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GIS and RS Based Spatio-Temporal Analysis of Soil Moisture/Water Content Variation in Southern Irrigated Part of Sindh, Pakistan

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Abstract

Throughout history, earth's climate has changed like the rise in average temperature of the Earth's climate and global sea level rise leading to storms, flooding, drought and other extreme and disastrous events. Remote sensing and GIS has this potential to determine the soil moisture status over large areas and a longer span of time using satellite images and different indices like moisture stress index, soil moisture index or normalized difference water index with respect to the changing climatic conditions like temperature and precipitation. All of which, convey different information but when interpreted and analyzed appropriately can be used to determine the soil moisture status of the specified area. The study investigates the moisture stress along with moisture variability from the year 1991 to 2002 on the southern part of Pakistan, Sindh to determine the spatial and temporal changes. Resulting products basically show the spatial distribution of moisture content over the study area and also it could be really efficient to predict the moisture percentage for the areas where *in-situ* measurements are not available.

Keywords: Phycoremediation; Dairy industry; Waste water effluent; Microalage

Introduction

In this world of changing climate, it is necessary to be aware of the soil water availability and its changing trends in a particular area to maximize the crop production so that the demands of growing food could be fulfilled. In-situ measurements of the moisture content over large region is quite arduous, time taking, expensive and troublesome. Also, sometimes it is not possible to practically travel so far away in remote areas selecting suitable sampling sites over a large region and finally acquiring information about the water/moisture contents. Soil moisture is one of the important components of the Global hydrological cycle while playing an essential interaction role between land and atmosphere [1]. Soil moisture serves as a main natural water resource for vegetation as well as agriculture [1].

The rural areas of Sindh specially, are subjected to a lot of water shortage issues. These issues are having an adverse effect on agriculture and thus the living conditions of people are also getting worse. Specifically, farmers have to suffer due to the water conditions because they fail to get the official price of sugar cane. Apart from water used for agriculture, it is not even enough for the drinking purpose. Sindh is right now suffering from drought-like circumstances. The last controlling structure constructed on Indus river is Kotri barrage, built on the confluence of Hyderabad, Jamshoro and Kotri cities Kotri [2]. The barrage was built to pass a flow of 24,780 cusecs, maximum. It is a source of industrial, domestic and irrigation water supply to the Hyderabad, Badin and Tando Muhammad Khan districts [2]. Phuleli Canal runs through the periphery of Hyderabad city and provides water to Hyderabad, Tando Muhammad Khan and Badin districts which are specifically represented with a boundary in all the output maps generated in this study. The canal is non-perennial and its total length is 721.8 miles, which covers GCA of 100, 3100 acres and CCA of 920847 acres with full supply discharge of 15026 cusecs [2]. Phuleli canal's command area is about 0.93 million acres [3].

Various studies have been carried out to determine the soil moisture contents over different areas making use of different RS and GIS indices. According to water stress Index, developed by Mallin Falkenmark, Pakistan is already a country which is water stressed and eventually by 2020 it will be categorized as a country with acute water shortage [4]. In this study the indices that have been used are moisture stress index (MSI) and Normalized difference moisture index (NDMI) for determining the areas with highest and lowest moisture content along with their changes over time. Both of these indices give opposite results that further assists in counter checking the accuracy that each calculated index come up with. This study could be really helpful for large regions over a long time-span and also those which are physically and practically out of reach.

Sindh- Punjab Water Dispute

After Punjab, Sindh is considered to be Pakistan's largest province by population with total population estimation being 30 million. To meet the needs of these 30 million people, almost 1250 million gallons of water is needed. But the present situation of the Sindh province is so worst that not even half of the water is considered safe to be consumed.

