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Impact Assessment of Diggi based Canal Water Storage and Irrigated Land Expansion on Wind Erosion Hazards in IGNP command area of Rajasthan using Geospatial Technique

P.C. Moharana[1], Manoj Parihar[1], Nimish Narayan Gautam[1], R.K. Goyal[1], N.R. Panwar[2] and Mahesh Kumar[1]

[1]*ICAR-Central Arid Zone Research Institute, Jodhpur 342 003, India*

[2]*ICAR-Central Arid Zone Research Institute, Regional Research Station, Bikaner 334 004, India*

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Abstract: Wind erosion is the most significant process of desertification in hot arid region of Rajasthan, that is continuing to influence the livelihood of desert inhabitants in several ways. The IGNP canal water has brought a paradigm shift in wind erosion problem impacting the desert ecology and agriculture. However, availability of canal water at tail end has always remained challenging for both government and farming community. To overcome this problem and to utilize canal water more judiciously, farmers have developed intermediate water storage structures, called *diggi*. This study analyzed satellite images for the period of 2001, 2011 and 2021 and found that canal water stored in *diggi* has increased the extent of irrigated agriculture, thus vegetation cover has increased impacting reduced occurrence of aeolian or wind related hazards in IGNP canal command area of Jaisalmer district. Satellite remote sensing-based assessment has shown decreasing wind erosion/deposition. The results showed that number of *diggi* structures in Jaisalmer district has increased 10 times in 2021 compared to the year 2001 which facilitated the use of sprinklers and improved the irrigated crop cover area 4.5 times. Most of the new irrigated croplands, mainly in the tail end were diggi-centric where the irrigated area has expanded over the sandy wastelands. Desertification maps also showed decreasing extent of wind erosion affected area by 163371 ha between 2001 and 2021 in the canal command area.

Key words: Desertification; *Diggi*; Agriculture; Remote sensing; IGNP: Western Rajasthan.

***Correspondence**

P.C. Moharana
Pratap.Maharana@icar.gov.in

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Wind erosion is a pervasive environmental problem which affects 550 M ha or 4% of the global land area (Oldeman, L R, 1992, Webb *et al*., 2006) and ~5.6% area in India (Ajay et al. 2009, SAC-2021). The major wind erosion affected area in country lies in the Indian Thar Desert which covers western part of Rajasthan, northern part of Gujarat, and some parts of Punjab and Haryana. Due to greater severity and larger extent, western Rajasthan is particularly more vulnerable to wind erosion hazards as its affecting 28 million people living across 12 districts of this region. To address this problem by transforming extensive tract of sandy wasteland into green vegetative covers, IGNP (Indira Gandhi Nahar Pariyojana) project was introduced in Rajasthan during 1960s. This project was completed in two phases. Initially in Stage-I, it was restricted to SriGanganagar, Churu, Bikaner and Hanumangarh districts and the Stage-II further extended to Jaisalmer and Barmer districts. The project covers total 19.63 lakh ha of Culturable Command Area (CCA) in seven districts of western Rajasthan. Despite of large CCA of IGNP, regular and timely water availability is one of the major constraints to limit the farm productivity and profitability at tail end of the canal. Initially at nascent stage of IGNP, the irrigation supply had four turns per month but with gradual increase of the command area, the frequency of water supply is reduced to fortnightly. The beneficiaries of IGNP project receive water from canal through warabandi system which has its own limitation to provide irrigation water at suitable crop growth phase and therefore some other alternatives or interventions are required to manage this canal water in more judicious manner. However, water crisis is not a new phenomenon for this region as rainfall pattern of study period revealed that during a time span of 20 years, hot arid western region has witnessed five droughts including most severe of 2002 which had affected livelihood of 300 million people across the country (Samra, 2004; CAZRI, 2005). To address this problem, desert farmers are using their traditional knowledge since long back and developed various water harvesting and conservation structures such as *tanka*, *kund*, *nadi* (village ponds), *khadin* (a runoff harvesting system) and *baoli* for drinking and crop cultivation purpose (Narain and Khan, 2000; Moharana *et al*., 2022). Recently, farmers of IGNP command area of western Rajasthan are constructing indigenous water storage structures, called *diggi* for conserving and managing the canal water for irrigation purpose. Since, these structures are constructed on the farmer's field, they can utilize store canal water in best possible manner considering soil-plant-atmospheric condition. Farmers transfer their allotted quota of canal water in *diggi* and later pump out this water using solar or electric motor connected with sprinkler or drip irrigation system. Moreover, the concept of farm pond is already practiced as integral component of integrated farming system in other regions of country which helped farmers to achieve farm diversification and higher profitability. Here, in arid western Rajasthan, the purpose of such water storage structure is to ensure the better water supply and deal with farm water crisis.

