Land use and agricultural change dynamics in SAT watersheds of southern India

Irshad M. Ahmed[1], Murali Krishna Gumma[1,*], Shalander Kumar[1], Peter Craufurd[2], Ismail M. Rafi[1] and Amare Haileslassie[3]

[1]International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, India
[2]International Maize and Wheat Improvement Center, Nairobi, Kenya
[3]International Water Management Institute, Addis Ababa, Ethiopia

Impact of dynamic land use and land cover changes on the livelihood of local communities and ecosystem services is a major concern. This is particularly evident in most dryland agricultural systems in South Asia. We study land use/land cover (LULC) changes over the last two decades in a watershed (9589 ha) located in semi-arid eco-region in South India (Anantapuram district) using Landsat and IRS imagery. We captured additional data through field observations and focused group discussions. The high resolution 30 m data and the spectral matching techniques (SMTs) provided accuracy of 91–100% for various land use classes and 80–95% for the rice and groundnut areas. The watershed studied has undergone significant land use changes between 1988 and 2012. Diminishing size and number of surface water bodies, and contrastingly increased areas under irrigation clearly explain that the system has evolved significantly towards groundwater-irrigated groundnut production. Such changes could be beneficial in the short run, but if the groundwater withdrawal is without sufficient recharge, the long-term consequences on livelihoods could be negative. The water scarcity could be aggravated under the climate change. The construction of checkdams and dugout ponds to recharge groundwater is a potential solution to enhance recharge.

Keywords: Agriculture areas, land use changes, livelihoods, water harvesting structures, watershed.

Introduction

DEMAND and competition for scarce freshwater resources among different uses and users (including agriculture, livestock and domestic supply) is one of the major challenges facing dryland production systems. Land use changes and water allocation strategies are the major factors to such challenges. A number of emerging evidences from the study area suggested that the water use for agriculture is increasing. With mean annual rainfall (MAR) of around 522 mm, Anantapuram is one of the most drought-prone districts of southern peninsular India.

To understand the trends in water supply and demand, a survey of tanks in Kalyandurga mandal was commissioned in 2003, and the work identified a total of 85 tanks in the area. The survey also showed that 25% of the tank bunds and weirs were in poor condition, thereby such tanks are used as water recharge structures rather than for surface irrigation[1].

Erratic and low rainfall during the southwest monsoon and recurring droughts have led the farmers of the rainfed cropping area to focus mostly on groundnut. When asked about the frequency of drought and its impact on crop yields, the farmers complained that they get only two years above average yields in 10 years and the trend is worsening. District level data also shows that the average productivity of groundnut tends to decrease over recent years. Despite the introduction of other crops (e.g. pearl millet) that can better perform under such less rainfall conditions, farmers generally prefer to grow groundnut because of higher returns. Sometimes groundnut is intercropped with pigeon pea. In fact, the latter is decided by the onset of southwest monsoon and rainfall distribution during the season. Crop intensification led to expansion driven by the availability of water, cropping options and technologies, and this has led to a major land use change, witnessed in the study area.

The deterioration of soil and water conservation structures coupled with increasingly erratic rainfall has reduced the options to use surface water bodies for irrigation. The question as to how long the groundwater can support the increased intensification depends largely on how regularly the soil and water conservation structures are maintained, and how carefully resources are exploited within its carrying capacity limits.

The Central Ground Water Board (CGWB)[2] in a report on Anantapuram district, indicated that the pre-monsoon depth of water level was 10–20 m bgl (below ground level) in Kalyandurga mandal where the study area is located. The post-monsoon depth of water level was >10 m bgl. The total number of wells in the mandal is 3413 and the density is 7 per km^{-2}, which is also the district average. Long-term studies of observation wells by

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*For correspondence. (e-mail: m.gumma@cgiar.org)

CGWB and state departments between 1996 and 2005 show declining water level in 85% of the wells in the district as a whole. It also categorizes the Kalyandurga mandal as over-exploited mandal with 2896 Mha extracted from the available 2588 Mha groundwater resulting in a deficit of 308 Mha. The natural resource scarcity, unchecked overexploitation and resultant land degradation are pervasive in many parts of dryland ecosystems[3]. Types and intensity of problems across drylands vary substantially and thus this drier region is the most affected region[3].

