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ORIGINAL PAPER

Implications of Watershed Management Programs for Sustainable Development in Rural Scenario—A Case Study from Foothills of Punjab State, India

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Abstract
Watershed management programs (WMP) are widely adopted across the globe for judicious use of natural resources. It can help us to achieve UN sustainable goals by 2030 also in a sytematic way. These programs help in preserving environmental and ecological balance by maintaining the natural and anthropogenic pressures in the watershed. WMPs have enabled sustainable management in typical rural scenarios where land degradation is predominant at an alarming rate due to intensive agricultural cum anthropogenic activities. A huge amount of central and state government funds have been utilized for construction of check dams, silt detention structures, gabion structures, afforestation schemes, capacity building programs for rural lively hoods, etc. to elevate the region from the poverty line. This necessitates for monitoring of these activities; and the present study demonstrates use of geospatial technology in monitoring effects of WMPs in the rural landscape of Punjab, India. High-resolution satellite images were used for monitoring the conservation measures at grass root level and analyzing the implications in the region. Field investigation and growth in net productivity of the region also clearly indicated that there is significant improvement in the selected watershed due to augmentation of the conservation measures, infrastructure facilities, and socio-economic conditions.

Keywords Rural livelihood · Land use/land cover change · Rural · Watershed management

Introduction

Climate change is constantly posing a number of challenges across the world such as water scarcity, land degradation, poor agriculture, and livestock productivity [1]. Developing nations around the globe are more prone to the above challenges because of increasing population pressure, poverty, malnutrition, fragmented land holdings, poor administrative policies, and frequent crop failure [2, 3]. Realizing these challenges, watershed development programs have been introduced in several countries focused on landscape-based interventions to holistically address land–water-crop-tree-livestock components [4] because watershed management programs help to directly restore ecological balance [5]. Several nations have demonstrated the positive impact of watershed-based natural resource management interventions on improving livelihood and environmental security carried by the Food and Agriculture Organization (FAO) of the United Nations and World Bank [6, 7]. In India, the watershed management program has evolved over the years,initially, it focused on landscape protection and erosion control through field bunding as an *in situ* soil conservation measure [8] but since these efforts also require community participation, therefore, its full potential was unrealized. With time and change in population magnitude, socio-economic conditions and geopolitical scenario sustainable management practice of natural resources are one of the most prime mandates in the upcoming years especially for developing nations like India where land degradation is prevalent due to intensive use of land.

Land use/land cover is a crucial component in the assessment of biodiversity and ecosystem services [9]. Therefore, watersheds can be used as management units which can integrate ecological, geographical, geological, and cultural aspects of the land use/land cover (Omernik et al. 32, [10]. This approach has been often used for the holistic management of arid, semi-arid, and rain-fed regions in the country [11, 12]. Several government policies have been introduced

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in India during the last few decades for the efficient management of land resources using watershed management programs [13, 14]. The Famine Commission of 1880 was one of the first government-based initiatives in India during the pre-independence era (Gray et al. 29, [15]. This program was focused on the soil conservation approach only, but later it was felt that focus needed to be shifted to soil and water conservation simultaneously,therefore, an integrated approach of all factors was required to plan sustainable management of the resources (Joshi et al. 31, [16]. Post-Independence, Drought-Prone Area Programme (DPAP) was introduced by the central government in 1972, which came up with several conservation technologies that were beneficial for several farmers in the country [17]. The Ministry of Agriculture and Ministry of Rural Development, Government of India, introduced several such programs with the aim of sustainable watershed management namely the Desert Development Programme, Watershed Management Programme, Integrated Wasteland Development Programme, Integrated Watershed Management Programme, National Watershed Development Project for Rain-fed Areas, Watershed Development Project in Shifting Cultivation Areas, Watershed Development Fund, Soil Conservation in the Catchments of River Valley Projects, Flood-Prone Rivers, Western Ghats Development Programme, Hill Area Development Programme, Hill Area Land and Water Development Project, Hariyali Project, and National Bank for Agriculture and Rural Development Watershed Programmes [18–20]. Several conservation strategies included under this program were the construction of contour bunds, graded bunds, field bunds, check dams, farm ponds, gully control structures, pit excavation terrace building, deep plowing, minimum tillage, zero tillage, composting, mulching, broad bed and furrow practice, leveling and smoothening, and several other soil moisture conservation practices [21]. Although several programs were operational, the need of the time was to assess whether these programs were ultimately benefiting sustainable development in the region or not at the micro-level.