Recently there is an upsurge noticed in the construction of number of *diggi* structures in this distant canal command area (Table 1). Satellite images of past years indicate that such improvements have further increased the scope of bringing more area under crop cultivation which is otherwise remained mostly barren or fallow during crop growing season. In addition, due to increasing water availability for agriculture purpose, new crops (isabgol and cumin) have been introduced which are having high economic value and water requirement. Such radical changes are clear indication of transformation from previous subsistence to intensive form of agriculture. During the field survey, it has been clearly noticed that *diggi* based farm pond structure provide better control over canal water and further encourage farmers to expand crop cultivation in new lands. Increasing agricultural intensification on existing crop field and adjoining sandy terrain have certainly resulted some positive impact on desertification. To ascertain these transformations, this impact assessment study has been conducted with the following objectives: 1) to quantify the spatial and temporal distribution of *diggi* structures, 2) to study the change in irrigated cropped area during study period 3) to assess the impact of *diggi* based irrigation system on agricultural expansion and wind erosion reduction.

Materials and Methods

Study area

Jaisalmer District (26°4′ and 28°23N, and 69°20′ and 72°42E) lies within the Thar Desert part in the NW India (Fig. 1.). The Thar is one of the most populated deserts in the world and in India, it is located in the extreme western part of Rajasthan where it spreads over 61% area. Jaisalmer district is dominated by desertic environment and receives an annual average rainfall of 186 mm with temperatures ranging from 2°C in the winter months to 47°C during Summer. During 2010 and 2020, the annual rainfall was 308 and 302 mm respectively

Table 1. Extent of irrigated croplands, diggi distribution and wind erosion affected area in IGNP area of Jaisalmer district

Year	Irrigated crop area	Number of *Diggi* structures	Wind erosion affected area
2001	13798 ha	395	863696 ha
2011	19631 ha	509	762116.4 ha
2021	80514 ha	4478	700325 ha

Table 2. Annual rainfall received in Jaisalmer District

Year	Annual Rainfall (mm)
2001	186.18
2011	308.17
2021	302.16

(Table 2). Historical data on annual rainfall shows that Jaisalmer received the greatest annual rainfall of 583.1 mm long back in 1944. During 2015, the district received higher annual rainfall of 497.5 mm and more than 300 mm annual rainfall in 2020, 2021, 2022 and 2023. Thus, the district represents a dry and rainfed environment. About 20% of district area is also rocky, 74% area is sandy and 0.40% area is saline (Moharana *et al*., 2013). The sand covered areas are characterized by sandy plain and dunes of various size and shape covered with slight to medium calcareous sandy soils. This region is occupied with open grassland, scattered trees and thorny bushes and shrubs. The topography of region is characterized by extensive alluvial plain of the Pleistocene period and creeping sand dunes developed in the early Holocene period on the alluvial surface. In mid 1980s, IGNP canal was introduced in this region with objective to transform the desert wasteland to productive green cover (cropland) area and reduce the creeping sand movement. Recently, this desert region with extensive sandy plains is witnessing tremendous agricultural transformation mainly along the IGNP canal area (Table 3).

Mapping of diggi structures

Diggi is an indigenous micro-hydrological structure having a defined geometry, has become quite popular strategy for water storage at field scale. Such structures are man-made and constructed in crop field where farmers transfer the nearby canal water in to these ponds using solar, electricity or diesel-based pumps. Farmers reported that canal water as per allocation reached them at an interval of 17 days, thus water in diggi can be retained for maximum of 15 days before the next delivery arrives. The *diggi* structures were identified and delineated from satellite