To ensure the future livelihoods of farming communities and to enhance productivity and manage the risk of farming more effectively, future trajectory of resilience building or intensification needs to acknowledge the land use/land cover (LULC) changes. Hence, an approach that used remote sensing and participatory tools to analyse the information on LULC changes, land degradation and as their implications for sustainable agricultural intensification is important[4].

The study of spatial and temporal changes, backward and forward from a known point in time using remote sensing, is possible when high resolution imagery and local agricultural statistics are compared. Data on local agricultural statistics provide a coarse view on changes in cropping and land-use patterns[5,6] under fluctuating irrigation supply, whereas satellite imagery can provide maps of cropping patterns that significantly change in response to water availability[7]. Thus we aim to map and analyse LULC changes in a small watershed in SAT region over two decades. We also examine the implications of changes in water sourcing and cropping pattern on the farming systems.

Method of analysis

Farming systems in the study area

Palvai watershed of Kalyandurga mandal (the third level administrative unit in India) lies in the northeast part of Anantapuram district of Andhra Pradesh. The study area is located in the SAT region of Indian peninsula (77°4′–77°10′E and 14°20′–30°40′N, Figure 1). The total geographical area is 10,000 ha. Agriculture is the mainstay of people’s livelihood and is dominated by groundnut-based crop–livestock production systems. The current mean land holding size is about 2.8 ha per household and the number of Standard Livestock Unit (SLU; equivalent to 350 kg live weight) is about 2 (Table 5). The MAR (for the period 1960 to 2000) in the study area was about 589 mm with annual range between 176 mm and 1411 mm. About 95% of the soils are Alfisols and the remaining are Vertisols. Erratic and low rainfall with poor water-holding capacity of the dominant soils type (Alfisols) are the major limitations to crop and livestock production in the study area.

Data source

Satellite imagery

Three dates were selected based on the availability of cloud-free imagery in the recent decades. Landsat ETM+ tiles were downloaded from the US Geological Survey (USGS), global land cover facility website (http://edcsns17.cr.usgs.gov/NewEarthExplorer/) for October 1988 and October 2001. IRS-RS2 satellite LISS IV data were procured from the National Remote Sensing Centre (NRSC) for October 2012. All the Landsat ETM+ and IRS-RS2 LISS IV tiles were converted into reflectance to normalize the multi-date and multi-sensor effect[8–11] using a model developed in ERDAS Imagine[12]. Data belonging to different years and their spectral characteristics are given in Table 1.

MODIS (Moderate Resolution Imaging Spectroradiometer) data for the study area were obtained from NASA and composed datasets from individual images[13]. The 250 m spatial resolution, 2-bands MODIS data

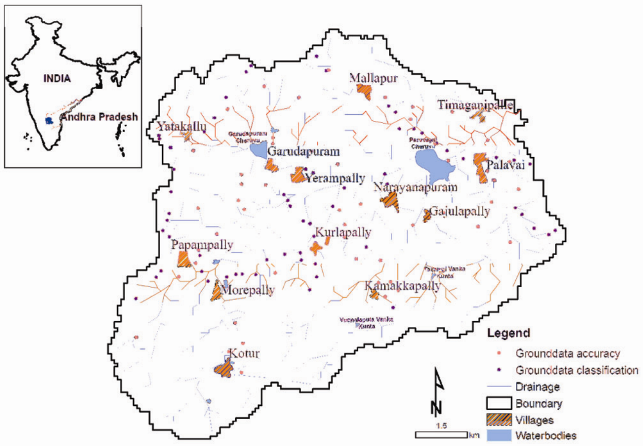

Figure 1. Study area showing the ground data with drainage network. (Drainage network derived from SRTM 90 m DEM).