Water tests from many districts of Sindh including that of Karachi have proved the water being unsafe for a healthy living. Phuleli canal which is considered one of the biggest canals of Indus river in Sindh is again contaminated to such an extent that risks the life of people residing in its command area. Those living in the downstream areas, including Tando Muhammad Khan and Badin, are facing serious health and environmental issues. There are various locations where untreated wastewater is thrown directly into the Phuleli Canal. This practice is polluting the Phuleli Canal at an alarming rate and it is clear violation of sections 11, 13, 14 and 15 of the Pakistan Environmental Protection Act, 1997 [5]. Punjab-Sindh water dispute is not a newly

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raised issue but rather it's a challenge to Pakistan since the development of irrigation system in the region. Sindh claims that Punjab, taking the advantage of its domination over the machinery of the state, diverts the water resources at the cost of Sindh. Partition of India in 1947 also partitioned this existing irrigation systems and since then many attempts have been made to resolve this inter-provincial issue between Sindh and Punjab. Both, Sindh and Punjab have economy that is agriculture based and is mainly dependent on the Indus river waters.

People of Sindh actually feel most resentful as water appointment accord does not promise a minimum environmental flow of river water through the province and eventually in the Arabian sea, keeping in view the drought like conditions in Sindh. The water appointment accord is basically an agreement regarding sharing/distribution of water of the Indus basin among all the provinces of Pakistan which is majorly based on the historical use of water by each province. It was signed into effect in 1991 but yet its anniversaries pass without any acknowledgement from the government and thus the accord failed to end the disputes of water sharing between Sindh and Punjab provinces [6].

This study also investigates the changes in the moisture/water content over past years in the southern part of Sindh so that necessary steps can be taken keeping in view the severity of the issue because this is one of the major problems that not only the province of Sindh but Pakistan has to confront today.

Materials and Methods

Study area

The study area selected is that of southern part of Sindh, Pakistan including cities like Shaikh Bhirkio, Tando Muhammad Khan, Digri, Jhuddo, Tando Bago, Badin, Kadhan, Bhegra Memon, Jati, Pangrio, Malkani Sharif, Ahmed Rajo and Golarchi. Figure 1a further represents the study area in detail. In this study, the main focus is given to the Phuleli canal and its command area.

Phuleli canal off takes from left bank of Kotri barrage providing water to the districts of Hyderabad, Tando Muhammad khan and Badin.

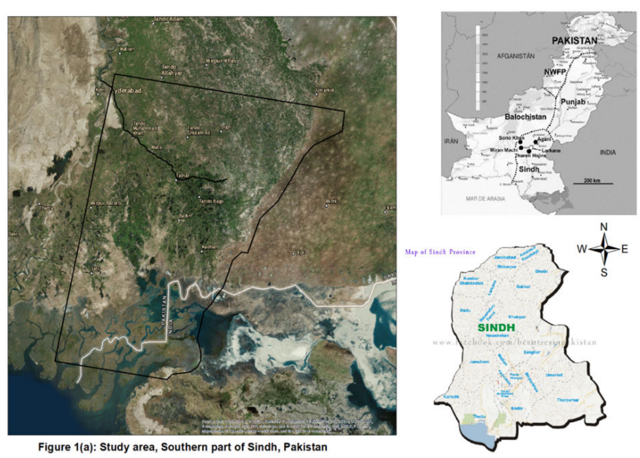

Figure 1a: The study area is represented by a boundary line.

Phuleli canal can also be seen in the figure which springs from Kotri barrage and passes through Hyderabad, Tando Muhammad Khan before ending in Badin district. Phuleli canal is one of the biggest canals of the Indus River and is the drinking and irrigation source of the three districts [7,8].

Data sources

Data used in this study is downloaded from the USGS Earth Explorer website (www.earthexplorer.usgs.gov), which is a United States Geological Survey agency of the US government. USGS is a primary source of Geographic Information System (GIS) data and the information and data is presented spatially as well as geographically. Pakistan administrative boundaries were also downloaded from DIVA-GIS which is again a free and open source Geographic Information system for mapping and analysis of the geographic data while at the same time it provides free spatial data for the whole world.

