Land Use Change in Rajasthan, India, from ca.1985 to ca.2010

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1985年頃〜2010年頃のインドラジャスタタン州における土地利用変化
永見山幸夫・五十嵐勇輔

Abstract

インドは世界第2位の人口を有するが、第二次世界大戦後今日に至るまで指数関数的な人口増加が続き、2028年頃には中国を抜いて世界一の人口大国となる見通しである。近年経済発展にも拍車がかかったており、社会経済的に、また食糧需給や地球環境などとの関わりにおいても、世界的に大きなプレゼンスを示している。首都ニューデリーの南西郊数十キロから南西に広がる同国最大の州ラジャスタタン州は、東部に農業地帯、西部に広大なタール砂漠を擁する。本稿は州都ジャイプルを含むこの州の東部を対象に、1985年頃以降の土地利用変化を明らかにし、その特性と問題点を探るものである。インドでは大規模地形図の利用が規制されているため、1985年頃の土地利用図の作成には旧ソ連部が軍事目的で作成し、現在ウェブサイトmapstor.comで公開されている20万分1地形図を用いた。またGoogle Mapの衛星画像と現地調査で得た情報から2010年頃の土地利用図を作成した。両者を比較分析した結果、ラジャスタタン州東部における1985年頃〜2010年頃の都市集落の急速な拡大、農地の減少などの土地利用変化を地図と土地利用種別面積の変化で示すことができた。

Keywords: India (インド), Rajasthan (ラジャスタタン州), land use change (土地利用変化), land cover change (土地被覆変化), mapstor, Google Map

1. Introduction

India has the second largest population in the world. Its population is still increasing exponentially, and is expected to exceed that of China by around 2028 (United Nations, 2013). India has also been experiencing a rapid economic growth of 8.3% per year during 2011-2014 (World Bank, 2015). Such rapid changes of population and economy together impose substantial impact on its land use, and consequently on food production, environmental quality, and people's lives. The present study is part of a series of research...
Fig. 1  Trend of per capita real GDP of India (Source: IMF, 2014)

Fig. 2  Study area and survey route

Fig. 3  Land use map in “Bhuvan Gateway to Geospatial World” for 2005-2006
conducted at Hokkaido University of Education Asahikawa Campus on land use changes in India in the recent decades that identify and show the state and the change of land use, its processes and mechanisms, and the related problems in this country since ca. 1985. Figure 1 shows the trend of per capita real GDP of India since 1980, indicating that it increased threefold during 1985-2010 (IMF, 2014). This period is significant in the sense that it covers the pre-stage as well as middle-stage of the rapid economic growth of the country.

Figure 2 shows the study area of the present study, which is 28°N-24°N and 74°E-78°E, and is located mostly in eastern Rajasthan. The State of Rajasthan is 342,239 km² in area and its population is 56.47 million, with its density 165/km² (Statistical Bureau of India, 2011). Rajasthan is located in south-western India, bordering with Pakistan to the west, Haryana and Punjab to the north, Uttar Pradesh to the north-east, Madhya Pradesh to the south-east, and Gujarat to the south. Jaipur, the capital of Rajasthan, is an eminent historical city with population of 3,060 thousand (2011) which is growing rapidly as a great city not far from Delhi.

2. Study Method

Previously, Himiyama & Hasegawa (2013) studied part of northern India stretching from Haryana to Punjab. The change of land use has been identified by comparing two land use maps produced based on the 1:200,000 topographic maps obtained through ‘mapstor’ and the satellite images obtained through ‘Google Map’, each representing the land use of ca. 1985 and ca. 2010, respectively. It is noted that ‘Bhuvan Gateway to Geospatial World (2015)’ presents land cover maps of India in ca. 2005-2006 and ca. 2011-2012 free of charge (Fig.3). Bhuvan presents 1:500,000 land use maps of 2005 onwards for each state of India and 1:100,000 land use maps for major cities free of charge with as many as 32 land use categories, as well as some statistical data on land use. However, ‘Bhuvan’ addresses the data of the 2000s and 2010s only, and a longer term change is beyond its scope. As the societal and environmental changes in India in the last three decades are so great in comparison to the preceding decades, it was thought that the data of the 1980s were in need. It was therefore fortunate that ‘mapstor’ offers the data of ca.1985. A field survey was conducted in November 2014 in order to grasp the ground truth of the present and the near past.