Table 1. Characteristics of satellite sensors used in the study

Sensor	Spatial (m)	Bands	Band range (mm)	Irradiance (W m^{-2} sr^{-1} mm^{-1})
Landsat ETM+	30	1	0.45–0.52	1970
		2	0.53–0.61	1843
		3	0.63–0.69	1555
		4	0.75–0.90	1047
		5	1.55–1.75	227
		7	2.09–2.35	1368
IRS-RS2 LISS IV	5	1	0.52–0.59	1854
		2	0.62–0.68	1582
		3	0.77–0.86	1114
MODIS	250	1	0.62–0.67	1528.2
		2	0.84–0.88	974.3

(centred at 648 nm and 858 nm; Table 1) collection 5 (MOD09Q1) were acquired for every eight days during the crop-growing seasons from June 2000 through May 2001. The data were available in 12-bit (0 to 4096 levels), which was stretched to 16-bit (0 to 65,536 levels). Further processing steps are described in earlier papers[14–16].

Collection of ground data and other relevant information

Ground information was gathered from 115 locations during 4–10 October 2012. The farmer focus group discussions and consultations with local experts were made to collect ancillary information and their perceptions on implications of changes in resource status. On the basis of local expert knowledge and field observations, the representative field samples were selected. The spatial resolution of Landsat is 30 m on each side and a minimum sampling unit of 30 m × 30 m was selected for ground data validation. Ground data locations were selected based on the homogeneity of locations and road access. The emphasis was on 'representativeness' of the sample location in identifying one of the classes to ensure precise geo-location of the pixel. Class labels were assigned in the field using a labelling protocol[17].

At 63 out of the 115 locations, the following data were collected: (a) geographic location using a handheld GPS unit, (b) crop type(s), (c) cropping seasons (rainy, post-rainy and summer) based on interviews with agricultural extension officers and farmers, (d) cropping pattern (crop combinations), (e) land holding size (small (≤2 ha), medium (2–5 ha) and large (≥5 ha)), (f) land cover categories (including trees, shrubs, grasses, water bodies and hills), (g) digital photographs for illustration purposes and (h) whether systems were rainfed or irrigated and the method of irrigation (Figure 1). The geographic coordinates, cropping pattern/intensity, and digital photos were recorded for the remaining 52 points.

Analysis and interpretation

LULC mapping

Image normalization is applied to normalize the multi-date effect[8,11] of Landsat images for accurate classification. The images were converted into top of atmosphere (TOA) reflectance using a reflectance model built in ERDAS Imagine Modeler[8,10,11]. The meta-data needed for normalization are available in the header files. Unsupervized ISOCLASS cluster K-means classification was used to capture the range of variability in phenology in the image. The class identification and labelling process involved the use of the various datasets such as Bi-spectral plots, ground data, google high resolution imagery and MODIS time series NDVI signatures. Methods and protocols were adopted from previous studies[15,16].

Accuracy assessment was performed with ground data based on error matrix and the theoretical description is from an earlier report[18]. The error matrix is a multi-dimensional table in which the cells contain changes from one class to another class. The columns of an error matrix contain the field-plot data points and the rows represent the results of the classified land use maps[19]. The columns of the error matrix represent the actual field information (field-plot data) and the rows of the error matrix correspond to a class in the land use map. The overall classification accuracy was computed as a diagonal point divided by the total number of points. Kappa[20] statistic was used to assess accuracy for comparing results from different classifications.

Results

LULC maps and area statistics

LULC classes were identified and labelled (Figure 2) using spectral matching technique. The major classes in the study area are: (a) irrigated-groundnut/rice, (b) rainfed-groundnut/pulses, (c) rangelands/fallow, (d) rangelands/shrub lands, (e) shrub lands/wastelands/trees, (f) water bodies and (g) built-up lands. An error matrix was generated using field-plot data, with sample points varying from 10 to 100. The LULC areas, including the irrigated areas, are shown in Table 2. The final class name or