Landsat satellite data

The data of the year 1991-2002 and 2011 downloaded, was that of Landsat 4-5 TM C1 Level-1 with Center Latitude: 24°32'47.98"N and Center Longitude: 69°06'06.48" E. Thematic Mapper sensor was used because it also added mid-ranged infrared band to the data unlike Multi spectral sensor and thus includes a total of seven bands including a thermal band (i.e., band 6) with spatial resolution being 120 m for thermal band while 30 m for all other bands. While for the year 2017, the satellite image used is that of Landsat 8 OLI/TIRS C1 Level 1. It consists of nine spectral bands with spatial resolution of 15 m for band 8 and 30 m for bands 1-7 and 9, along with two thermal band (10 and 11) which are acquired at spatial resolution of 100 m but are resampled to 30 m in delivered data product. All the downloaded satellite images have Path 141 and Row 53, but the tile was further extracted accordingly to a specific area for more detailed interpretation and conclusions, also making to easier to assess the accuracy of the outcome. Table 1 represents the detailed information about the data that was downloaded including the information regarding the date and month of the acquisition of the satellite image.

Satellite	Path/Row	Date acquired
Landsat 4-5 TM C1 Level 1	151/43	4th-May-1991
		6th-May-1992
		9th-May-1993
		12th-May-1994
		15th-May-1995
		1st-May-1996
		1st-March-1997
		23rd-May-1998
		26th-May-1999
		12th-May-2000
		15th-May-2001
		6th-August-2002
		2nd-October-2011

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Landsat 8 OLI / TIRS C1 Level 1	151/43	14th-May-2018

Table 1: Landsat satellite data details.

Methodology overview

After acquiring the data, layer stacking all the Landsat images and extracting the required study area, moisture stress index (MSI) and Normalized difference water index (NDWI) were calculated using ERDAS IMAGINE 2014, the images were then imported to ArcMap 10.3.1 where the values were stretched along an appropriate color ramp for accurate visualization and analysis of the study area. The three districts, that of Hyderabad, Tando Muhammad Khan and Badin were further exported from Pakistan admin data (downloaded from DIVA-GIS). The data when overlaid, highlighted the boundaries of three districts which further assists in visualizing the changes in that part specifically. Phuleli canal was also digitized using base map in ArcMap 10.3.1. Digitization of the canal was initiated from Hyderabad and ended somewhere in Badin district. Finally, the maps were generated in ArcMap representing output values/results.

Moisture stress index

MSI is basically reflectance measurement which reflects sensitivity to the leaf water content. The results of this index are opposed to that of other water indices [9] such that higher values indicate greater moisture stress or in other words low moisture content whereas, lower values indicate lower moisture stress or greater moisture content. It is calculated using the near-infrared and mid-infrared spectral bands [7] of the Landsat images by equation (1).

MSI=Mid-Infrared/ Near-Infrared (1)

Figure 2 represents all the Moisture stress index maps, generated for the study area.

Normalized difference moisture/Water index

NDMI is again another index which shows sensitivity to water content. NDMI and NDWI are similar to each other both suitable for detecting the spatial variation of surface wetness. NDWI refers to two types of indexes, one is sensitive to water content in water bodies, whereas other is used to monitor changes in water content of leaves. Near Infrared (NIR) and Shortwave Infrared (SWI) spectral bands are used in the former and NIR and Green spectral bands are used in latter. GAO and Huang presented a modified normalized water index (NDWI) where Mid-Infrared band was used along with Near Infrared band to minimize the errors of NDWI on soil water monitoring. This modified index is also known as NDWI GAO (as proposed by GAO).

Similarly, NDMI (Normalized Difference moisture index) as proposed by Wilson and Sader also made use of the same spectral bands (NIR and MIR) for determining soil moisture. In this study also, NDMI/GAO NDWI have been used with the formula given by equation 2.

NDMI/GAO NDWI=(NIR – Mid-IR)/(NIR + Mid-IR) (2)

NDMI results varies between +1 to -1 depending on the soil moisture content. NDWI and NDMI products provide information about spatial and temporal variation of surface wetness. Generally, when compared with NDVI, NDMI is more suitable as an effective indicator for quantitative analysis of LST [10,11]. Figure 3 represents all the NDMI maps that were generated for the study area.

