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Linkages between land use changes, desertification and human development in the Thar Desert Region of India

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ABSTRACT

Planning Commission of India has identified 15 Agro-eco regions (AEZs) for efficient resource management. Among the various regions, the Western Dry Region covers nine districts of the state of Rajasthan. Huge portion of Rajasthan is desiccated and houses the biggest Indian desert—the Thar Desert. The forest cover in all the nine districts of this zone has shown a declining trend owing to the land being diverted to cultivation. Besides forests, the area under other land uses is also being diverted to cultivation. This can have serious implications on sustainability of the livelihoods and extent of poverty of the people in this region. This in turn has implications on the health and other human development indicators. In this paper, the authors have used Markov Chain analysis to see the direction of change in the land use pattern in the districts covered under the Western Dry Region. The authors have also examined the linkages between various human development indicators of these districts in light of the changing land use pattern in the districts and suggested policy prescriptions for arresting desertification in state of Rajasthan.

1. Introduction

1.1. Desertification and development

Desertification is the persistent degradation of dryland ecosystems due to anthropogenic activities and variability in climate. Chapter 12 of Agenda 21, as approved by the United Nations Conference on Environment and Development (UNCED), defines desertification as “land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities”(Fao, 1993). Currently, 41 percent of the landmass worldwide is prone to desertification and around two billion people are affected by desertification and degradation of land (Millennium Ecosystem Assessment, 2005). Land degradation occurs everywhere, but is defined as desertification when it occurs in the drylands. In drylands, scarcity of water limits the production of crops, forage, wood and other services that ecosystems provide to humans. Drylands, are therefore highly vulnerable to increases in climatic variability and anthropogenic pressures.

Common indicators of desertification include loss of biodiversity or declining habitat, loss of water-retention capacity, reduced soil fertility and increasing wind and water erosion (Gorse, 1985). The chief drivers of desertification include deforestation, over grazing, over cultivation, pressure of population, industrialization and poor land use practices. According to the (Millennium Ecosystem Assessment, 2005) report, nearly 10–20% of drylands are already degraded, and ongoing desertification threatens many of the world’s ecosystems, including those inhabited by some of the poorest human populations. Therefore, desertification is one of the greatest environmental challenges today and a major barrier to meeting ecological and human needs especially in drylands. A large majority of dryland populations live in developing countries. Compared to the rest of the world, these populations lag far behind in terms of human well-being, per capita income and health parameters. Dryland populations are often marginalized and unable to play a role in decision making processes that affect their well-being, making them even more vulnerable. If no countermeasures are taken, desertification in drylands will continue to threaten future improvements in human well-being and possibly reverse any developmental gains in some regions.

Even though India shares only 2.4 percent of the world’s total land area, it supports 17 percent & 15 percent of the world’s human and livestock population respectively (Ministry of Agriculture,

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2013). These increasing pressures alone play a major role in promoting desertification. The increase in human and animal population increases the demand on natural resources leading to permanent loss of vegetation and plant species. This may also lead to the conversion of large areas into wastelands and to the frequent occurrence of natural disasters. Planning Commission of India has identified 15 Agro Climatic Zones for efficient resource management. Among the various regions, the Western Dry Region covers nine districts of the state of Rajasthan. These districts are (1) Bikaner (2) Jaisalmer (3) Barmer (4) Jodhpur (5) Churu (6) Nagaur (7) Sikar (8) Jhunjhunu and (9) Jalore. The Districts (1)–(5) formed the sub-zone of Arid Western Plain, districts (6)–(8) formed the sub-zone of Transitional Plain of Inland Drainage and the 9th district formed the sub-zone of Transitional Plain of Luni Basin. Fig. 1 shows the study area as shaded portion.

The huge portion of Rajasthan is desiccated and houses the biggest Indian desert—the Thar Desert. The forest cover in this region/zone is showing a declining trend owing to the land being diverted to cultivation. Besides forests, the area under other land uses is also being converted into arable lands. The capacity of these lands is limited. Pressures of human and livestock population have further compromised them (Planning Commission, 2002). This can have serious implications on sustainability of the livelihoods and extent of poverty of the people in these districts. This in turn has implications on the health and other human development indicators. Hence it is of importance to know the direction of change in the land use pattern in these districts. It would also be of relevance to study the performance of these districts in terms of various development indicators *vis a vis* various drivers of desertification existing in these districts. This paper describes the analysis of anthropogenic developmental activities in relation to degradation of natural ecosystems & depletion of resources.