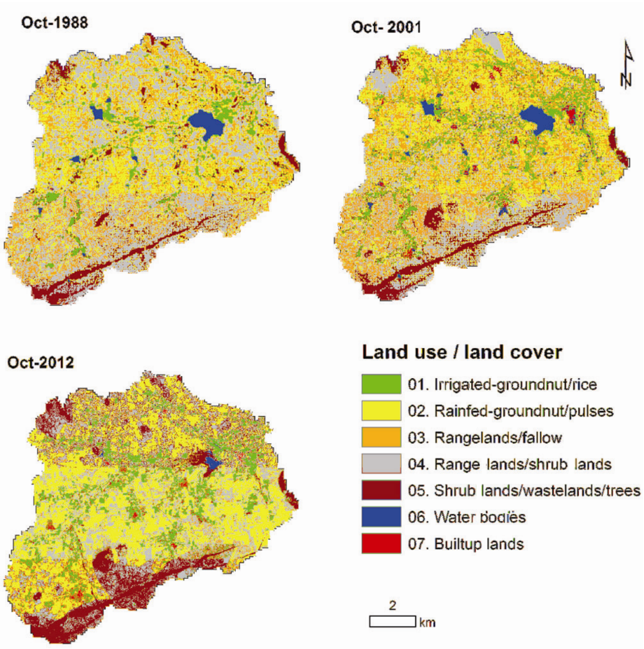

Figure 2. Land use/land cover classes in study area over time.

label is based on the predominance of a particular land use class, source of irrigation (e.g. irrigation, surface water dominant) (Figure 2 and Table 2). For example, 'rainfed-groundnut pulses' illustrates cultivation of predominantly rainfed-groundnut during the crop season. Class 01 is predominantly located along inland valleys and have high groundwater potential for agriculture.

LULC changes

The temporal imagery has revealed significant changes in agricultural croplands during the last two decades (Figure 3, Table 3). The changes in cropping intensity of the agricultural cropland areas during 2012–13 indicate that 1179 ha changed to irrigated agriculture from rangelands and rainfed agriculture; 1629 ha from rangelands/shrub lands to rainfed-groundnut and 142 ha from water bodies to other LULC.

Table 2. Distribution of land use/land cover classes in the study area

	Area (ha)		
LULC Class#	October 1988	October 2001	October 2012
Irrigated-groundnut/rice	537	1005	1719
Rainfed-groundnut/pulses	2471	2133	4117
Rangelands/fallow	2753	3106	868
Rangelands/shrub lands	2745	1996	1731
Shrub lands/wastelands/trees	886	1100	1022
Water bodies	171	163	30
Built-up lands	26	86	102
	9589	9589	9589

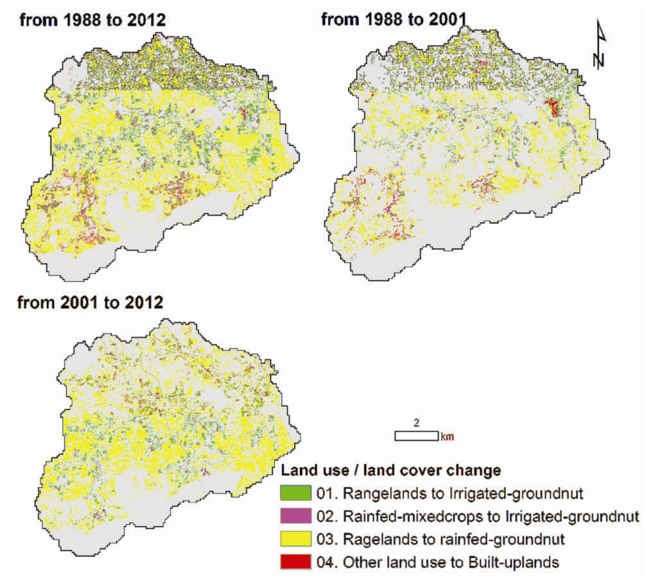

Figure 3. Land use/land cover change classes as related with the source of water.