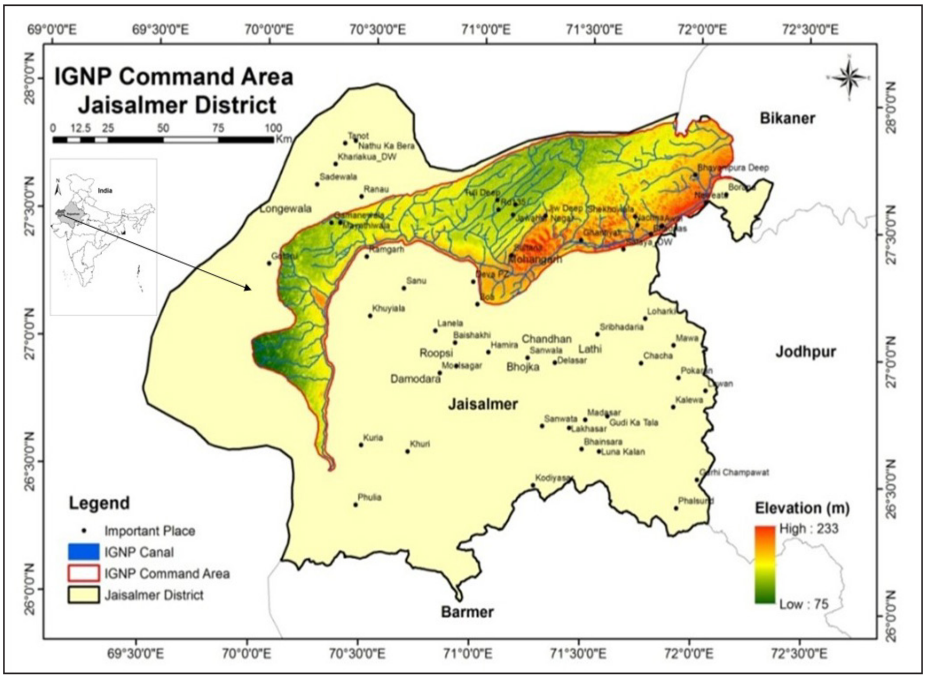

Fig. 1. IGNP command area in Jaisalmer district, and its Digital Elevation Model.

Fig. 2. Types of Diggi structures; Earthen type (upper two) and cemented (lower row) in IGNP command area of Jaisalmer district.

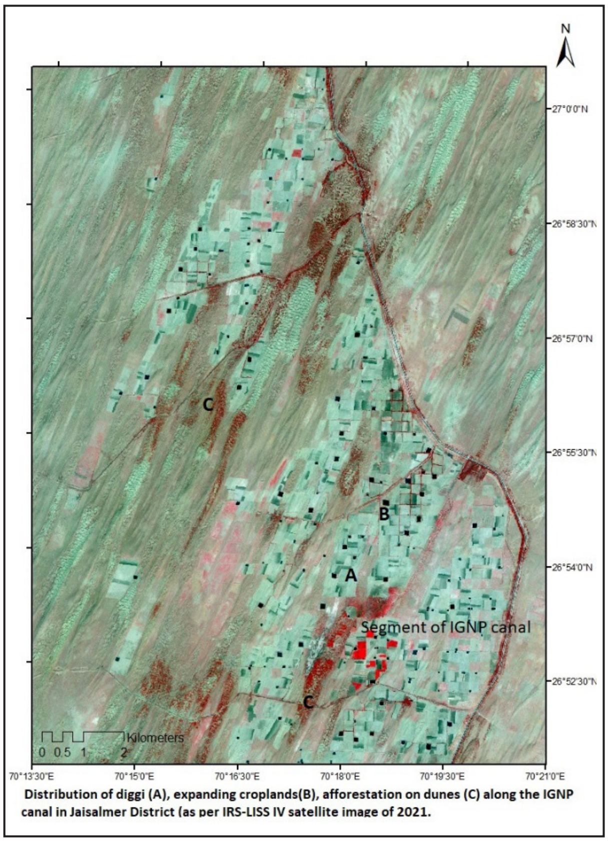

Fig. 3. FCCs of IRS-LISS IV satellite images showing sand dunes, diggi structures and croplands around IGNP canal areas of Jaisalmer district.

images of Google Earth, IRS-LISS 4 and Sentinel-2A of the years 2001, 2011 and 2021 (Table 4) and their spatial extent was mapped in geographic information system (GIS). In Jaisalmer district, diggi structures are mostly rectangular in shape (Fig. 2) and dimensions are 110 ft x 110 ft x 6 ft (deep). These micro field-water storage structures are clearly visible in the remote sensing satellite (optical) imagery which have very high spatial resolutions of 5.8 m (in IRS-LISS 4) and 10 m (in case of Sentinel-2A) and it was possible to verify their numbers from Google Earth Images (Table 4). In general, *diggi* structures *possess* three distinct features that helps in their quick identification on satellite images such as (i) size of *diggi* structures, (ii) shape (circular or rectangular), and (iii) their topological association with canals and croplands (Fig.3). Once identified, *diggi* structures were precisely mapped on the GIS platform as point features using on-screen visual techniques and digitization from false color composites (FCCs) of satellite images for the years 2001, 2011 and 2021 using ArcGIS software.

Use of digital elevation model (DEM)

For precise delineation of IGNP command area for this study, we used the Advanced

Table 3. Classification of Agricultural lands and their geographical area under various land use categories in Jaisalmer district

Category/Area (in ha)	2001	2011	2021
Culturable Waste	2657254	2424703	2076130
Current fallow	40255	78462	99801
Net Area Sown	425351	618750	798873

Spaceborne Thermal Emission and Reflection Radiometer (ASTER) for automatic steam network extraction and analysis. ASTER is Japanese multispectral imaging RS instrument onboard the Terra sensor lunched by NASA in 1999 and the data is available since February 2000 (Abrams, 2000). This data for study area was downloaded from United State Geological Survey (USGS) Earth Explorer (http://www.earthexplorer.usgs.gov).