Geospatial technology can help to strengthen the watershed management programs outcome because it can continuously capture thematic information which critically can bring out positive or negative impacts in any area in a single synoptic view, enabling judicious critical support for management and planners [22]. It was observed during earlier phases that with the exhaustion or end of funds from the government or international schemes conservation structures disappeared and marginal improvements in livelihood also gradually vanished. Therefore, monitoring the existence of these structures was a prerequisite [23, 24]. Thus, the second phase of the Integrated Watershed Management Program (IWMP) initiated monitoring and geotagging of each asset built during the project initiation to retain the facilities for rural sustainability. This study focuses on one subwatershed from Shahid Bhagat Singh (SBS) Nagar District of Punjab located in North Western part of India to evaluate the effects of the watershed management program using satellite-based images. This area lies in the extreme eastern boundary of the district; emphasis is given to this region because it lies in the rural–urban continuum belt along river Satluj [25],therefore, it is affected by high anthropogenic pressures. Apart from this, the region is also physically challenged because it is prone to heavy rainfall culminating in flash floods which carry heavy sedimentation and make the soil fragile. The selected region is part of the Kandi tract which in the local language means an island of poverty [26, 27]. The basic objective of the study involves (a) the use of high-resolution time series satellite images from Indian Remote Sensing (IRS sensors LISS-IV and Cartosat-1 for effectively monitoring the region,(b) geotagging of assets being built to support rural livelihood. (c) to understand the growth in the sustainability of the region, Net Primary Productivity (NPP) from MODIS is compared across the chosen timeline to validate the impacts in the region due to the increase in IWMP project propositions.

Study Area

The selected micro-watershed lies in the SBS Nagar District of Punjab; it is part of the Satluj Basin which is located in the foothills of Shiwalik (lower Himalaya) popularly known as *Kandi* region (Fig. 1). The central latitude and longitude of the study area are 76° 20' East and 31° 5' North; it is covered with denuded forest in the northeastern part and has a vast expansion of piedmont plain in the south. The forested region is highly dissected by numerous small streams locally known as *Choes*. The *Choes* emerge from the hills and flow westwards through the piedmont plain. The unconsolidated sediments comprise coarse to fine sand, silt and clay representing a sandy loam to silty loam clay soil texture which covers the entire area. The summer season starts in April and lasts up to the end of June, followed by the rainy season when it becomes too hot and sultry. The rainy season sets with the onset of monsoon in the beginning of July and lasts up to the end of September. The winter season starts after the rains are over from October and lasts up to March. May and June are the hottest months when mercury may cross even 45 °C on some days. During the period from December to February, the winter is quite severe and mercury may hover around 5 °C, and on some days, it may even touch 0 °C. The average rainfall in this region is around 507.4 mm annually. The total area covered by this micro-watershed is 8850 ha.