Groundwater status and impacts of observed changes on livelihood and ecosystem services

It is observed that the irrigated area has increased mainly on account of increased number of deep bore wells (Figure 4 and Table 4); however the groundwater level has continuously declined due to increased use of water from the bore wells for irrigation. Shallow wells have failed because of increase in deep aquifer extraction from new deep bore wells. Net groundwater extraction for irrigation, domestic and livestock use was estimated at 11.0% of mean annual rainfall. As the Andhra Pradesh Groundwater Department's estimate of groundwater recharge in this area is approximately 10% of the annual rainfall, this suggests that current levels of extraction in Kalyandurg are not sustainable[1] (Figure 5). Farmers have preference for high water-requiring crops like paddy/rice if they have access to irrigation water (Table 5).

Discussion

Multi-date imagery has great potential to analyse land use, changes over time and probable reasons for the

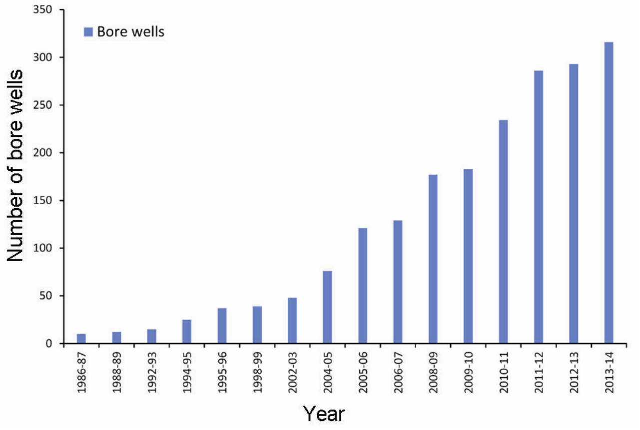

Figure 4. Number of bore wells in the watershed over the years.

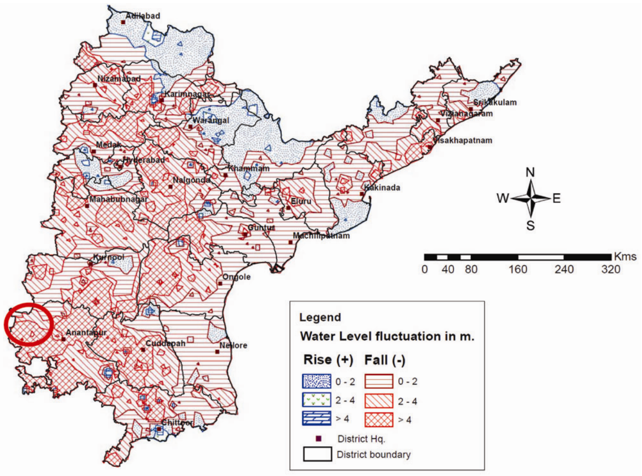

Figure 5. Fluctuation in groundwater levels in Andhra Pradesh[21].

Table 3. Land use changes in the study areas for 1988 to 2012

LULC Class$^{\#}$	Area (ha) 1988 to 2012	1988 to 2001	2001 to 2012
Rangelands to irrigated-groundnut	894	437	784
Rainfed – mixed crops to irrigated-groundnut	468	270	378
Rangelands to rainfed-groundnut	2683	1544	2578
Other land use to built-uplands	87	60	61
Total	4132	2311	3801

Table 4. Temporal increase in bore wells in Kalyandurg mandal

	1993–94		2000–01		2006–07		2013–14
Mandal	Shallow*	Deep*	Shallow	Deep	Shallow	Deep	Total
Kalyandurg	324	Nil	425	Nil	1927	123	5883

*Shallow: tube well <70 m depth and deep: >70 m.

Table 5. Farmers choice of different crops – proportion of farmers in each category growing a particular crop and raising livestock (in %)