Results and Discussion

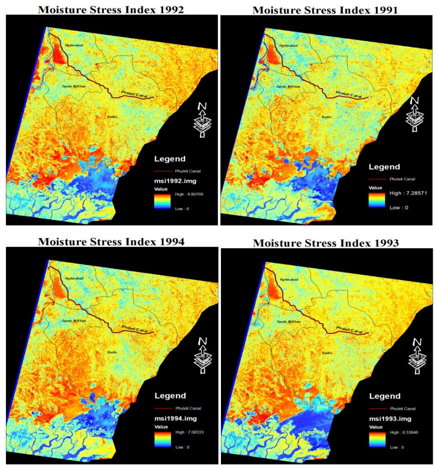

Figure 2a: Representing Moisture Index Maps for the year 1991-1994.

The Moisture stress Index represents the moisture stress areas with red color representing the areas with highest moisture stress and dark blue representing those with lowest moisture stress.

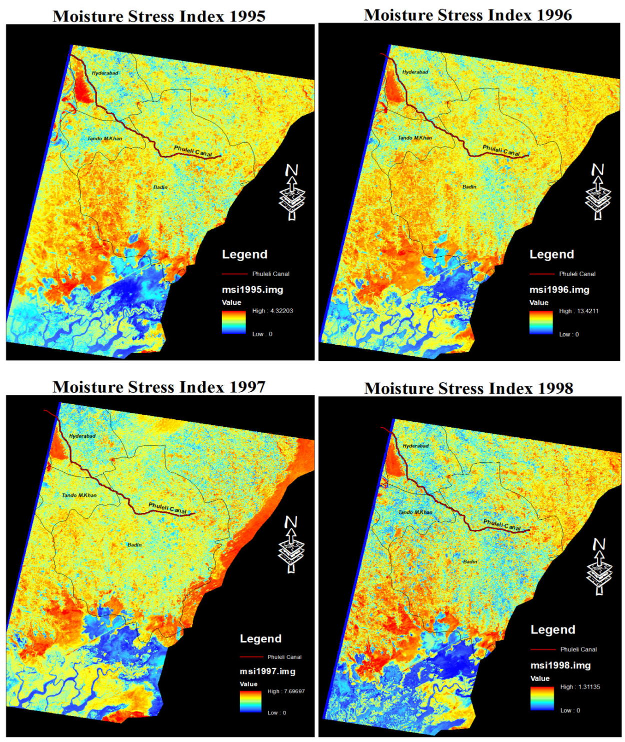

Figure 2b: Moisture Index Maps for the years 1995-1998.

It is quite evident that there is not a sudden or drastic change in these four years, but the moisture stress specifically has increased in Badin district spreading towards southern part while the other two districts have relatively less moisture stress which in other words means more water content or soil moisture.

The years 1995 and 1996 shows comparatively less moisture stress overall than the year 1994 while in the year 1998 water is spread over all in the area southern part of the area accompanied by some extreme water stress areas represented in red. The three districts have higher stress values in some areas in the year 1998 as compared to the previous year. Again, at the same time these areas with high stress values are accompanied by wet areas with very low water stress in the year 1998 which reflects that the intensity of the stress has been increased in the districts at some points but soil moisture is overall increased spatially in 1998 as compared to 1997 which may be due to rainfall or some other factors.

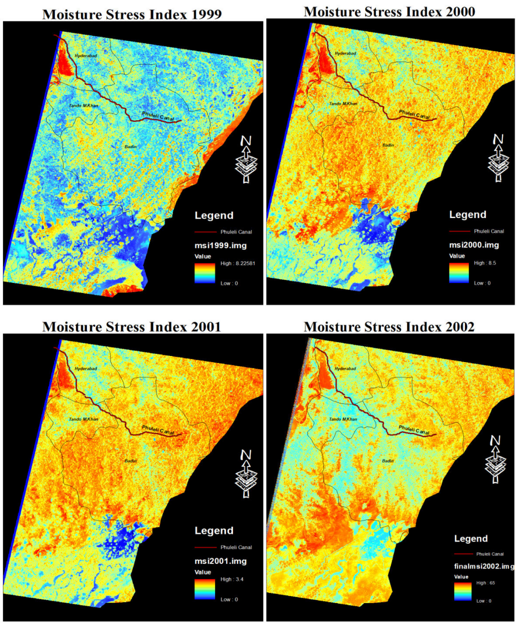

Figure 2c: Moisture Index Maps for the year 1999-2002.