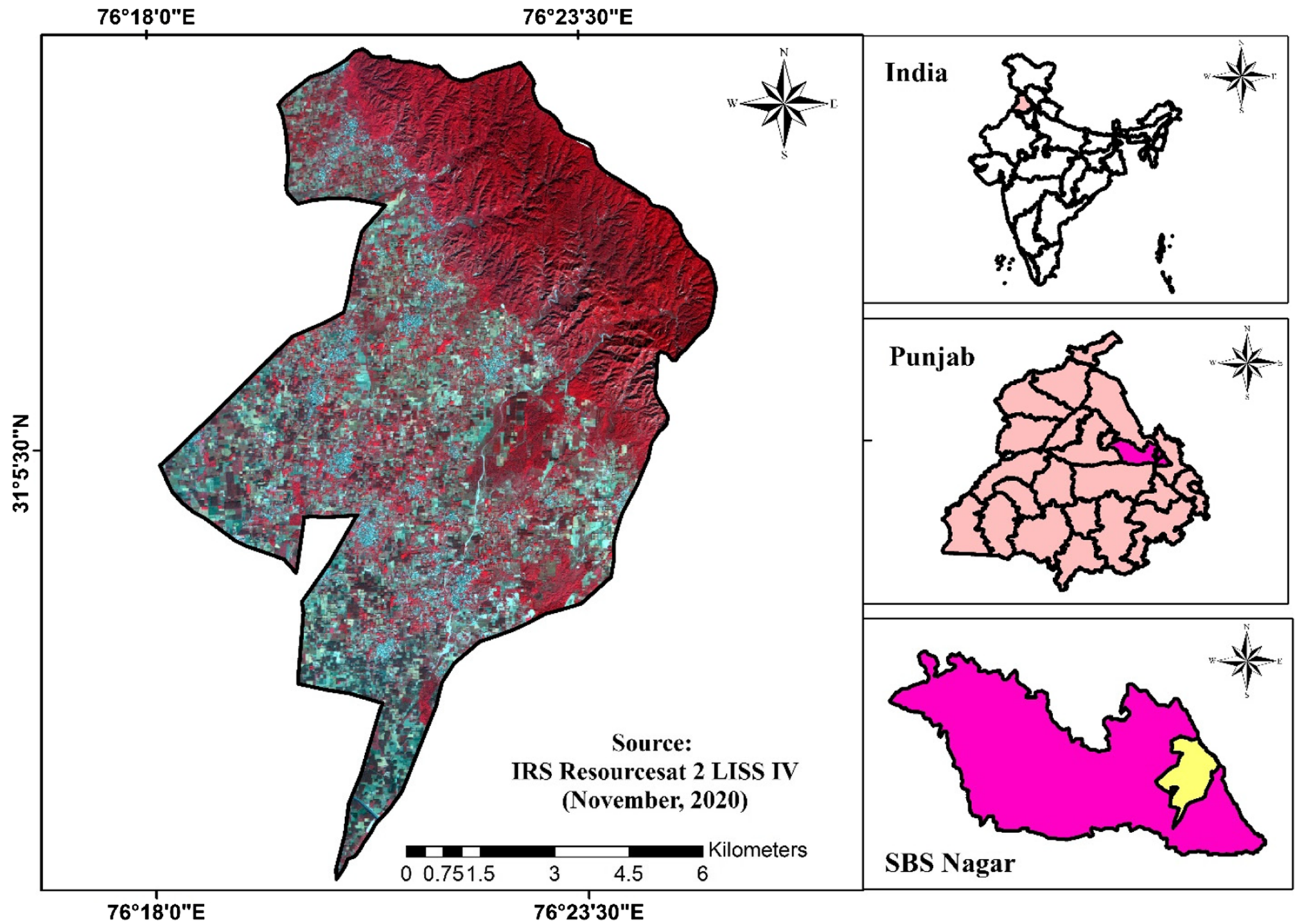

Fig. 1 Subwatershed in SBS Nagar District Punjab

Data Used

Three major types of satellite datasets were used in the study, i.e., IRS LISS-IV, Cartosat-1, and MODIS. Four time frames were chosen for monitoring: T1-2009–2010, T2-2013–2014, T3-2017–2018, T4-2019–2020. LISS-IV is a high-resolution multispectral satellite dataset from Resourcesat-2; it has a push broom sensor with a high spatial resolution of 5.8 m having three spectral bands green (0.52–0.59), red (0.62–0.68), and near infrared (0.77–0.86) and a swath of 70 km (Gupta et al. [28]). CARTOSAT-1 is a single panchromatic band of high spatial resolution of 2.5 m covering a swath of 30 km [19, 20]. Both the satellite data products were retrieved by National Remote Sensing Center (ISRO) and then merged together to bring about better interpretation results for digital mapping of land use/land cover (LU/LC) of the region. Cartosat-1 helps to magnify the native LISS-IV resolution to 2.5 m so that each feature is well identified. Further to understand the sustainability in the region, Net Primary Productivity (NPP) from MODIS datasets MOD17A3 was analyzed for the above time frame.

Methodology

The flow chart in Fig. 2 depicts the methodology that was followed during the study. Two kinds of software were mainly used for the analysis and management of the datasets: (a) ARC GIS 10.6 and (b) ERDAS 2014. Firstly, satellite datasets were acquired for four time frames T1 to T4 (including a time period from 2009 to 2020; then, each image was georeferenced). After georeferencing, each image was registered with respect to T1 year, i.e., 2009–2010 image as the base layer. Further time series LISS-IV datasets were fused in ERDAS 2014 with the time series CARTOSAT-1 datasets using the Ehlers fusion technique. This technique is based on Intensity Hue Saturation (IHS) transformation coupled with Fourier transformation (Jalan and Sokhi. 30). Later, onscreen digitization was carried out to outline the major LU/LC features in the region at a scale of 1:10,000 using the level one classification system of LU/LC (Table 1). After extraction of LU/LC for four time frames, change detection was carried out to estimate positive or negative effects in the region. In conjunction with this, each man-made structure