2.1 Reconstruction of land use in ca. 1985 based on the 1:200,000 topographic maps supplied by ‘mapstor’

‘mapstor.com’ offers some 3,800 digital images of topographic maps at scales of 1:1,000,000 to 50,000. They were originally made by USSR and in some former East European countries for military purposes during the Cold War (mapstor, 2015). These maps are now available online at marginal price. In the present study 24 sheets of 1:200,000 map of the study area were downloaded from the ‘mapstor’ website. These maps were printed and processed as follows (Himiyama & Hasegawa, 2013):

a) To colour the map sheet with colour pencils according to the land use classification and the colour key in Table 1.

b) To draw grid lines on the map sheet in the way to divide the 10 km interval grid lines into four equally spaced units both N-S and E-W, making 2.5 km×2.5 km grids. Thus 720 grid squares per sheet and 17,280 grid squares for all the study area were made (Fig.4).

c) Land uses on the coloured map sheet are read for each grid square, and the code numbers of the observed land uses are written for each grid square. The information for each grid square is recorded in one line as
Fig. 4  Sample of 1:200,000 topo map (ca. 1986)
(Source: mapstor.com)

Fig. 5  Land use classification of Google Map
(Source: Google Map)

Table 1  Land use classification of mapstor 1:200,000 maps

<table>
<thead>
<tr>
<th>Land use</th>
<th>Code number</th>
<th>Image</th>
<th>Land use</th>
<th>Code number</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural</td>
<td>14</td>
<td></td>
<td>Water</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>20</td>
<td></td>
<td>River</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Shrub</td>
<td>21</td>
<td></td>
<td>Lake</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Sparse forest</td>
<td>24</td>
<td></td>
<td>Well</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td></td>
<td></td>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban land use</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Settlement</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source: mapstor.com)
follows: x-coordinate; y-coordinate; code number of the land use on the top-left corner of the grid square; code number of the largest land use in the grid square; second largest land use; third largest land use; …; smallest land use.

d) The data files thus produced are processed by a number of BASIC98 programmes for making various maps and statistical tables. The following is some examples of types of map easily made (Himiya & Takamatsu, 2013; Himiya & Abe, 2014):

- **general land use map** shows the largest land use type of each grid square
- **dominant-existent map** shows grid squares having a selected type of land use as the largest land use type in one colour, and as ‘existent land use’ in another colour.
- **two-level density map** shows grid squares having a selected type of land use as the largest or the second largest land use in the grid
- **three-level density map** shows grid squares having a selected type of land use as the largest, second largest or the third largest land use in different colours, respectively.

In the present paper, ‘general land use map’, ‘dominant-existent map’ and ‘three-level density map’ are shown.

2.2 Reconstruction of land use in ca. 2010 based on the satellite images provided by Google Map

The satellite image of the study area, i.e. 28°N-24°N and 74°E-78°E, released by Google Map (2015) has been downloaded, and subdivided to 16(north-south) × 8(west-east) = 128 subareas ca. 2010 based on the satellite images provided. The images used in the present study were taken during 2006-2010, though there were some missing or less clear images. The image of each sub area is print-screened, pasted on the paint, and stored as a TIFF file. It is processed for analyses and mapping according to the method developed by Himiya & Maeda (2012). The satellite image is coloured manually on the computer screen by using the function of Adobe Photoshop CS4 called ‘colour range command’ by types of land use, as shown in Fig.5. This classification scheme is based on Himiya & Hasegawa (2014), but ‘dry land’ has been added in order to meet the requirement of Rajasthan.

Thus, six layers representing each of the above six colours are made. The work has been done while referring to the corresponding satellite image. In some cases some external sources of information are needed. Google Earth uses the same satellite data as Google Map, but acquires the best image available, most of which being approximately one to three years older than Google Map. However, Google Map images have an advantage of keeping elevation while scrolling the image and of easiness of comparing the image with other thematic maps.

After colouring has been finished, the images are assembled to one continuous image. The map thus made is called a ‘general land use map’. Maps of each type of land use are also made.