1.2. Western dry region: an overview

Rajasthan occupies 10 percent of the geographical area of India and is now the largest state in the country. The Aravalli ranges divide the state into two distinct regions. The region in the west of Aravalli, consisting of 11 districts, constitutes a part of the Great Indian Desert or the Thar Desert. Nine out of these eleven districts constitute the Western Dry Region. The average temperature of this region varies from 45 °C in May–June to 2 °C in December–January. The annual rainfall in this region is around 400 mm with very high year to year variation. The cropping intensity (ratio of net sown area to total cropped area) is higher in districts which receive higher rainfall. The average size of holdings in this region is higher than the state average of 2.78 ha in seven out of nine districts (Table 1).

The population in this region has been increasing at a rate faster than national average. According to 2011 Census, the percent decadal growth rate of the population of Rajasthan between 2001 and 2011 was 21.44 percent as compared to 17.64 percent for India. This has led to increased pressure on land for food security of the increasing population and fodder security for the livestock. Due to less rainfall, people in this region practice a crop and livestock based mixed farming system. Low and erratic rainfall coupled with highly erodible and nutrient poor soil cause great uncertainty in the production of foodgrains. Under such circumstances, livestock significantly supplements the household's economy in Thar. Livestock such as sheep, goat and camel can survive in arid environment and are superior in combating physiological stress caused by lesser intake of food and water. Livestock are utilized efficiently by the desert people. The hide is used in making water storage bags, milk, milk products and meat are used for local consumption, bones of dead animals are used for carving and during financial stress livestock are also sold to get money. Some of the districts of this region

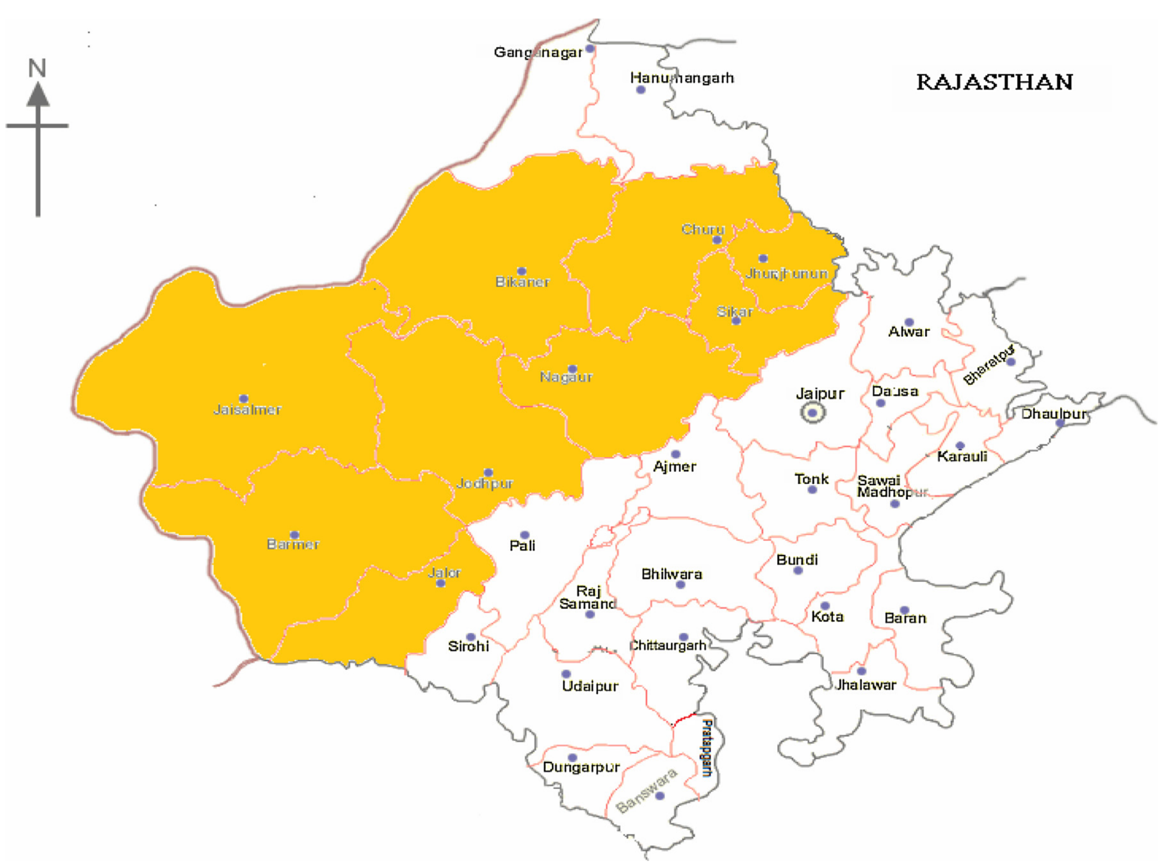

Fig. 1. The Western Dry Region.