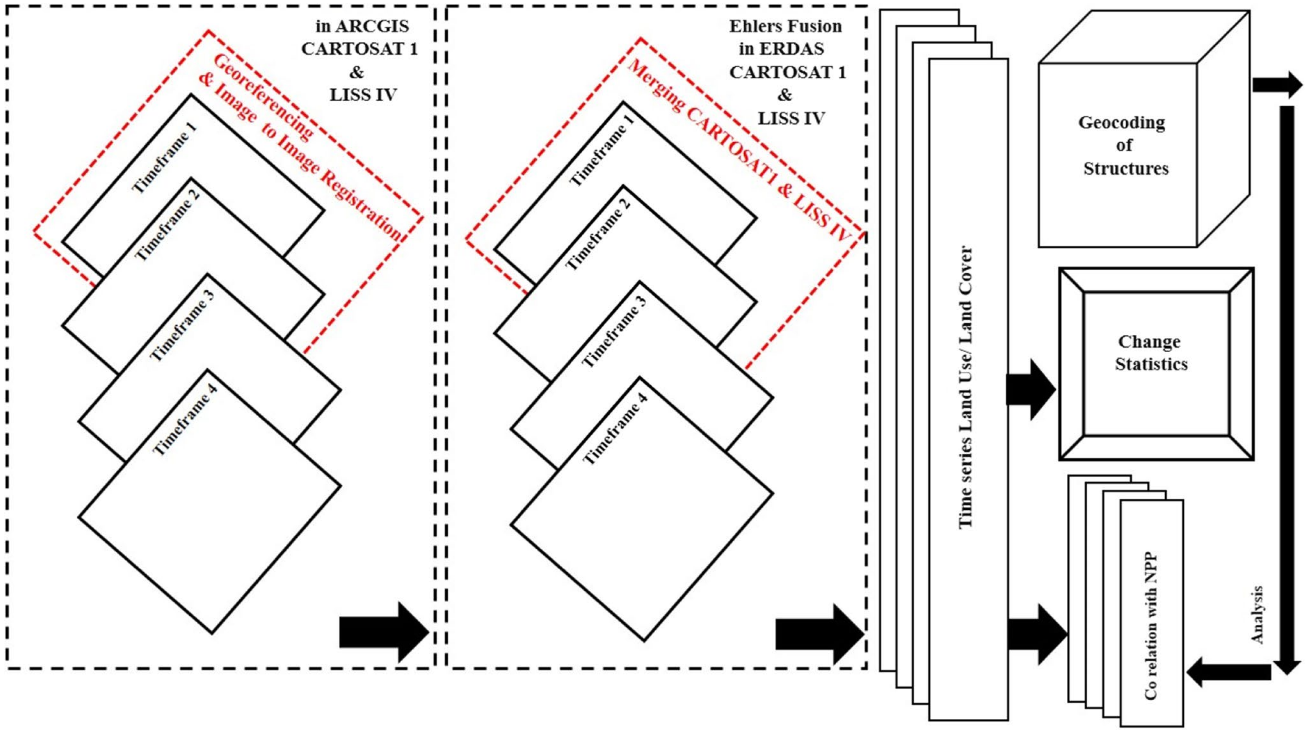

Fig. 2 Workflow of the study

Table 1 The land use/land cover classification of the region

LULC classes	Description
Agriculture	Cropland (irrigated and unirrigated), fallow land
Forest	Mixed deciduous forest, forest plantation
Scrubland	Mixed thorny scrubland, barren land
Built-up	All infrastructure including residential, commercial, village, settlements, and man-made structures for livelihood
Mining/dump	Soil extraction area or dumping
Plantation/horticulture	High-value commercial crops
Reservoir tank	Man-made water bodies
Canal	Man-made linear structures for water transmission
River/stream/drain	Natural water bodies

that was built during the selected time frame was geotagged. This geotagging of structures also helped to understand the impact of sustainable development brought about in the study area. Furthermore, we have analyzed the trend of NPP from (2009 to 2020) in the region to understand that these facilities have helped in the growth of the region by increasing the main livelihood economy that is agriculture in the region.

Results and Discussion

Mapping of Land Use and Land Cover for Four Time Frames

Land use/land cover mapping was carried out over selected micro watershed in the SBS Nagar District of Punjab at a scale of 1:10,000 for four time frames 2009–2010,

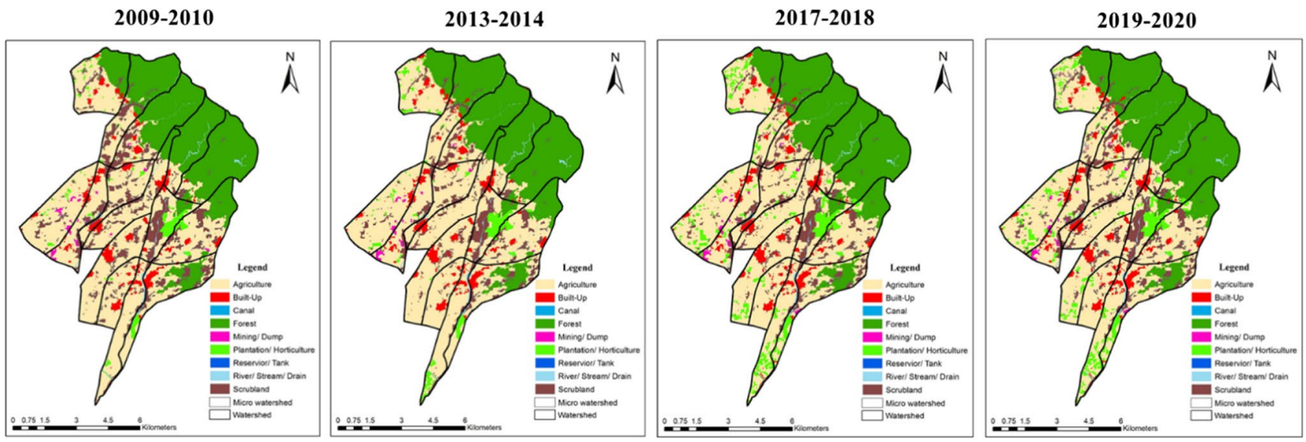

Fig. 3 Change in land use/land cover

2013–2014, 2017–2018, and 2019–2020 (Fig. 3). Nine major classes were identified in this watershed: (a) agriculture, (b) forest, (c) plantation/horticulture, (d) mining/dump, (e) scrubland, (g) built-up, (h) canal, (i) reservoir/tank, and (j) river/steam/drain. Almost three-fourth of the area is covered under agriculture. In three seasons agricultural crops are cultivated over this region because there are irrigation facilities from tributory and distributory canals. A mixed forest of deciduous nature is observed in the northeastern part of the study area. Apart from this, hamlets are well observed in the region; even agglomerated villages are seen. Plantation and horticulture have been promoted, and soil conservation strategy adopted; therefore, the growth of this is well seen in the LULC maps. Mining and dumping is a very common dynamic activity in this region because the soil is often used in the brick kilns, as one of the main raw materials for infrastructure construction. Scrublands are unproductive land in the area with no economic value. Rivers, streams, and drains are visible in the region coming down from the eastern upland to the lower piedmont plain. Canals and reservoirs are well distributed in the region for use for irrigational purposes.

