of India. *Land Degradation & Development*, **32**(4), 1522–1536.
- QGIS Development Team. (2023). *QGIS user guide and training manual*. <https://docs.qgis.org>
- Ray, D. K., Gerber, J. S., MacDonald, G. K., & West, P. C. (2020). Climate variability and intensification of cropping systems in India. *Nature Communications*, **11**(1), 123–134.
- Singh, S. K., Kumar, S., Singh, P. K., Gautam, D. K., Patle, P., & Pandey, H. K. (2022). Water accounting using satellite products and WA+ framework in a semi-arid Betwa River Basin, India. *Remote Sensing Applications: Society and Environment*, **26**(1), 100–117.
- Veldkamp, T. I. E., Wada, Y., Aerts, J. C. J. H., & Ward, P. J. (2017). Towards a global water scarcity risk assessment framework: Incorporation of probability distributions and hydro-climatic variability. *Environmental Research Letters*, **12**(4), 44–53.