Table 1
Some salient features of the Western Dry Region.

Districts	Total area (in km^2)	Percent forest area to total area	Average size of holdings (in hectares)	Cropping intensity	Percent area irrigated	Annual normal rainfall (in mm)
Barmer	28173.32	1.14	6.31	110.00	12.85	268.6
Bikaner	30404.76	3.05	8.57	114.00	25.01	274
Churu	13858.98	0.48	5.84	134.00	7.61	369.6
Jaisalmer	38391.54	1.16	7.17	121.00	26.49	181.2
Jalore	10566.02	2.09	4.06	161.00	29.99	427.1
Jhunjhunu	5915.36	6.71	1.76	173.00	32.2	481
Jodhpur	22564.05	0.31	5.28	115.00	25.76	308.1
Nagaur	17643.80	1.05	3.78	140.00	17.64	394.1
Sikar	7742.44	7.89	1.94	158.00	34.87	463.8

Source: http://agcensus.dacnet.nic.in/; Rajasthan Agricultural Statistics at a glance 2011–12.

Table 2
Livestock composition of the Western Dry Region.

District	Percentage in total livestock population					Density/Sq Km	
	% Cattle	Buffalo	Sheep	goat	Camel	Livestock	Human
Bikaner	26.08	5.10	31.08	35.35	1.93	94	78
Churu	13.55	11.35	23.91	48.62	2.18	112	147
Jhunjhunu	12.48	26.40	13.56	45.62	1.57	237	361
Sikar	11.22	22.74	14.08	50.75	0.68	293	346
Nagaur	13.42	14.78	25.54	45.60	0.45	176	187
Jodhpur	19.66	7.90	29.35	42.13	0.76	146	161
Jaisalmer	12.29	0.09	45.94	39.88	1.38	74	17
Barmer	14.26	3.50	30.66	49.67	1.31	158	92
Jalore	15.46	21.64	33.27	28.77	0.43	179	172

Source: Rajasthan Agricultural Competitiveness Project 2012, Government of Rajasthan, Department of Agriculture.

Table 3
Irrigation by source in the Western Dry Region.

District	Percentage of area irrigated by		
	Canal	Wells and tube wells	Others
Barmer	1.20	98.72	0.07
Bikaner	54.42	45.58	0.00
Churu	1.64	98.36	0.00
Jaisalmer	67.27	32.73	0.01
Jalore	10.88	88.81	0.31
Jhunjhunu	0.00	100.00	0.00
Jodhpur	0.00	99.94	0.06
Nagaur	0.00	100.00	0.00
Sikar	0.00	100.00	0.00

Source: Rajasthan Agricultural Statistics at a glance 2011–12.

are also characterised by a livestock density that is even higher than population density (Table 2). The composition of livestock has also seen a change over the years in this region with the cattle and buffalo population being replaced by small ruminants. This is mainly because of low fodder requirement of the latter as compared to the former.

Another important feature of this region which is also one of the drivers of desertification is the source of irrigation. In most of the districts of this region more than 80 percent of the irrigation and in some districts even 100 percent of the irrigation is done by wells and tube wells (Table 3). This has important implication from the view point of desertification and sustainable agricultural practices considering the already low levels of ground water in the desert regions.