Change Detection

Change detection is very important to understand the present condition of any location and to evaluate whether the implementation of any watershed management program has brought about changes in the region. Keeping in view this objective, land use and land cover maps were subjected to a change detection process. It is quite noticeable that due to the expansion of population and rural-to-urban transition, the built-up area has expanded over time from 399 to 452 ha in the region. Mining/dumping is a local activity in this region and dynamic in nature, and therefore slight changes have been observed. Plantation and horticulture have evolved in this region as an alternative source of economic development because the risk of crop failure significantly reduces in this case. Plantation and horticulture are promoted as one of the main conservation strategies in rural areas to raise sustainability standards. Scrublands are also seen to be decreased from 879 to 689 ha because most scrublands are lands which are either utilized for infrastructure construction or reclaimed. Due to expansion in built-up, agricultural land over time seems to have decreased from 4369 to 4205 ha. Figure 4 clearly shows that the forest cover area of 2900.42 ha remains unchanged at this scale of study for the four selected years. Permanent waterbodies like canals, reservoirs, and tanks show negligible changes because this region has well developed irrigation networks since long.

From Fig. 5, it is clear that plantation and horticulture show a positive trend in the region supporting the fact that conservation strategies are well implemented in this region. Built-up land also shows a positive trend because this region lies in the rural–urban continuum. Scrubland shows a negative trend which is good from the economic perspective of the region but the agricultural area is comparatively decreasing over the years with conversion to agriculture plantation. But if agriculture and plantation both are monitored then it can be concluded that livelihood opportunity in this region has increased over time.

Sustainable Development

Sustainable development is one of the major goals of the United Nations till 2030. Ruling out poverty in each place is one of the main drives. The Indian Government along with the State government, World Bank, and Non-Governmental Organizations (NGOs) is constantly working at the grass root level to build up policies and facilities to strengthen the economic ability of the country to address the above aims along with several other aims like zero