In order to delineate the boundary of IGNP, the spatial analyst tools from Arc toolbox were used and procedures of hydrological modelling was followed. Firstly, the fill tool was employed for the DEM until all sinks within the spatial z-limit were filled up. The flow direction was combined with the filled DEM as per input and raster of flow direction of each pixel to its steepest downslope neighbor was extracted. The flow direction layer was also used as input in the flow accumulation tool that simulated flow as the accumulated weight of all pixels following into downslope pixels for extraction of flow accumulation output. Raster calculation was used for the selection of flow accumulation threshold and extraction of automatic stream network based on DEM (Tenzin, 2014; Raducan, 2018; Moharana and Kar, 2001). The study area (Fig. 1) and its DEM indicated topographical variability and drainage network, which led to GIS based automated creation of study area (IGNP command area) in Jaisalmer District.

Mapping of irrigated cropland area

Land cover maps of cropland area were prepared for the years 2001, 2011 and 2021 using satellite imageries of Landsat 5(TM) for rabi season period. For extraction of cropland area from satellite imageries of mentioned period, Normalized Difference Vegetation Index (NDVI) based geospatial technique was used which is popularly utilized to assess the vegetation cover and vegetation health (Kumar *et al*., 2022). It is performed based on visible range RED (R) and NEAR INFRA RED (NIR) reflectance and normalized that difference by the sum of reflectance. From the equation-1, it is calculated as

$$NDVI=(NIR-RED) / (NIR+RED)$$

where RED is visible red reflectance, and NIR is near infrared reflectance. The wavelength range of NIR band is (750-1300 nm) and red band is (600-700 nm). A Rule based classification technique was used for classification of vegetation cover and non-vegetation cover values based on minimum value of vegetation cover (Singh *et al*., 2021). A threshold NDVI value of 0.3 was used to discriminate the irrigated crop area from other kind of vegetation.

Mapping of wind erosion affected area

In order to locate the spatial distribution of wind erosion affected area, we used desertification maps of Jaisalmer district which was available for the year of 2003, 2010 and 2020 at various scales from 1:250000 to 1:50,000 scale. Such maps have been prepared by Central Arid Zone Research Institute under various collaborative projects on Desertification and Land Degradation with Space Application Centre, ISRO, Ahmedabad. These desertification maps depict information on three levels of hierarchical classification system; Level 1 (land use/land cover), Level-2 (Degradation Processes) and Level-3 indicate severity of problem. For example, a unit Ee2

Table 4. Data used in the study

Thematic layer	Name of satellite /sensor	Spatial resolution	Date of acquisition
Irrigated crop area	Landsat 5, TM	30.0 m	January, 2020
Diggi (small farm pond structures)	IRS-LISS-IV ESA-Sentinel-2A	5.8 m 10.0 m	January, 2020 January 2020
Digital Elevation Model	SRTM	30.0 m	

would indicate that the first letter (E) stands for Sandy/Sand dune area, the second letter 'e' represents area affected by wind erosion process and third letter '2' indicates degree of severity as moderate wind erosion/deposition. The categories of severity for wind erosion would depend upon the spread and thickness of sand deposition and also on the per cent cover by vegetation.

Results and Discussion

Changes on the occurrences of Diggi

The maps of spatial distribution of *diggis* during the period of 2001, 2010 and 2021 are presented in Fig. 4(b). Mapping of *diggis* revealed that from 2001-10 and 2011-20, numbers of such water storage structures have increased by 28 and 780%, respectively. After 2010, a sudden upward trend has been noticed in the construction of *diggis* which shows the relevance and quick acceptance of such water storage structures in canal command area of Jaisalmer district. As per our data of 2021-22, highest density of *diggi* was observed in villages such as Buili (1476), Bahla (929), Mohangarh (599) and Sultana (561) mostly situated at upper and middle region of CCA in Jaisalmer district while in the distant or lower region of CCA, *diggis* number are relatively less. However, total counts in this region during the study period i.e. 2001 to 2020 are increased tremendously by 11.34 times. These micro farm ponds on an average can store 20-25 lakh liter of canal water, justifying it as crucial for efficient and productive utilization of water in desert ecosystem. To support this intervention, government is also providing subsidy to the farming community of this region under various schemes. For cost reduction, instead of cement blocks, high-density polyethylene (HDPE) sheets of 300 to 500-micron thickness are also being used in case of non-subsidized condition. In order to make this intervention more viable and sustainable, farmers are using the benefits of solar energy by connecting photo voltaic solar panels with electric pump to run associated drip or sprinkler-based irrigation system.