1.3. Desertification in Thar: a historical perspective

Prior to independence, the Jagirdari system of land tenure prevailed in Thar region. Land tenure was based on a system in which the king assigned land estates to sovereign intermediaries (the Jagirdars) in exchange for military services and the payment of tribute. These intermediaries in turn leased the land to sharecroppers who had to pay a levy (Jodha, 1985). The farmers were allowed to use the common resources such as forests, pastures and common water sources to feed their livestock. However, cutting of trees was prohibited and the act was subject to severe penalties. Customary laws and rules governed the use of common resources. According to (Jodha, 1985), the resource conservation that emerged under this system was a result of an exploitative mechanism. Prior to the introduction of land reforms, the feudal landlords were the custodians of all the village lands. Though the common property resources were owned by the landlords, the villagers had access to them on payment of certain charges. Through levies and penalties on the use of common property resources, the landlords exploited the peasants. Traditional natural resource management in Rajasthan is characterized by community managed lands, consisting of Agors which are areas that serve as catchments for water bodies; Gouchars that serve as community grazing lands; and Orans that serve as community forests. The Orans are regulated by community rules which have strong regulations against tree cutting. Grasses may be grazed but not cut and lopping of tree leaves is generally prohibited. It is therefore the act of cutting itself which is restricted rather than the use or extraction of any particular resource (Robbins, 1998). The development policies of the post independence era transformed the local landscape. The jagirdari system was abolished in the ensuing agrarian reforms. Cultivated lands, as well as a significant proportion of common land and pastures, were privatized in order to be redistributed to local peasants (Gagné, 2013). The green revolution in late 1960's introduced farmers to new farming technologies. Government policies in favour of green revolution encouraged farmers to increase their livestock (Robbins, 2001), increase cropped area by cutting down trees and abandon traditional agricultural techniques in favour of more lucrative but input intensive techniques. This profit driven agriculture led to an increase in mechanization of agriculture (Jodha, 1974), introduction of hybrid seeds and use of chemical fertilizers (Bandyopadhyay, 1987), and an increased use of tubewells as a source of irrigation (Birkenholtz, 2009). These newly adopted farming practices in this region have caused soil erosion, deforestation and depletion of natural resources for increasing farming acreage and depletion of ground water levels due to increasing number of tubewells. Field experiments conducted by CAZRI (Central Arid Zone Research Institute, Jodhpur) reported that during a dust-storm, the tractor-ploughed sandy plains lost more than 3000 tonnes of soil per hectare while the sandy plains with 10–12 percent of vegetation cover (desert scrub) suffered almost negligible erosion (Dhir, 1987; Dhir et al., 1992). Together with recent climatic changes, these pressures combine to degrade and destroy the fragile desert ecosystems (WWF, 2014).

1.4. Desertification and climate

The Thar desert is characterized by low and erratic rainfall, low humidity, high solar radiations, strong winds and sparse vegetation. Thar desert lies in the westernmost part of India and hence the rainfall received from the summer monsoon current is almost negligible in this region. The Thar gets its monsoon from the Bay of Bengal current. In the western Rajasthan (Thar region), the average annual rainfall ranges from less than 100 mm in north-western part of Jaisalmer (lowest in the state) to over 400 mm in Sikar and Jhunjhunu districts and along the western periphery of the Aravali range. The rainfall trend during the last 100 years revealed that the summer monsoon rainfall, which contributes more than 85% of the total annual rainfall in the region, has increased marginally (<10%) in the southern and eastern parts of Thar Desert, but has already declined by 10-15% in its north-western part (Poonia and Rao, 2013). Some studies by Central Arid Zone Research Institute (CAZRI) do show a decline in wind speed and reduced number of dust storm days in the region. The studies of Jodhpur region showed that there was no alarming change in rainfall and air temperature but the increase in human population (by 400%) and livestock population (by 127%) during the twentieth century resulted in a major shift in land use pattern and put tremendous pressure on surface and ground water resources (Rao, 1996; Rao and Miyazaki, 1997). Desertification and land degradation may intensify due to increased human activity, over grazing and loss of vegetation cover.

1.5. Desertification and livelihood

Prior to the green revolution and availability of irrigation facilities in the desert, the livelihood system was semi pastoral. During the summer season, in the years with good rainfall, pearl millet, sesamum and pulses like moth and moong were grown. With the coming of Indira Gandhi Canal, irrigation facilities increased and Thar witnessed a replacement of the conventional Kharif crops with clusterbean, fodder, groundnut and cotton. In the winter season, wheat, mustard, chickpean and berseem (rabi fodder) are the main crops. Animal husbandry is still an important and integral part of the livelihoods in Thar, however, the composition of livestock population has shifted in favour of small ruminants like goats and sheep. Migration of small animals is traditional practice and also a major coping mechanism against spatial variation in rainfall. Migration takes place to regions far off from the homestead. The driving force behind this kind of migration is acute shortage of fodder. The Thar probably is the world's most densely populated desert. Grazing of livestock, mostly sheep and goats, is intensive, affecting soil fertility and destroying native vegetation. Many palatable perennial species are being replaced with inedible annual species, thus changing the vegetation composition and the ecosystem dynamics.

Migration is another important livelihood strategy amongst the rural poor in this region. Migration is almost exclusively a male phenomenon in Rajasthan. Historically, women in this region have had minimal rights. Women's participation in community based activities and in decision making is extremely limited. This region has an extremely low female literacy rate with an average of 49 percent in the region of the study. Average under 5 mortality rate in this region is 75 per 1000 population.