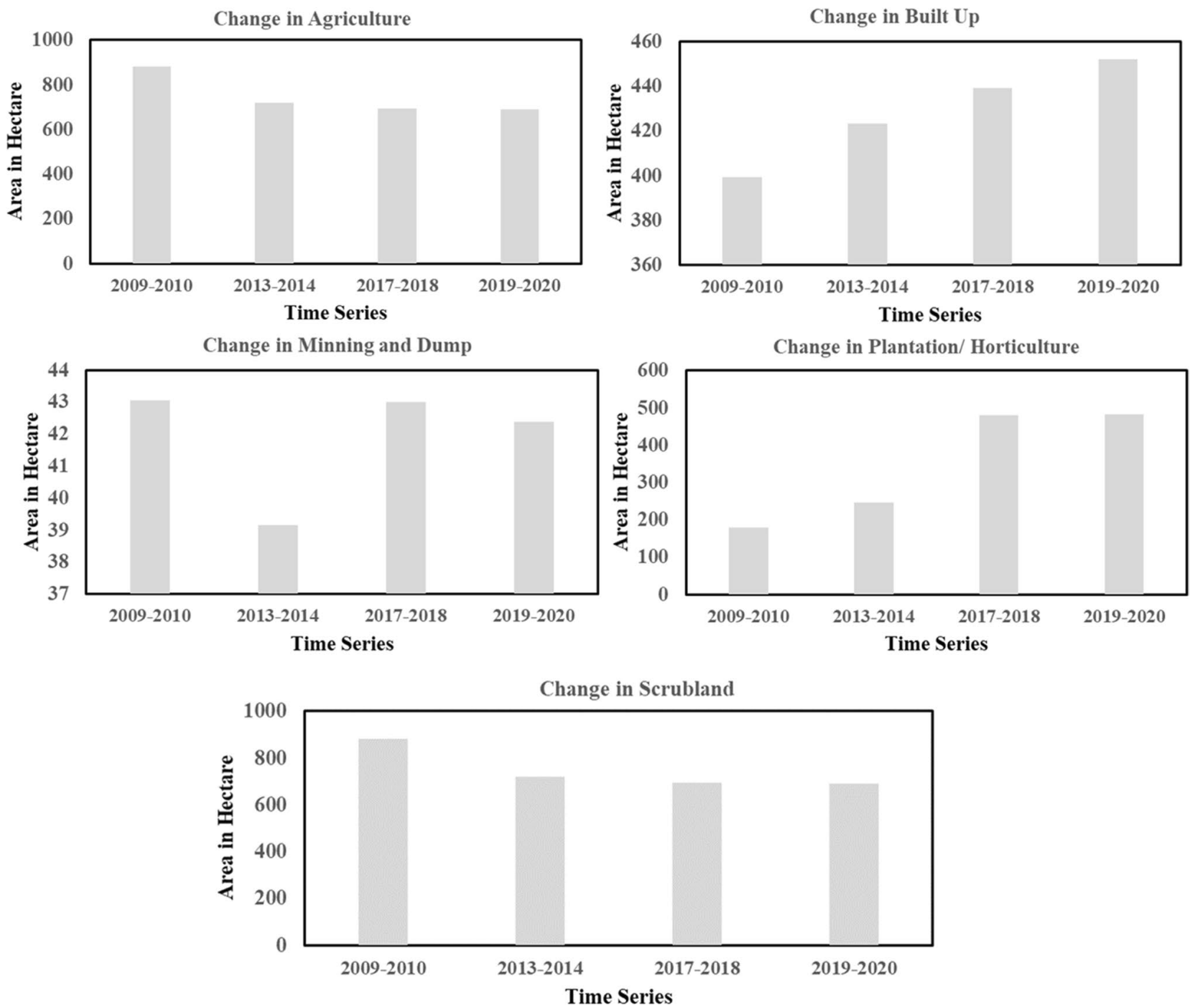

Fig. 4 Changes in land use/land cover classes over 2009 to 2020

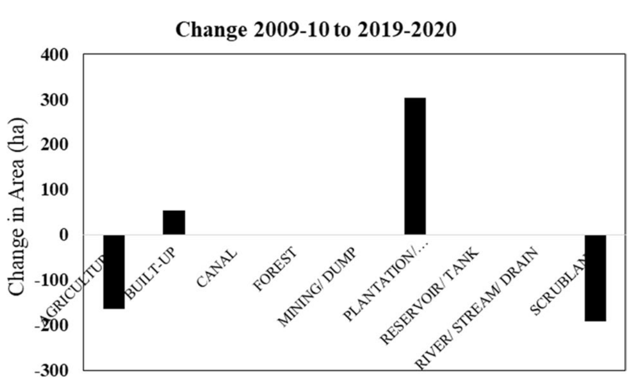

Fig. 5 Negative and positive trends in LULC over the monitoring years

hunger, good health and well-being, improved quality of education, removal of gender disparity, clean water availability and sanitization, renewable source of energy, decent economic growth, innovation in industrial growth, sustainable cities and communities, and climate hazard reduction which are all related to each other. Since India has a rural population of 65.07%, therefore, the government mainly focuses on the development in rural areas which are economically backward. Therefore, full support in terms of infrastructure building, education, and economic alternatives of livelihood are constantly being introduced in the region to upheaval the economic conditions and facilitate towards better life standards. From the above discussion based on the statistics, it is clear the second phase of integrated watershed management has been very fruitful in terms of sustainable management.