The area size of each land use in the region is calculated by using a function of Adobe Photoshop CS4 called histogram (Himiya & Abe, 2010). A general land use map is the one showing all the colour layers together, while each layer can also be shown separately. The areas of each land use type in the study area shown in Fig.2 have been calculated for each period, and then compared. The area of the whole study area has been measured by using the polygon function of Google Earth, which offers accurate distance and area on the map (Google Earth, 2014).
Fig. 6  Land use in ca.1985 in S1  (Based on mapstor)

Fig. 7  Land use at top-left corner of the grid square in S1 (Ca. 1985)

Fig. 8  Land use in ca.2010  (Based on Google Map)
3. Land Use, General

The land use maps of the two time periods, namely ca.1985 and ca. 2010, are now compared and land use changes examined with the help of thousands of photographs taken in the field study. The study area is the area covered by the 1,200,000 mapstor map. The study area is 88,252 km², according to the area measuring tool of Google.

3.1 Land use in ca. 1985

Table 2 shows land use in ca. 1985, and Fig.6 shows the general land use map of ca. 1985. Agricultural land occupies 68.5%, though the study area includes some dry areas. Forest occupies 13.4%, much of which in the south-eastern part of the study area and some in between Jaipur and Alwar. Settlement occupies only 0.75%, with a concentration at Jaipur. Water surface, which includes rivers, lakes and wetlands, occupies 1.7%. Dry land occupies 15.2%, which is largely found in the west. The area of each land use type in the study area is measured by systematic point sampling. In practice the land use type at the top-left corner of each grid square is recorded, and it is counted by a BASIC programme for area measurement by land use type. Fig.7 is a special land use map made by using the information of land use at the top-left corner of each grid square as if it represents the land use of the grid square it belongs to. It sometimes gives a distribution pattern similar to Google Map.

3.2 Land use in ca. 2010

Table 2 shows land use in ca. 2010 and Fig.8 is the land use map in ca. 2010. Agricultural land occupies 64.4%, indicating the dominance of agriculture in the area. Forest occupies 13.8%, mainly found in the east and south. Urban land use occupies only 2.9%, and there is visible concentration at Jaipur. Water surface covers 1.8%, mostly irrigation ponds and canals. Dry land occupies 16.8%, with high concentration in the west, which continues into the Thar Desert. In the southern part of the study area, around Rana Pratap Sagar Lake and Gandhi Sagar Lake, are forest and trees. The area is the border area with Madhya Pradesh, and elevation is the highest in Rajasthan (Google Earth, 2014).

4. Settlement

Urban land use generally includes settlement and road, but the land use map of ca. 2010 does not have road in its land use classification, because it is difficult to identify on the Google Map satellite image. Therefore, settlement of ca. 1985 and that of ca. 2010 are compared as below.

4.1 Settlement in ca. 1985

Figure 9 is the dominant-existent map of settlement in ca. 1985. It shows a distinguished concentration of 5 dominant cells of settlement at Jaipur. The population of Jaipur in 1980 was 987 thousand (Government of India, 2011). Other concentrations of settlement include the border area with Haryana, which is close to Delhi, and Ajmer in the south-west of the study area, with 4 dominant cells and an existent cell. The population of Ajmer in 1990 was 402,700 (Government of India).
Table 2  Land Use in ca. 1985 and ca. 2010 in S1

<table>
<thead>
<tr>
<th>Land</th>
<th>ca.1985</th>
<th></th>
<th>ca.2010</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>km²</td>
<td>%</td>
<td>km²</td>
<td>%</td>
</tr>
<tr>
<td>Water</td>
<td>1517</td>
<td>1.70</td>
<td>1544</td>
<td>1.80</td>
</tr>
<tr>
<td>Settlement</td>
<td>661</td>
<td>0.80</td>
<td>2577</td>
<td>2.90</td>
</tr>
<tr>
<td>Forest</td>
<td>11781</td>
<td>13.40</td>
<td>12134</td>
<td>13.08</td>
</tr>
<tr>
<td>Agricultural</td>
<td>60452</td>
<td>68.50</td>
<td>56834</td>
<td>64.40</td>
</tr>
<tr>
<td>Dry land</td>
<td>13396</td>
<td>15.20</td>
<td>14791</td>
<td>16.80</td>
</tr>
<tr>
<td>Other</td>
<td>132</td>
<td>0.20</td>
<td>194</td>
<td>0.20</td>
</tr>
<tr>
<td>Total</td>
<td>88252</td>
<td>100</td>
<td>88252</td>
<td>100</td>
</tr>
</tbody>
</table>
In the south-east of the study area, dominant cells of settlement are rare. Sariska and Ranthanbor in this area are registered as national parks. Settlement is distributed extensively, with notable concentration around Bharatpur in the east. Bharatpur is a city adjacent to Uttar Pradesh and close to its capital Agra. There is only one dominant cell there, but between there and Agra are found 46 existent cells, indicating a relatively dense rural settlements. Photo 1 shows a town’s street which is full of motor cycles and people. Many of the ‘dominant’ cells in Figure 9 correspond to such towns scattered in this agricultural area.