2. Materials and methods

2.1. Direction of change in land use pattern

Several methods have been developed for forecasting land use change (Tanga et al., 2005; Yin et al., 2007). The simplest types of models for forecasting land use change are Markovian models such as Markov chain models, which tend to treat land use change as a stochastic process (Iacono and David, 2009). Markov chain models are essentially projection models that describe the probabilistic movements of an individual in a system comprised of discrete states. When applied to land use and many other applications, Markov chains often specify both time and a finite set of states as discrete values. Transitions between the states of the system are recorded in the form of a transition matrix that records the probability of moving from one state to another.

The change in the directions of land use pattern was analyzed using the first order Markov chain approach. Central to Markov chain analysis is the estimation of the transitional probability matrix P. Element P_{ij} is the probability of transition from state i at time t to state j at time t + 1. Elements of P are non-negative and each row sums to 1. The elements P_{ij} of the matrix P indicates the probability that land use will switch from ith use to jth use with the passage of time. The diagonal elements of the matrix measure the probability that the share of land use will be retained.

In the context of the current application, eight major land uses were considered. The average share of land to a particular use was considered to be a random variable which depends only on the past shares to that land use, which can be denoted algebraically as

$$E_{it} = \sum_{i=1}^{r} E_{it-1} - P_{ij} + e_{jt} \quad (1)$$

where E_{it} = share of land use from ith to jth use during the year t; E_{it-1} = share of land use from ith to jth use during the period $t-1$; P_{ij} = probability that the shares will shift from ith use to jth use; e_{jt} = the error term which is statistically independent of E_{it-1}; t = number of years considered for the analysis; r = number of land uses considered.

The transitional probabilities P_{ij} which can be arranged in a (c × r) matrix, have the following properties:

$$0 \le P_{ij} \le 1 = 1, \text{foralli}$$

There are several approaches to estimate the transitional probabilities of the Markov chain model such as unweighted restricted least squares, weighted restricted least squares, Bayesian maximum likelihood, unrestricted least squares. In the present study, minimum absolute deviations (MAD) estimation procedure was employed to estimate the transitional probabilities which minimize the sum of absolute deviations. For this purpose district wise land use data from 2001 to 2002 to 2010–11 was taken. The conventional linear programming technique was used, as this satisfies the properties of transitional probabilities of non-negativity restrictions and row sum constraints in estimation (Varghese, 2011). Linear programming formulation is stated as

$$\text{MinOP}* + \text{Ie}$$

subject to,

$$\text{XP}* + V = Y$$

$$\text{GP}* = 1$$

Table 4
Changes in direction of land under forest cover in the nine districts of Western Dry Region of Rajasthan.

Districts	Forest area	Area under non-agricultural uses	Barren uncultivated land	Permanent pastures & other grazing land	Land under tree crops & groves	Culturable waste land	Total fallow lands	Net sown area
Bikaner	**0.8044**	0.0000	0.0000	0.0049	0.0000	0.1907	0.0000	0.0000
Churu	**0.0000**	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jalore	**0.6220**	0.1603	0.0000	0.2177	0.0000	0.0000	0.0000	0.0000
Jaisalmer	**0.3503**	0.5948	0.0000	0.0549	0.0000	0.0000	0.0000	0.0000
Jodhpur	**1.0000**	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nagaur	**0.2713**	0.2755	0.0000	0.0000	0.0000	0.0000	0.0000	0.4531
Jhunjunu	**0.0000**	0.0061	0.0000	0.0000	0.0008	0.0500	0.9431	0.0000
Sikar	**0.0000**	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
Barmer	**0.2427**	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.7573

Table 5
Changes in direction of barren and uncultivable land in the nine districts of Western Dry Region of Rajasthan.

Districts	Forest area	Area under non-agricultural uses	Barren uncultivated land	Permanent pastures & other grazing land	Land under tree crops & groves	Culturable waste land	Total fallow lands	Net sown area
Bikaner	0.0000	0.0000	**0.9606**	0.0093	0.0000	0.0000	0.0000	0.0301
Churu	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	0.0000	1.0000
Jalore	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	1.0000	0.0000
Jaisalmer	0.0000	0.0000	**0.2170**	0.0000	0.0000	0.4211	0.1697	0.1921
Jodhpur	0.0000	0.0000	**0.5766**	0.0000	0.0000	0.0041	0.4193	0.0000
Nagaur	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	0.0000	1.0000
Jhunjunu	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	0.0000	1.0000
Sikar	0.0831	0.1638	**0.7531**	0.0000	0.0000	0.0000	0.0000	0.0000
Barmer	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.6537	0.3463	0.0000

$$P* \geq 0$$

where O is the vector of zeroes; P^* is the vector in which probability P_{ij} are arranged; I is an apparently dimensioned vector of area; e is a vector of absolute error (1 U 1); Y is the vector of area under each land use; X is the block diagonal matrix of lagged values of Y; V is the vector of errors; G is the grouping matrix to add the row elements of P arranged in P^* to unity.