Changes in crop cover area

The extent of irrigated cropland area for the period of 2001, 2010 and 2021 is presented in Table 1 and corresponding maps are given in Fig. 4(a). The data showed that during initial 10 years period i.e. 2001 to 2011, irrigated cropped area increased by ~42% (13798 to 19631 ha) while in the next decade (2011-2021) this increment was more than 300% (19631 to 80514 ha). The total change in cropping area was observed around 6 times or ~484% from 2001 to 2021. The sudden positive growth and expansion in irrigated cropland areas and *diggi* structures in the CCA of Jaisalmer district during the period of 2011 to 2021 clearly indicated that assured water or irrigation facility has primarily driven the expansion of cropland area in this region as vegetation cover is highly correlated with water balance and regional climate regulation (Foley *et al*., 2007). Over the period, significant change in net primary productivity (1 to 78%) was observed in CCA of this region which may be due to a proportionate increase in large area under irrigation (Sur and Chauhan, 2019). With increasing canal water availability some remarkable changes or transformation such as land levelling and crop cultivation on low to medium height of sand dunes, mono-cropping to double cropping, shifting from rainfed to irrigated system have been observed in arid western Rajasthan (Moharana *et al*., 2022). Other than the cropland area, a significant change was noticed in shift from traditional crops to more ruminative and water intensive crops like cumin and isabgol during field survey. Crop statistics data of Jaisalmer district also explains that the area of important irrigated *rabi* crops like mustard, cumin and gram increased by ~66, 432 and 2616%, respectively during the period of last 20 years. Similar to crop area, production and productivity of irrigated crops are also moving upwardly in this extreme hot arid region which demonstrates the significance of assured irrigation facility to encourage the farmers for adopting improved crop varieties, fertilizers and other farm inputs. Analysis of Agricultural land use statistics of Jaisalmer District (Table 2), between 2001 and 2020, net sown area has increased by 7.92% (+204301 ha), while culturable wastelands have decreased by 13.15% (- 505086 ha) area. Current fallow also increased during the same period by merely 1.69% area. This data indicates how the region is witnessing a faster agricultural land transformations over the period of 20 years. Studies revealed that reliable water delivery due to *diggi* based farm practices provided 68% higher net return per hectare than crop cultivation without *diggi* which can further be explained due to increased cropping intensity, input application and crop productivity (Amarasinghe et al., 2008). In another study, such on-farm water storage structures are found significant with a benefit–cost ratio of 2.2 and internal rate of return of 35% for farms with moderate to high irrigable land (>5 ha). However, it is further cautioned that the benefits may vary significantly along the distributary due to inequitable distribution of water between head and tail reaches (Amarasinghe *et al*., 2012**).** In addition to land transformation, continuous increment in cropland or vegetation cover has strong impact on regional, economic and social upliftment of local inhabitant which is prerequisite for sustainable development of this region (Turner *et al*., 1993). From above discussion it is clear that diggi structures have great potential to meet the crop irrigation requirement timely and its increasing trend is directly linked with farm productivity and profitability.

Changes in extent of wind erosion affected area

In general, wind erosion takes place involving two geomorphic processes, such as deflation and abrasion (Goudie, 2004). In western Rajasthan where soils are mainly sandy and where farmers expose the soil by ploughing, most of the soil erosion takes place due to wind deflation process. In the process, the surface is covered with a number of geomorphic features like sand dunes, sandy plain, sand sheet. The extent of wind erosion is indicated and delineated on the basis of occurrences of these features which are otherwise called as physical indicators of wind erosion.

The maps showing extent of wind erosion for the period of 2003, 2010 and 2020 are presented in Fig. 4(c). Data suggested ~19% reduction in wind erosion extent during the time frame of 2001 to 2021 which accounts 163371 ha area. During the mentioned period, net sown area increased by ~88% while 21% reduction has been noticed in the culturable wasteland of Jaisalmer district which are mainly sand dune or sandy plain areas. Considering the extent of culturable wastelands in 55% area, there is scope for more transformation of this region in agriculture. At present, diggi structures look to help such transformations. In present study, data has clearly indicated that cultivated area has increased around diggi structures of individual farmers (Fig. 3.) and such practices can be considered as one of the means of SLM (Sustainable Land Management) as per UNCCD's LDN targets. This study indicates how benefits of such interventions has started signs of reverse the desertification in Jaisalmer district. Similar impacts of such water storage structures have been observed in CCA of Bikaner district and it is reported that during study period (2004-18) large areas under sand dunes, scrublands and fallow lands have been converted to agriculture and plantations/ shelterbelts (Moharana *et al*., 2022).