4.2 Settlement in ca. 2010

Figure 10 shows urban land use in ca. 2010. Settlement is concentrated in and around Jaipur, and in the border area with Haryana. It is also common in and around Ajmer. The population of Ajmer in 2010 was 402,000, a more than double increase since 1991 (Government of India, 2011).

Figure 11 shows expansion of Jaipur. In ca. 1985 there are 23 dominant or existent cells of settlement, while in ca. 2010 the number increased to 38, i.e. 1.6 times as many. Population in 1980 was 980,000 in 1985, while it became 3 million in 2010. The population density of Jaipur in 2010 was 27,280/km². The gap between the rich and the poor is eminent in the cities in India, and Jaipur also has this problem. Many street dwellers were found, and some roads were full of garbage. These are a great contrast with the international economic activities and better roads in some part of the city.

Photo 2 shows a herds man and his cattle and sheep walking along the edge of a metalled road in the suburbs of Jaipur. The main highway connecting Jaipur with Delhi and Agra is a well-maintained, high-grade road. However, the roads in the old part of Jaipur are narrower, poorly maintained, and more crowded. In the eastern edge of the study area, part of Agra is seen, with two dominant cells in ca.1985. Small settlements are distributed widely in both periods with relatively minor change. Area of settlement increased from, 0.8% to 2.9%, i.e. more than tripled in 25 years. It is mainly attributed to the expansion of main cities such as Jaipur, Ajmer and Bharatpur. Although Jaipur is a large city, the percentage of urban use (settlement) in the study area was only 2.9%. In the northern part of the study area are found many small rural settlements.

Photo 3 shows a farmstead typical in this area, with many dung cakes dried in the yard for fuel. A farmstead of this size may or may not be identified as settlement. Settlement in ca.2010 was 1.6% (Bhuvan, 2015), or 5,407 km². As shown in Table 2, settlement occupies 2,577km². Knowing that the study area occupies about 25% of Rajasthan, most of the settlement in this state is in the study area.

5. Agricultural Land Use

5.1 Agricultural land use in ca. 1985

Agricultural land use occupies 68.5% of the study area in ca.1985. Figure 12 is the dominant-existent map of agricultural land in ca. 1985. Dominant cells are found widely in the study area, but in the south-east where Ranthanbor National Park exists it is rare. The area is semi-dry, and irrigation is vital necessity. Although there are no major rivers in this area, wells and irrigation canals are widely seen. Main staple foods are nan and roti, and wheat and peas are widely seen. Main crops of Punjab and Haryana are rice, wheat, cotton and bajra.
Fig. 12  Agricultural land use in ca. 1985 in S1  
(Based on mapstor)

Fig. 13  Agricultural land use in ca. 2010  
(Based on Google Map)

Fig. 14  Forest in ca. 1985 in S1  
(Based on mapstor)

Fig. 15  Forest in ca. 2010  
(Based on Google Map)
5.2 Agricultural land use in ca. 2010

Figure 13 shows agricultural land use in ca. 2010. Agricultural land use is prevalent in the study area, including the area around Jaipur. Irrigation system is well developed in this area, as seen in Photo 4, and irrigated dry field is a popular scene. Photo 5 shows mustard field, which is common in this area. Also common is sporadic isolated trees in the field. Main crops are beans, wheat, and tabacco. Beans and wheat occupy 15% of national total production. Paddy field is rare, with less than 5% of national total. In Rajasthan oil seeds production is increasing, occupying 17.71% of national total. Guar Gum in particular occupy over 30% of national total (Government of Rajasthan, 2015).