2.2. Development indicators

Development is a multidimensional process and its impact cannot be fully captured by a single indicator. A number of indicators when analyzed individually do not provide an integrated and easily comprehensible picture of reality. Hence, there is a need for building up of a composite index of development based on optimum combination of all the indicators. Composite indices of development and desertification have been obtained for all the nine districts by using the data for the year 2011–12 on the following developmental indicators.

2.2.1. Development indicators

1. Decadal growth rate of population
2. Decadal growth rate of population
3. Percent rural population
4. Percent literacy
5. Percent female literacy
6. Percent households with access to electricity
7. Percent households with access to clean drinking water
8. Crude birth rate/natality
9. Infant death rate/ mortality
10. Under five death rate/ mortality
11. Sex ratio
12. Work participation
13. Per capita net district domestic product

2.2.2. Drivers of desertification

1. Percent forest area
2. Percent population employed in primary sector
3. Cropping intensity
4. Percent net irrigated area
5. Percent irrigation by well
6. Tractor density
7. Livestock density

In the study, the composite index developed by (Narain et al., 2009) was used. The values of the variables are not quite suitable for combined analysis. Hence, the variables are transformed into z scores for the combined analysis. Then the indices are calculated using the formula

$$D_i = \bar{C} + 3S_i$$

where $\bar{C}$ = mean of C_i; S_i = standard deviation of C_i.

$$C_i = \sum_{j=i}^{k} \left(\frac{R_{ij}}{(CV)_j} \right)^{\frac{1}{2}}$$

Where $R_{ij} = (Z_{ij} - Z_{oj})^2$; Z_{ij} = Z scores of each indicator; Z_{oj} = best value of each indicator; CV = coefficient of variation.

The best value (Z_{oj}) is taken as the minimum standardized value or Z score for unfavourable indicators (e.g. infant mortality) which have a negative direction of impact and maximum standardized value or Z score for favourable indicators (e.g. literacy) which have a positive direction of impact.

In order to find out the correlation between development and drivers of desertification, Spearman's rank correlation coefficient was worked out.

$$r = 1 - \frac{6\Sigma d^2}{n\left(n^2 - 1\right)}$$

Where r = Spearman's rank correlation coefficient; d = difference between ranks; n = number of observations.

Table 6
Changes in direction of permanent pastures in the nine districts of Western Dry Region of Rajasthan.

	Forest area	Area under non-agricultural uses	Barren uncultivated land	Permanent pastures & other grazing land	Land under tree crops & groves	Culturable waste land	Total fallow lands	Net area sown
Bikaner	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	1.0000
Churu	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0000	0.0000	1.0000
Jalore	0.0000	0.0974	0.0000	**0.0000**	0.0000	0.0000	0.0000	0.9026
Jaisalmer	0.0006	0.3220	0.0000	**0.3120**	0.0000	0.3528	0.0126	0.0000
Jodhpur	0.0000	0.0000	0.0000	**1.0000**	0.0000	0.0000	0.0000	0.0000
Nagaur	0.1703	0.2950	0.0000	**0.1163**	0.0000	0.0734	0.0000	0.3449
Jhunjunu	0.0000	0.0000	0.0000	**0.6226**	0.0000	0.0000	0.0000	0.3774
Sikar	0.0000	0.0000	0.0000	**0.3434**	0.0000	0.0000	0.6566	0.0000
Barmer	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0000	1.0000	0.0000

3. Results and discussion

3.1. Desertification and changing land use patterns

Knowledge about changing land use pattern in all the nine districts is imperative to understand and analyse the desertification process in Western Dry Region of Rajasthan. One of the first casualties of desertification is natural vegetation. Degradation of natural vegetation is also one of the major causes of desertification. In Table 4, the numbers in bold show the probability of retention of forest area in the nine districts of the Western Dry Region of Rajasthan. It shows a particularly alarming situation in Churu, Jhunjunu and Sikar where the probability of retention of forest land is zero. While in Churu, the probability is that all of the land under forest will be diverted to non agricultural uses like roads, buildings etc., in Jhunjunu and Sikar, most of the land will probably be diverted to agricultural cultivation. The districts that come under the Western Dry Region of Rajasthan are already way behind the optimum level (33.33%) of forest cover. Furthermore, among the nine districts, Jhunjunu and Sikar have the highest percent of forest cover, around 7 and 8 percent respectively. Besides, wind erosion of soils is a common problem in this region specially for agricultural fields which are ploughed during high winds of summer months and the land is stripped off its protective cover of vegetation. This problem is aggravated by deforestation as the natural shielding offered by trees cause sand dunes to shift (Jodha, 1997). If these districts tend to divert their already low forest area to other uses, it may have serious implications in terms of increasing desertification and increasing stress on the already stressed resources.