This study found extensive area from Ramgarh to Mohangarh town are now under irrigated cropping in place of earlier natural grasslands. Such land transformations may have serious implication in terms of increasing desertification (Varghese and Singh, 2016). Wind erosion of soils is a common problem in this region especially for agricultural fields which are ploughed during high winds of summer months and the land is stripped off its protective cover of vegetation. In this farthest district from the canal's source, water remains available only in winter season while subsequent summer period either remain fallow or else farmers practiced rainfed cropping system Irrigated cropping meant that the land will be cleared of natural tree, shrubs and grass cover, the sandy undulations is flattened and deep ploughing by tractor is practiced continuously. This has made a large area under sandy soil vulnerable to wind erosion in subsequent fallow/kharif season. Thus, the collapse of an irrigated farming system may pose a highest threat of wind erosion and atmospheric dust load (Kar, 2011). However further detail studies are needed using long-term real time databased monitoring of wind erosion and vulnerability risk assessment for better understanding and comprehensive overview on this aspect.

Conclusions

Effective means of water storage and their management is one of the key strategies for improving farm productivity, profitability and combating desertification in arid ecosystem. In this regard, indigenous micro-hydrological structures called *diggi* has appeared as a new and proven intervention by farmers of arid

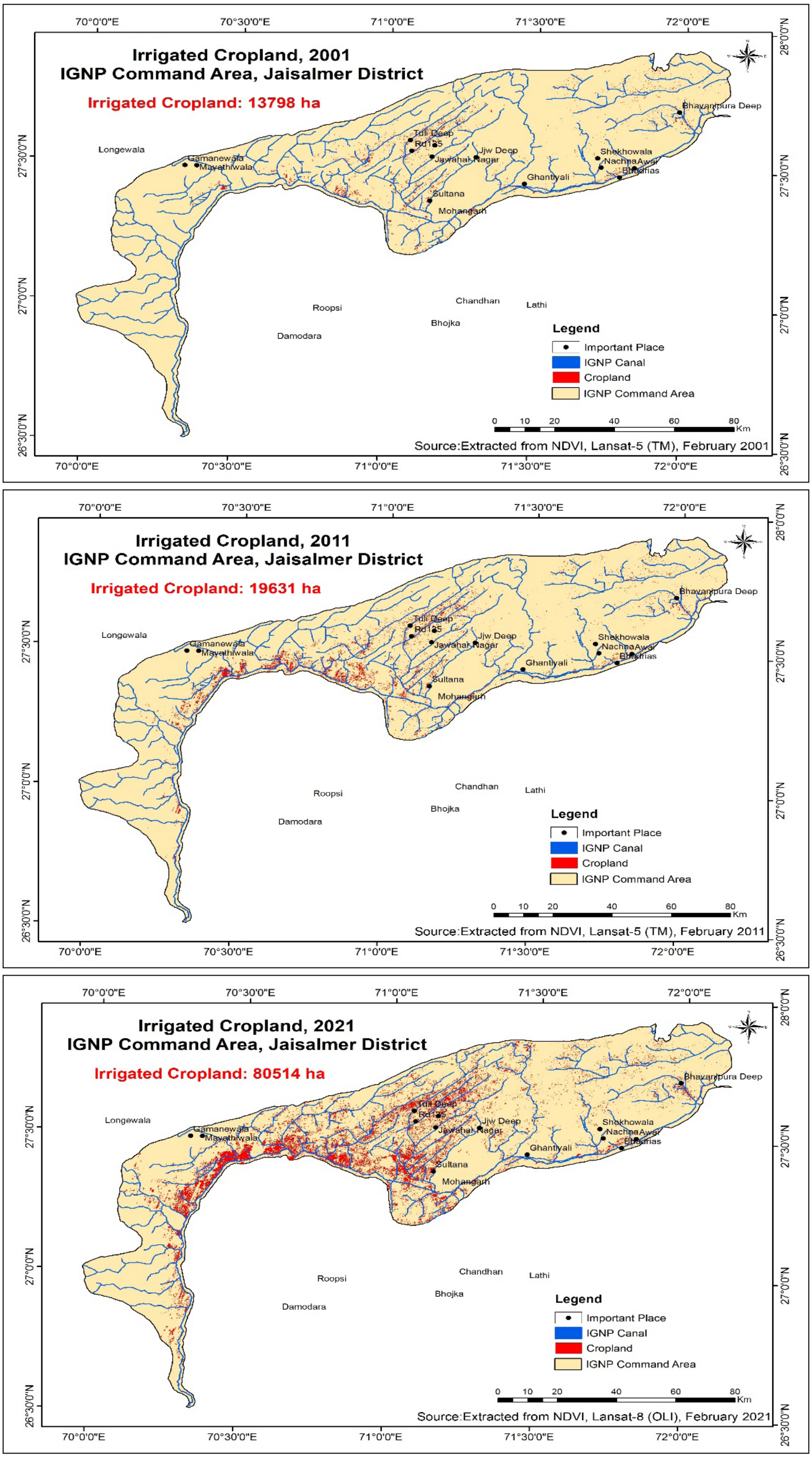

Fig. 4(a). Temporal extent of irrigated croplands in IGNP command area of Jaisalmer.