Fig. 6 Facility and capacity building in the region for achieving SDGs

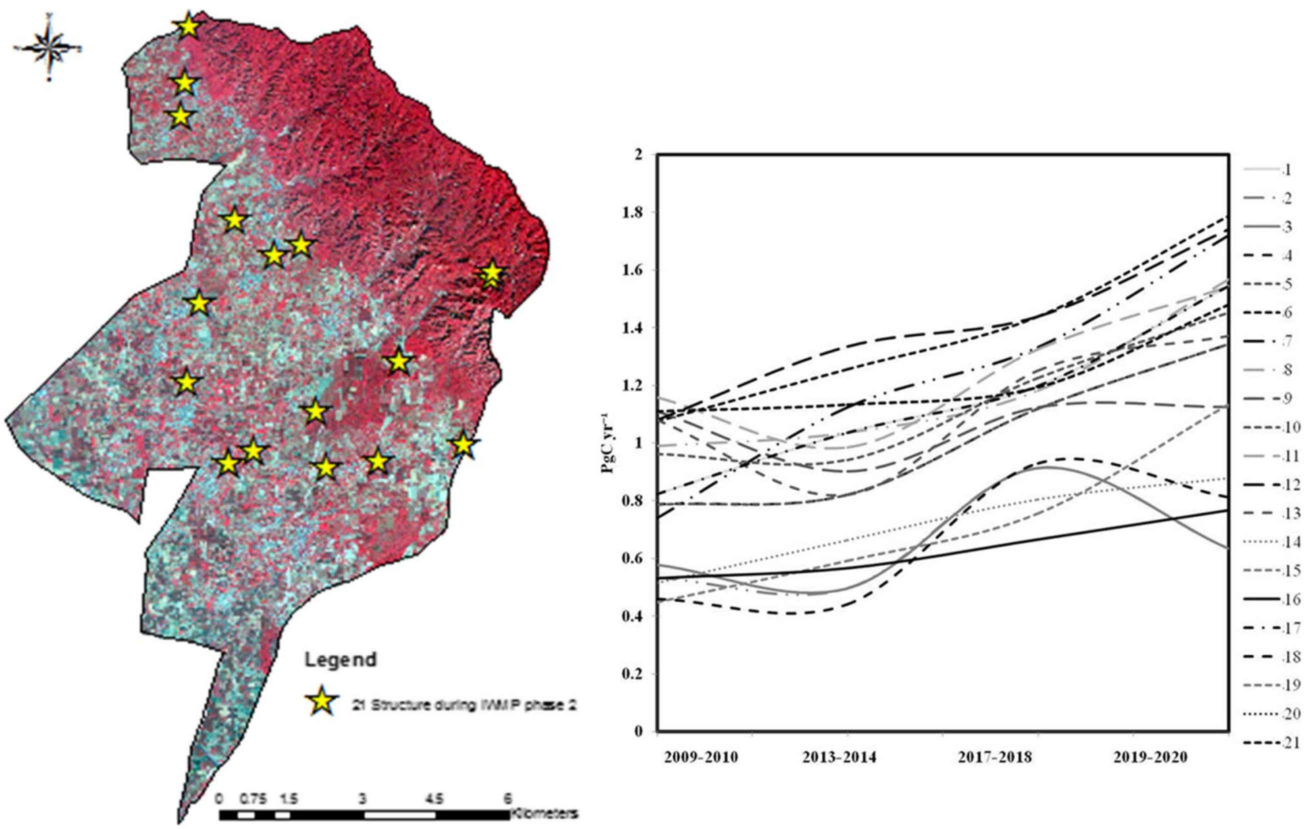

Fig. 7 Trend of NPP along 21 structures built in the subwatershed

Several examples from the study area can be set to show the growth in the infrastructure facility that can lead to or facilitate the livelihood of the people. Conservation structures like the silt detention structures have been built to control soil/water erosion. Gabion structures have been built across the area to stabilize soil and prevent soil erosion. Further proper entry point activities have been carried out for villages so that villagers can be entitled to proper facilities like clean water and sanitation. Both at government and non-governmental levels, capacity building has been carried out focusing on women so that alternative income sourcing can come up to families apart from basic income (Fig. 6).

From the field survey, it is clear that within this watershed, a total of 21 structures/measures were taken up for upholding the livelihood level.

Furthermore, to see the benefits of this structure in the region, a trend analysis (Fig. 7) of Net Primary Productivity (NPP) was done to understand the net carbon stock level in the region. The study shows a clear rise in annual NPP over the time frame from 2009–2010 to 2019–2020. Thus, it is clear that the projects like IWMP have contributed a lot to the socio-economic development of the people in this region by providing facilities which could improve the soil and water conditions of the region and ultimately uplift the social structure.

Conclusion

Watershed management programs in the northeastern part of Punjab nestling in Siwalik Hills and associated piedmont plains are very essential to protect and manage the region from getting subjected to degradation. The present study aimed at the evaluation of the impact of watershed management program phase 2 by LU/LC mapping over four time frames 2009–2010, 2013–2014, 2017–2018, and 2019–2020, change detection analysis, and validation of ground level measures including structures under IWMP program. Change detection at the micro-watershed level was carried out in detail over this region to understand the impact of the management strategies. The detailed analysis clearly showed that IWMP schemes have been properly implemented at the grass root level to manage the watersheds in a holistic manner; therefore, the region shows considerable improvement in the net carbon stock.

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Author Contribution A. Birinder Kaur—analyzed the data.

B. Dr. Koyel Sur—wrote the first draft of the manuscript and helped in the analysis.

C. Dr. Vipan Kumar Verma—finalized the draft manuscript and guided.

D. Dr. Brijendra Pateriya—overall guidance.

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Data Availability The datasets generated or analyzed during the study are available from the corresponding author on a reasonable research request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare no competing interests.

References

1. Singh C, Solomon D, Bendapudi R, Kuchimanchi B, Iyer S, Bazaz A (2019) What shapes vulnerability and risk management in semi-arid India? Moving towards anagenda of sustainable adaptation. Environ Dev 30:35–50. https://doi.org/10.1016/j.envdev.2019.04.007
2. Chikwanha OC, Mupfiga S, Olagbegi BR, Katiyatiya CL, Molotsi AH, Abiodun BJ, Dzama K, Mapiye C (2021) Impact of water scarcity on dryland sheep meat production and quality: key recovery and resilience strategies. J Arid Environ 190:104511
3. Vollset SE, Goren E, Yuan CW, Cao J, Smith AE, Hsiao T, Bisignano C, Azhar GS, Castro E, Chalek J, Dolgert AJ (2020) Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study. The Lancet 396(10258):1285–1306
4. Dev I, Singh R, Garg KK, Ram A, Singh D, Kumar N, Dhyani SK, Singh A, Anantha KH, Akuraju V, Dixit S (2022) Transforming livestock productivity through watershed interventions: a case study of Parasai-Sindh watershed in Bundelkhand region of Central India. Agric Syst 196:103346
5. Kumar V, Mishra N (2021) Sustainable watering of the watershed: a qualitative analysis of the Choral River Revival Project in Narmada Basin, India. Dev Pract 1–12. https://doi.org/10.1080/09614524.2021.1958164
6. Garg KK, Anantha KH, Nune R, Akuraju VR, Singh P, Gumma MK, Dixit S, Ragab R (2020) Impact of land use changes and management practices on groundwater resources in Kolar district, Southern India. J Hydrol: Regional Studies 31:100732
7. Jain P, Ramsankaran RAAJ (2019) GIS-based integrated multi-criteria modelling framework for watershed prioritisation in India—a demonstration in Marol watershed. J Hydrol 578:124131
8. Karlen DL, De M, McDaniel MD and Stott DE (2021) Evolution of the soil health movement. Soil Health Series: Volume 1 Approaches to Soil Health Analysis, pp.21–48
9. Sur K, Chauhan P (2019) Dynamic trend of land degradation/restoration along Indira Gandhi Canal command area in Jaisalmer District, Rajasthan, India: a case study. Environ Earth Sci 78(15):1–11
10. Meng S, Huang Q, Zhang L, He C, Inostroza L, Bai Y, Yin D (2020) Matches and mismatches between the supply of and demand for cultural ecosystem services in rapidly urbanizing watersheds: a case study in the Guanting Reservoir basin China. Ecosystem Services 45:101156
11. Thakkar AK, Desai VR, Patel A, Potdar MB (2017) Impact assessment of watershed management programmes on land use/land cover dynamics using remote sensing and GIS. Remote Sensing Appl: Soc Environ 5:1–15
12. Wani SP and Garg KK (2018) Improving water use in tropical rain-fed systems: the situation in India Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India. In Water management for sustainable agriculture (pp. 443–464). Burleigh Dodds Science Publishing