Barren and uncultivated land includes land under hilly terrains. Vegetation especially trees and shrubs play an essential role in protecting the soil, because their long life and capacity to develop powerful root systems assure protection against soil erosion. Their disappearance can considerably increase the vulnerability of the land to turn into a wasteland. Any shift away from this use should be considered as a positive sign as it helps in expanding the vegetative cover in the otherwise barren and unused land. In Churu, Jalore, Nagaur, Jhunjunu and Barmer the probability of retention of land under this use is nil. In Churu, Nagaur and Jhunjunu the shift is away from barren and uncultivated land towards net sown area (Table 5). This also shows the expansion and intensification of cultivated land to meet the increased demand for food.

Land degradation is linked with overgrazing of fragile soils (UNEP, 2007). Transformation of rangelands and silvi-pastoral dryland systems to croplands increases the risk of desertification due to increased pressure on the remaining rangelands or to the use of unsustainable cultivation practices (Millennium Ecosystem Assessment 2005). The probability of retention of land under permanent pastures has been zero in four out of nine districts (Bikaner, Churu, Jalore and Barmer) as shown in Table 6. This would be an alarming trend considering the importance of livestock in the livelihoods of the people of Rajasthan.

Culturable waste lands include land available for cultivation, whether not taken up for cultivation or taken up for cultivation once but not cultivated during the current year and the last five years or more in succession for one or the other reason. Such lands may be either fallow or covered with shrubs and jungles which are not put to any use. Wastelands can result from inherent/imposed disabilities such as by location, environment, chemical and physical properties of the soil or financial or management constraints. Thus, land under this category is vulnerable for severe degradation (Iyengar, 2003). Any deviation away from the culturable waste land would be a positive indication. In Churu and Nagaur, there is no probability of retention of culturable waste lands which have shown high probability of being diverted to agricultural use (Table 7). This also indicates increased practice of intensive agriculture in these two districts. Bikaner and Jaisalmer being located in the arid western plain and occupying maximum area of the Thar desert, show high probability of retention of land under culturable waste.

Churu, Nagaur, Sikar, Jhunjunu and Jalore show more than 70 percent retention of land under net sown area (Table 8). These are the agriculture intensive districts of the Western Dry Region. Notably, there has not been much shift in the land use away from the net sown area in the Arid Western Plain as well. It is also noteworthy that the decadal growth of population is very high in the districts that occupy major part of the Thar Desert. This would lead to growing demand for food and in turn exert pressure for

Table 7
Changes in direction of land under culturable wastes in the nine districts of Western Dry Region of Rajasthan.

	Forest	Area under non-agricultural uses	Barren uncultivated land	Permanent pastures & other grazing land	Land under tree crops & groves	Culturable waste land	Total fallow lands	Net area sown
Bikaner	0.0126	0.0197	0.0000	0.0178	0.0000	**0.7241**	0.0000	0.2259
Churu	0.0122	0.0000	0.0000	0.0000	0.0000	**0.0000**	0.9878	0.0000
Jalore	0.0000	0.0000	0.0000	0.0000	0.0000	**0.5009**	0.0000	0.4991
Jaisalmer	0.0011	0.0000	0.0898	0.0211	0.0000	**0.8880**	0.0000	0.0000
Jodhpur	0.0000	0.0477	0.0328	0.0000	0.0000	**0.4951**	0.0000	0.4244
Nagaur	0.0022	0.0000	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.9978
Jhunjunu	0.0000	0.2938	0.0000	0.0000	0.0000	**0.7062**	0.0000	0.0000
Sikar	0.0906	0.0000	0.0000	0.0000	0.0000	**0.1541**	0.0000	0.7553
Barmer	0.0000	0.0000	0.0000	0.0000	0.0000	**0.3472**	0.6528	0.0000

Table 8
Changes in direction of land under net sown area in the nine districts of Western Dry Region of Rajasthan.