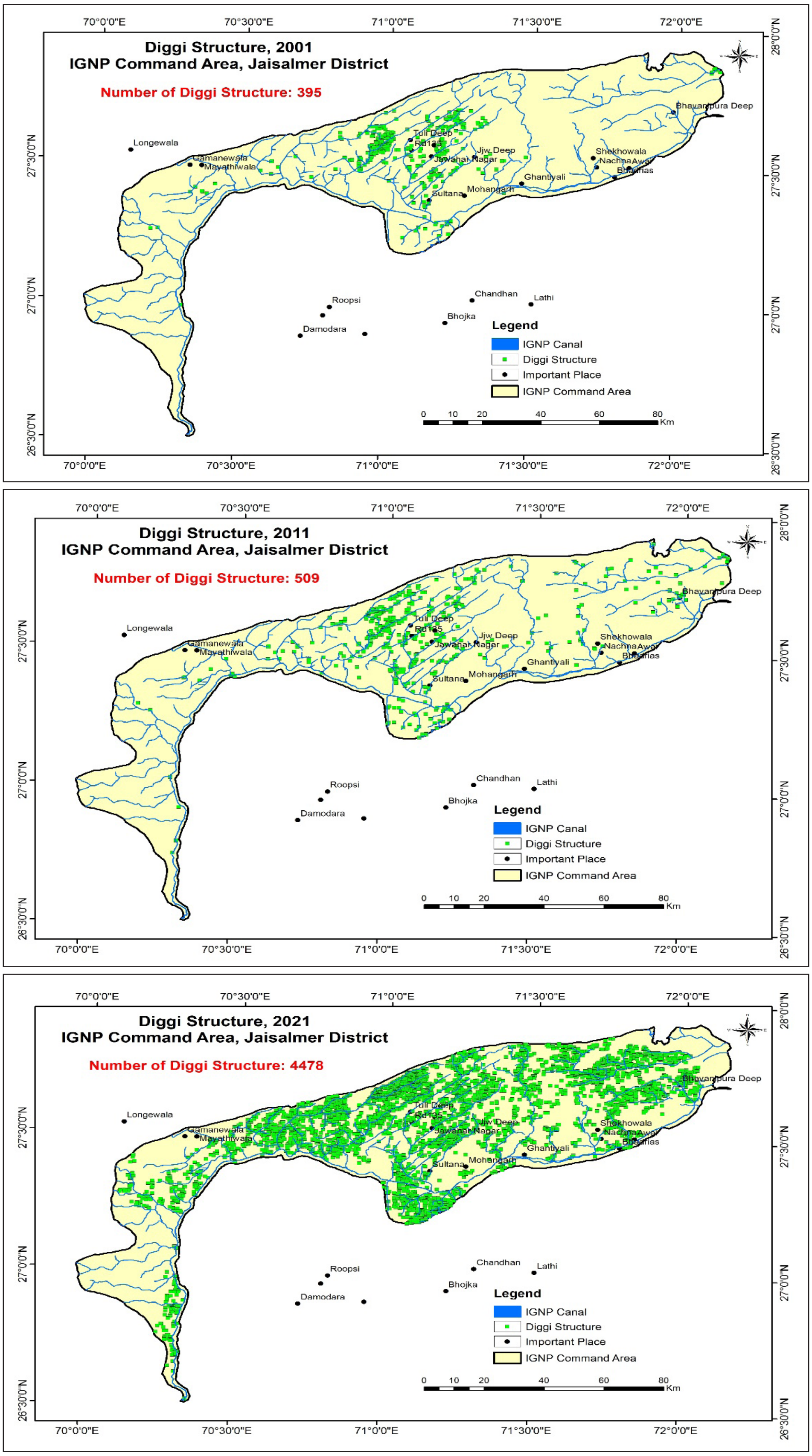

Fig. 4(b). Temporal distribution of Diggi in IGNP command area of Jaisalmer.