Households category	Landless	Marginal	Small	Semi-medium	Medium	Large
No. of households	13	45	95	71	29	6
Land holding (ha)	0	0.77	1.59	3.08	6.61	17.11
Households owning livestock (%)	30.8	26.7	50.5	71.8	69	66.7
Groundnut – *kharif*	–	93.3	90.5	95.8	96.6	100
Groundnut – *rabi*	–	0	7.4	8.5	13.8	16.7
Rice – *kharif*	–	2.2	2.1	4.2	10.3	0
Rice – *rabi*	–	0	9.5	5.6	27.6	50
Tomato	–	4.4	2.1	12.7	0	16.7
Mango	–	0	1.1	1.4	13.8	0
Banana	–	0	0	0	0	0
Castor	–	0	3.2	0	0	0
Cotton	–	0	0	1.4	0	0
Muskmelon	–	0	0	4.2	0	0

dynamics. Rainfed regions are more prone to these changes due to uncertainty of water availability. The available limited water could be best put to use for less water-requiring crops like pigeon pea, castor and cotton, but farmers opt for a smaller area under their staple crop rice according to the availability of water. Rice is not only the major constituent of diet of the people, but also has lower production and market risk. In the process of over extraction of groundwater, many bore-wells have dried. Most smallholder farmers, especially marginal (93%) farmers, have only one crop of groundnut. According to farmers, the groundnut cultivation was not profitable during the last 4–5 years. This has made farmers more vulnerable. Based on the discussion of focus-group with farmers, it was found that traditionally the livestock has been equitably distributed across the farm size categories and remained a major source of income for the landless and smallholder households. However, currently the livestock ownership of the landless and marginal farmer households in the studied systems is comparatively low. Only 26–31% of marginal farmers and landless households own livestock compared to 72% and 67% of medium and large farmers (Table 5). In farmer's perception, the scarcity for fodder and labour are major constraints for smallholders' livestock production. The drastic reduction in the area under rangelands/fallow/shrub lands as demonstrated in LULC maps could be negatively influencing the livestock production. In all, the changes in LULC and consequent production practices may result in less sustainable livelihoods. Water conservation is a successful coping strategy to sustain crop production.

The present study showed changes in water availability and its source, i.e. changing from rainfed to groundwater irrigation is directly affecting the land use and changes in the cropping pattern. The 1988 LULC map showed that a large extent of the land was under rangeland/fallow. However, due to severe drought in 2001, the land under rangeland/fallow has not decreased but has increased marginally (Table 2). The area under rainfed groundnut/pulses also decreased due to drought. It is observed that in 2012 the cropped area tripled, both in irrigated (from 537 ha in 1988 to 1719 ha in 2012) and rainfed classes (2471 ha in 1988 to 4117 ha in 2012) with a significant decrease (2753 ha in 1988 to 868 ha in 2012) in rangeland/fallows. Similar decrease in rangeland/shrub lands is also observed.

Conclusions

A visible relationship between groundwater availability over the years due to water conservation structures like check dams and the increase in total cropped area, especially irrigated area under tube wells was observed (Table 3). The construction of check dams started during 2001, and increased steadily until 2012 to a total of 70 with a simultaneous mushrooming of bore wells (Figure 4). The availability of irrigation water from bore wells encouraged farmers to go for assured cropping (Table 5) and crop intensification. It was also observed that in many places the tank sluices have been closed to convert the tanks to percolation tanks, thereby increasing the groundwater availability for more than one season even if monsoon fails. However, due to higher density of wells and excess extraction of water in Kalyandurg, around 30% of the wells are defunct or fail routinely[1]. Coping mechanism in the case of failure of monsoon rains includes livestock rearing, which is an important remunerative livelihood activity (Table 5). Rainwater conservation for recharging the open/shallow bore wells or supplemental irrigation through farm ponds would be the critical component of sustainable agricultural production in the semi-arid watersheds. These are significant changes in LULC that will have impact on food security. Such changes may be expected all over the Anantapuram district with increased use of groundwater (Table 2). Remote sensing and geospatial information along with ancillary data provide insights into the land use change dynamics of the SAT watershed in the semi-arid regions.