According to the output results the year 1999 has a lot of moisture content wide spread along the study area whereas the year 2002 reflects that not any part of the entire study area consists of zero moisture stress for its specific month in which the image was acquired (i.e., 6th August 2002) but still there is low soil moisture stress in Tando Muhammad khan, Badin and Hyderabad districts as compared to previous years 1999, 2000 and 2001. In the year 2001 moisture stress show really high values in the command area of Phuleli canal while these high values also spread towards the north of command area, as compared to the previous two years. The south-west part of the study area in the year 2001 shows relatively higher moisture stress with water flowing to Arabian sea from that area been reduced to a really high extent.

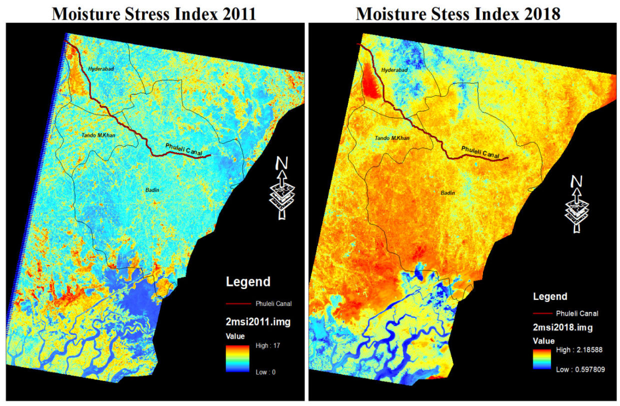

Figure 2d: Moisture Index maps for the year 2011 and 2018.

Moisture Index maps of the recent years (2011 and 2018) are represented by Figure 2d. The output of 2011 image probably shows a lot of moisture content not with respect to intensity but with respect to the area. There is really less moisture stress overall spatially in 2011, this may be temporary due to the rain or some other factor which may be further investigated with the help of date and month of the image acquired but still it can be seen that the amount of water flowing in the Arabian sea in the recent years of 2011 and 2018 is quite reduced in these maps as compared to the maps of previous years which leads to increased moisture stress in those areas relative to the output moisture stress values in previous years.

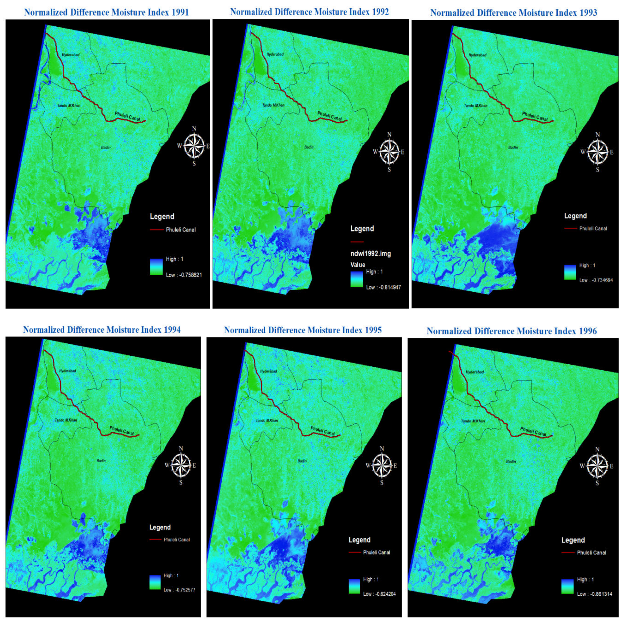

Figure 3a: NDMI maps for the years 1991-1996.

In Figure 3a the water moisture content can be seen being reduced on a larger scale but from the year 1991–1996. The year 1993 can be clearly seen having higher moisture/water content level accumulated to

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the lower right corner of the area as compared to the year 1996 accompanied with increased water stress in Badin district while Hyderabad and Tando Muhammad Khan districts still maintain their moisture level in the year 1996 to a quite good extent.