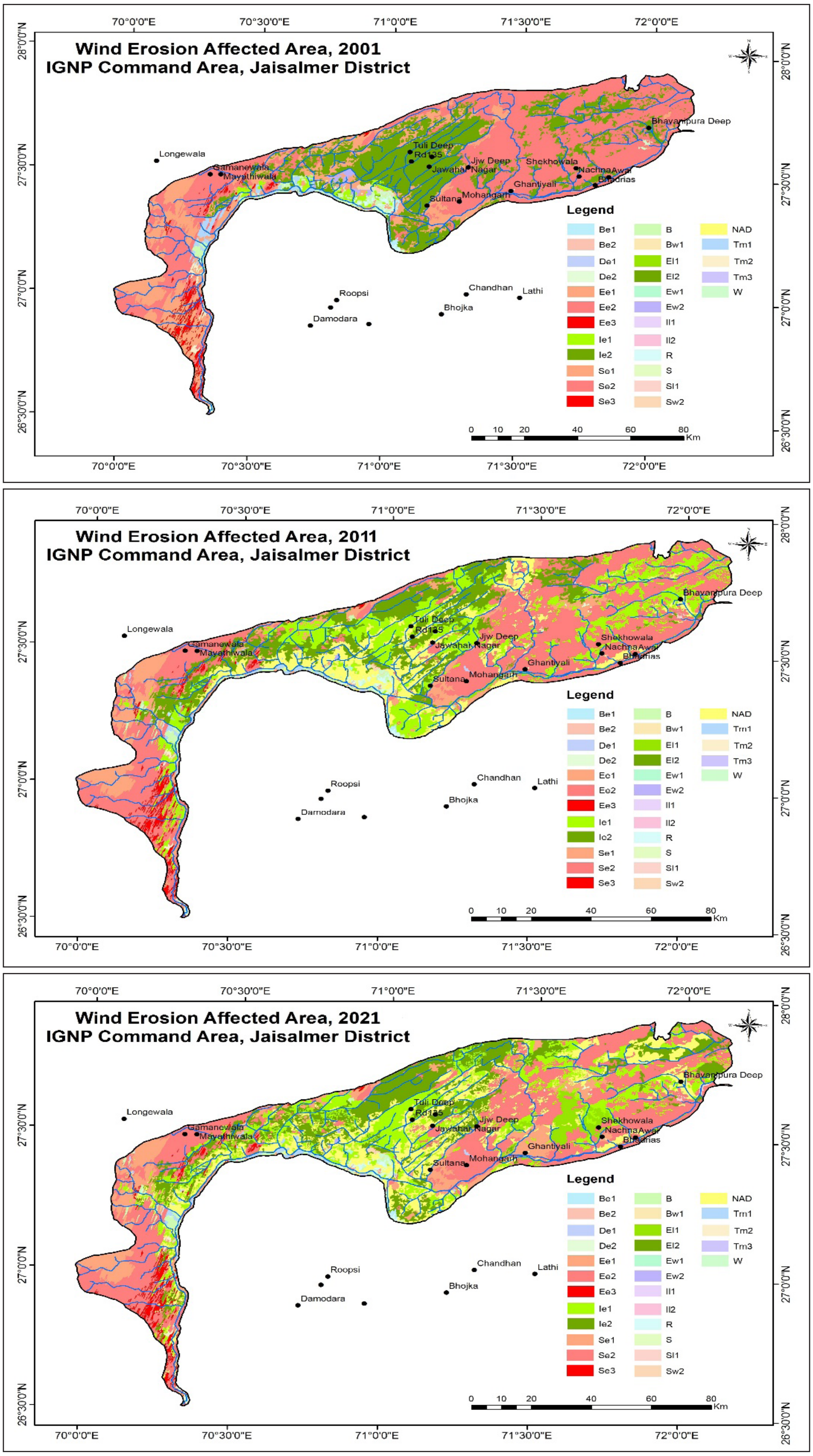

Fig. 4(c). Temporal extent of wind erosion affected area in IGNP command area of Jaisalmer.

Rajasthan for efficient utilization of water in canal command area of Jaisalmer district. Based on this assessment, it was possible to find that number of *diggi* structures increased by more than 10 times in last two decades which indicates its relative importance and acceptances by farmers in this region. Due to multiple advantages, *diggi* system was found to encourage farmers to expand more area under crop cultivation even at places in the tail end of IGNP which are drier and more filled up with sand dunes. Over the period, increased cropland area by converting sandy plains, scrubland and fallow wasteland to agriculture proved to provide a vegetation cover, thus, have managed to bring a green cover over the sandy wastelands and reverse the desertification process by wind erosion. However, study also found removal of natural grasslands for cultivating *rabi* crops during winter season followed by fallow in *kharif* expose the land surface during summer months, may cause this terrain more vulnerable to wind erosion. In addition, continuous irrigation through canal water may develop salinity risk when underground aquifers already contain saline water. To address these challenges, scientific and technological interventions must be explored to make *diggi* based indigenous water storage system more viable and sustainable from environment and farmer's perspective.

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