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1. Rama Mohan Rao, M., Batchelor, C., James, A., Nagaraja, R., Seeley, J. and Butterworth, J., Andhra Pradesh rural livelihood programme water audit report (APRLP), Rajendranagar, Hyderabad, India, 2003.
2. CGWB, Central Ground Water Board Report 2005. http://www.cgwb.gov.in/ (accessed in 24 July 2014), 2005.
3. van Ginkel, M. *et al.*, An integrated agro-ecosystem and livelihood systems approach for the poor and vulnerable in dry areas. *Food Security*, 2013, **5**, 751–767.
4. Mottaleb, K. A., Gumma, M. K., Mishra, A. K. and Mohanty, S., Quantifying production losses due to drought and submergence of rainfed rice at the household level using remotely sensed MODIS data. *Agricult. Syst.*, 2015, **137**, 227–235.
5. Gaur, A., Biggs, T. W., Gumma, M. K., Parthasaradhi, G. and Turral, H., Water scarcity effects on equitable water distribution and land use in a major irrigation project – case study in India. *J. Irrigat. Drain. Eng.*, 2008, **134**, 26–35.
6. Gumma, M. K. *et al.*, Changes in agricultural cropland areas between a water-surplus year and a water-deficit year impacting food security, determined using MODIS 250 m time-series data and spectral matching techniques, in the Krishna River basin (India). *Int. J. Remote Sensing*, 2011, **32**, 3495–3520.
7. Thiruvengadachari, S., Murthy, C. and Raju, P., Remote sensing study of Bhakra canal command area, Haryana State, India, Water Resources Group, NRSA, Hyderabad, India, 1997.
8. Gumma, M. K., Thenkabail, P. S., Hideto, F., Nelson, A., Dheeravath, V., Busia, D. and Rala, A., Mapping irrigated areas of Ghana using fusion of 30 m and 250 m resolution remote-sensing data. *Remote Sensing*, 2011, **3**, 816–835.
9. Markham, B. L. and Barker, J., Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures. *EOSAT Landsat Techn. Notes*, 1986, **1**, 3–8.
10. Thenkabail, P. S., Enclona, E. A., Ashton, M. S., Legg, C. and De Dieu, M. J., Hyperion, IKONOS, ALI, and ETM+ sensors in the study of African rainforests. *Remote Sensing Environ.*, 2004, **90**, 23–43.
11. Velpuri, N., Thenkabail, P., Gumma, M. K., Biradar, C., Dheeravath, V., Noojipady, P. and Yuanjie, L., Influence of resolution in irrigated area mapping and area estimation. *Photogramm. Eng. Remote Sensing*, 2009, **75**, 1383–1395.
12. ERDAS Field Guide, October 2007, vol. 1.
13. NASA. Moderate Resolution Imaging Spectrometer (MODIS); http://modis.gsfc.nasa.gov/ (last date accessed on 15 August 2014)
14. Gumma, M. K., Gauchan, D., Nelson, A., Pandey, S. and Rala, A., Temporal changes in rice-growing area and their impact on livelihood over a decade: A case study of Nepal. *Agric., Ecosyst. Environ.*, 2011, **142**, 382–392.
15. Gumma, M. K., Nelson, A., Thenkabail, P. S. and Singh, A. N., Mapping rice areas of South Asia using MODIS multitemporal data. *J. Appl. Remote Sensing*, 2011, **5**, 053547; doi:10.1117/1.3619838.
16. Thenkabail, P. S., Schull, M. and Turral, H., Ganges and Indus river basin land use/land cover (LULC) and irrigated area mapping using continuous streams of MODIS data. *Remote Sensing Environ.*, 2005, **95**, 317–341.
17. Gumma, M. K., Thenkabail, P. S., Maunahan, A., Islam, S. and Nelson, A., Mapping seasonal rice cropland extent and area in the high cropping intensity environment of Bangladesh using MODIS 500 m data for the year 2010. *ISPRS J. Photogramm. Remote Sensing*, 2014, **91**, 98–113.
18. Jensen, J. R., *Introductory Digital Image Processing: A Remote Sensing Perspective*, Prentice Hall, United States, 1986.
19. Congalton, R. G., A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing Environ.*, 1991, **37**, 35–46.
20. Cohen, J., A coefficient of agreement for nominal scales. *Educat. Psychol. Measurement*, 1960, **20**, 37–46.
21. GWD, Groundwater level scenario in Andhra Pradesh, 2014; http://apsgwd.gov.in/swfFiles/reports/state/monitoring.pdf; accessed on 18 August 2014.

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