	Forest	Area under non-agricultural uses	Barren uncultivated land	Permanent pastures & other grazing land	Land under tree crops & groves	Culturable waste land	Total fallow lands	Net area sown
Bikaner	0.0028	0.0039	0.0000	0.0206	0.0000	0.1485	0.3601	**0.4642**
Churu	0.0051	0.0246	0.0005	0.0300	0.0000	0.0084	0.0874	**0.8440**
Jalore	0.0026	0.0256	0.0956	0.0487	0.0000	0.0188	0.0569	**0.7518**
Jaisalmer	0.0021	0.1176	0.0890	0.0244	0.0000	0.1410	0.1961	**0.4297**
Jodhpur	0.0000	0.0335	0.0323	0.0000	0.0000	0.0151	0.3402	**0.5790**
Nagaur	0.0008	0.0065	0.0382	0.0428	0.0001	0.0068	0.2011	**0.7038**
Jhunjunu	0.0797	0.0027	0.0328	0.0323	0.0001	0.0000	0.0123	**0.8402**
Sikar	0.0847	0.0511	0.0069	0.0434	0.0001	0.0135	0.0934	**0.7070**
Barmer	0.0108	0.0244	0.0533	0.0695	0.0000	0.0345	0.1187	**0.6888**

intensifying the agricultural activities in these districts. This in turn would lead to diverting land away from other land use patterns towards cultivation. The proximate causes of desertification are dominated by agricultural intensification. This in turn leads to over-drafting of groundwater for irrigation purposes leading to lowering of water table in these regions. This relation explains more than 80 percent irrigation by wells and tube wells in most of these districts.

3.2. Linkages between development and drivers of desertification

After having looked into the changes in the land use pattern and desertification, it would be of interest to know how development is related to desertification. A composite development index was developed taking into consideration 13 indicators for each of these districts. Similarly, a composite index was calculated using the seven indicators pertaining to the drivers of desertification. The results are shown in Table 9.

Analysis revealed that Jhunjunu, Sikar and Bikaner are the most developed districts and Jalore, Jaisalmer and Barmer, which are also incidentally the districts having maximum area under desert, are the least developed districts. Bikaner, Jaisalmer and Barmer are the districts having worst drivers of desertification indicators whereas Jodhpur, Jhunjunu and Nagaur districts are better off. Further, looking at the best three and the worst three districts for both the indices, it is possible to identify the best and the worst districts in terms of both development and drivers of desertification. Jhunjhunu district is the best having better development and lesser intense drivers of desertification. Jaisalmer and Barmer districts on the other hand have lower development and more intense drivers of desertification. Spearman's rank correlation coefficient worked out to be −0.36. This shows that there is a negative correlation between development and drivers of desertification.

Table 9
Composite indices and ranks of districts according to development indicators and drivers of desertification.

S.No.	Districts	Development		Drivers of desertification	
		CI	Rank	CI	Rank
1.	Barmer	0.76	9	0.50	3
2.	Bikaner	0.37	3	0.35	1
3.	Churu	0.39	4	0.55	4
4.	Jaisalmer	0.68	8	0.48	2
5.	Jalore	0.67	7	0.67	5
6.	Jhunjhunu	0.30	1	0.71	8
7.	Jodhpur	0.42	6	0.70	7
8.	Nagaur	0.42	5	0.75	9
9.	Sikar	0.34	2	0.68	6
Spearman's rank correlation	−0.36				

4. Policy oriented recommendations

Some policy oriented recommendations derived out of this study are

- The forest area in the Thar Desert is very low. Any shift away from forests may have serious implications on increasing desertification. There is a need for policy intervention to prevent shifting of forest area to other land uses.
- Increased shift in land use in favour of net sown area indicates increasing demand for food. To avoid pressure on land in this region which already has a fragile natural resource base, it is important that the policies focus on diverting the workforce away from land based activities.
- The pasture lands of this region have shown very low probability of retention. This can be alarming considering the size of livestock population in the region. There is need for policy intervention to protect the grazing and pasture lands.
- Jaisalmer and Barmer which have been identified as the most fragile districts in terms of both development and drivers to desertification need policy attention for better development.

5. Conclusions

There is an urgent need for people and planners to recognize desertification as a pressing problem in the Western Dry Region of Rajasthan. The large growth rate in the human population in almost all the districts covered under this region pose an ever increasing need for generating income and employment opportunities largely dependent on land based activities as the literacy rate of the rural population is remarkably low in this region. This is leading to shift in land use pattern in favour of cultivation and other agriculture based activities. The increased burden on land arising from agriculture based activities is likely to adversely affect the efforts to arrest desertification in the region. There is an urgent need for policy interventions to prevent desertification due to human activities particularly in Barmer and Jaisalmer districts of the region as they are worse off in terms of both development and various indicators that are directly related to desertification and land degradation.

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