13. Chowdhury K, Behera B (2022) Institutional dynamics and water resource management: the case of traditional water bodies in West Bengal, India. Int J Water Resour Dev 38(5):836–860
14. Wani SP, Sreedevi TK, Vamsidhar Reddy TS, Venkateshvarlu B, Shambhu Prasad C (2008) Community watersheds for improved livelihoods through consortium approach in drought prone rainfed areas. J Hydrol Res Dev 23:55–77
15. Chowdhury AR and Rajhans SK (2021) Revisiting Wittfogel: "hydraulic society" in colonial India and its post-colonial legacies in hydropower management. In Theory, Policy, Practice (pp. 123–140). Routledge India
16. Pani A, Ghatak I, Mishra P (2021) Understanding the water conservation and management in India: an integrated study. Sustain Water Resour Manag 7(5):1–16
17. Patnaik U, Das PK, Bahinipati CS (2019) Development interventions, adaptation decisions and farmers' well-being: evidence from drought-prone households in rural India. Clim Dev 11(4):302–318
18. Mwinjaka O, Joyeeta G, Bresser T (2010) Adaptation strategies of the poorest farmers in drought-prone Gujarat. Clim Dev 2(4):346–363
19. Reddy Suraj R, Rajashekar G, Jha CS, Dadhwal VK, Pelissier R, Couteron P (2017) Estimation of above ground biomass using texture metrics derived from IRS Cartosat-1 panchromatic data in evergreen forests of Western Ghats, India. J Indian Soc Remote Sensing 45(4):657–665
20. Reddy V (2017) Ratna, Yashpal Singh Saharawat, and Biju George "Watershed management in South Asia: a synoptic review." J Hydrol 551:4–13
21. Sivakumar MV, Vittal KP, and Eslamian S (2021) "Indian experiences in water harvesting systems." Handbook Water Harvesting Conserv: Case Stud Appl Examples 325–339
22. Shankar Ram NR, Sharma, Mirza K, Goyal A, Chowdary VM, and Jha CS (2022) "Multi-criteria based land and water resource development planning using geospatial technologies." In Geospatial Technologies for Land and Water Resources Management, pp. 103–123. Springer, Cham
23. Bhardwaj P, Sharma T, Singh O (2021) Impact evaluation of watershed management programmes in Siwalik Himalayas of Haryana, India. Environ Dev Sustain 23(4):5251–5276
24. Saxena NC (1999) Foreword. In J. Farrington, C. Turton, & A. J. James (Eds.), Participatory watershed development: challenges for the twenty frst century. Oxford: University Press
25. Singh S, Sur K, Verma VK, Pateriya B (2022) Quantitative assessment of channel planform dynamics across Satluj River in North India over 45 years: analysis using geospatial techniques. Water Conserv Sci Eng 1–12. https://doi.org/10.1007/s41101-022-00154-z
26. Singh K, Sandhu HS, Singh N and Kumar B (1993) Kandi watershed development project: a critical evaluation. Econ Political Weekly 28(52):A122–A128 (7 Pages)
27. Yadav RP, Panwar P, Arya SL, Mishra PK (2015) Revisit of Shivalik region in diferent states of northwestern India. J Geol Soc India 86:351–360
28. Gupta RP (2018). Important spaceborne missions and multispectral sensors. In Remote Sensing Geology (pp. 61–86). Springer, Berlin, Heidelberg
29. Gray P (2006) Famine and land in Ireland and India, 1845–1880: James Caird and the political economy of hunger. Hist J 49(1):193–215
30. Jalan S, Sokhi BS (2012) Comparison of different pan-sharpening methods for spectral characteristic preservation: multi-temporal CARTOSAT-1 and IRS-P6 LISS-IV imagery. Int J Remote Sens 33(18):5629–5643
31. Joshi PK, Gairola S (2004) Land cover dynamics in Garhwal Himalayas—a case study of balkhila sub-watershed. J Indian Soc Remote Sensing 32(2):199
32. Omernik JM, Bailey RG (1997) Distinguishing between watersheds and ecoregions 1. JAWRA J Am Water Resour Assoc 33(5):935–949