About 45% of Rajasthan is under agricultural use according to Bhuvan, although Thar Desert occupies more than half of the state. It is noted, however, that in 2011 abandoned agricultural land occupied some 19%, i.e. 65,966 km². Abandoned agricultural land was 23% in 2005, or 79,437 km² while agricultural land covered 40%, or 137,368 km² (Bhuvan, 2015), and abandoned agricultural land decreased and agricultural land increased in six years. Figure 12 and Figure 13 are compared. Sujangarh in north-west had little agricultural land use in ca.1985, but in ca. 2010 it became more visible.

6. Forest

6.1 Forest in ca.1985

Figure 14 is the dominant-existent map of forest in ca. 1985. Forest has high concentration in the north-east of the study area. Forest in India in 1987 was 640,000 km², occupying 19.4% of the country (FAO FAOSTAT, 2006). Forest occupies 13.4% of the study area, with some concentration in the south-east, where Ranthambor National Park is located, and wild animals such as tigers and water buffalos are preserved (Photo 6). Existent cells are widely seen, reflecting the fact that isolated or patchy trees or woods are seen extensively in farmland, along highways, or even in built-up areas.

6.2 Forest in ca. 2010

Forest in India in 2010 is 684,300km², or about 20% of the country, while in Rajasthan, it is only 8%. Figure 15 shows the distribution of forest in ca. 2010. Forest occupies 13.1% of the study area. Sparse forest is common, but in the border areas with Gujarat is seen more dense forest. Palm and other trees are planted along the highway here and there. Palm trees are in fact common, and are used for many purposes. The distribution of forest in Fig. 14 and Fig.15 do not show much difference, as forest is protected as national parks.

7. Dry land

7.1 Dry land in ca.1985

Figure 6, which shows general land use pattern of ca. 1985, shows extensive dry land in the west, particularly around Sujangarh and Degana. Elsewhere, dry land dominant cells are scattered.

7.2 Dry land in ca. 2010

Dry land is widely seen in the study area. To the west of the study area, or to the west of Jodhpur exists
Photo 1  A town near Sawaimadhopur  
(26°19'N  76°21'E)

Photo 2  Conflict between the motorization and traditional life, near Anantaganji  
(25°56'N  75°59'E)

Photo 3  Farmstead near Paprili  
(25°57'N  76°12'E)

Photo 4  Irrigation canal, near Anataganji  
(25°56'N  75°59'E)

Photo 5  Mustard field near Theekri  
(25°57'N  76°14'E)

Photo 6  Forest in Ranthanbore  
(25°57'N  76°23'E)
the Thar Desert. In the area around Sujargarh was found some dominant cells of dry land in ca. 1985, and some of them became agricultural in ca.2010. Agricultural land was 15.2% in ca.1985, and it increased to 16.5% in ca. 2010. This increase was probably achieved by the improvement of irrigation system, which in turn may cause water contamination or acceleration of water shortage.

8. Water

8.1 Water surface in ca.1985

Water occupies 1.7% of the whole study area, and it includes lakes, irrigation canals and ponds. The irrigation systems are of paramount importance for agriculture in the region, and it is ubiquitous although dominant cells are rare.

8.2 Water surface in ca. 2010

Water surface occupies 1.8% of total area. There are numerous number of irrigation canals and ponds, some of which being surveyed and identified Rana Pratap Sagar Lake and Gandhi Sagar Lake in the south together occupy most of the water surface area.

9. Conclusion

Land use change in Rajasthan, India, since ca. 1985 to ca. 2010 has been studied by using ‘mapstor’ for ca. 1985 and ‘Google Map’ for ca.2010. It has been concluded that:
1) Thanks to ‘mapstor’ and ‘Google Map’, the study of land use change since the mid 1980s Settlement has become much simpler and cheaper than before.
2) Population increase and urban expansion in bigger cities are still immense. Settlement more than tripled during ca.1985-ca.2010.
3) Agriculture still has basic function of supporting rural population, but agricultural area is decreasing.
4) Land use classification of ‘mapstor’ maps is very detailed but its instruction is written in Russian, so it is not easy to fully utilize these maps.

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