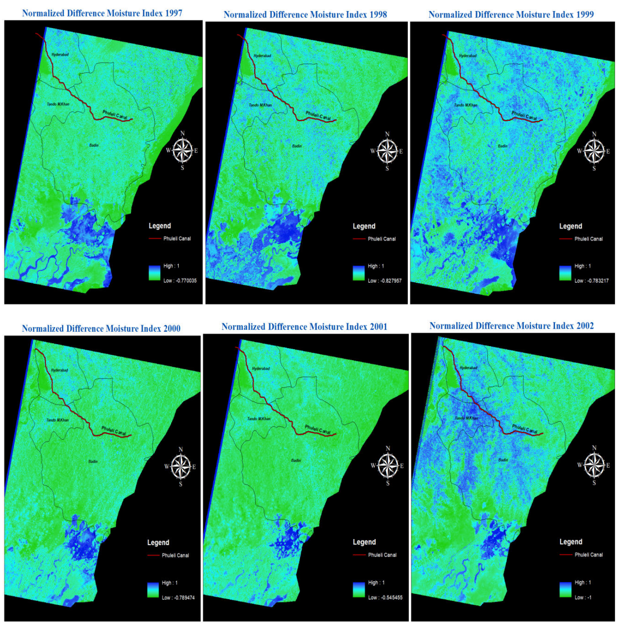

Figure 3b: NDMI Maps for the year 1997-2002.

Figure 3a and 3b show the outputs of normalized difference moisture Index which should be exactly opposite to the previous output of moisture stress index maps in a sense that highest values here represent the increased level of moisture whereas higher values in the latter represented lowest moisture level and increased stress. Dark blue areas highlight the areas with maximum moisture content while the areas represented by green color show the lowest moisture level and thus increased stress. Being one of the normalized indices, the output values are ranged from +1 to −1 with +1 representing highest moisture level and −1 showing the lowest moisture level. The years 1999 and 2002 have comparatively higher NDMI values or moisture distributed over all the area but the comparison of the images show that in the years 1991-1993, the intensities (level of moisture) is much higher at the specific places of the water bodies which kept reducing eventually in the succeeding years. The years 2002 and 1999 represents that the moisture level is increased at majority of places including the command area of Phuleli canal which is quite understandable as the moisture stress values at the same places/areas is significantly reduced as shown in Figure 2cF indicating increased moisture.

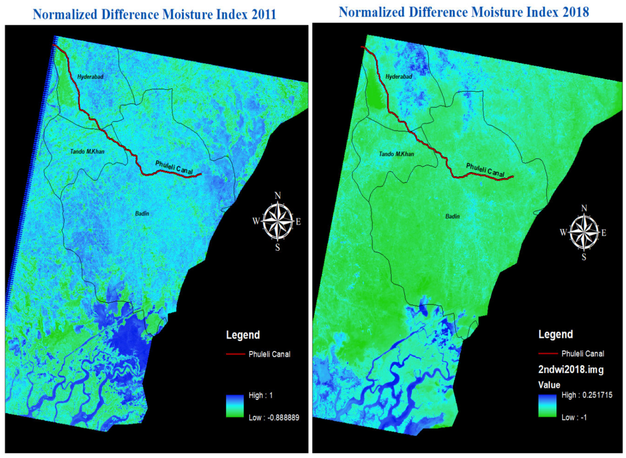

Figure 3c: NDMI Maps for the year 2011 and 2018.

The NDMI maps for the recent/present years (2011 and 2018) as shown in Figure 3c show a lot less moisture stress in the year 2011, which maybe because of the fact that 2011 image acquired is that of month of October unlike other images acquired mostly in the fifth month of the year (i.e., May) and some other factors in the acquisition month might have caused the higher moisture level and relatively different trends in this year because when we analyze the results of the year 2018, the moisture stress level can be seen increasing tremendously in Badin district and the areas to the South-west of the Badin district and an overall increase in the moisture stress or in other words decrease in the moisture level can be observed in the present year 2018.

Conclusion

Moisture stress, droughts, water content is a recurring phenomenon depending upon different factors including temperature, rainfall, precipitation. This research study was carried out for some consecutive years from 1991-2002 along with the year 2011 and the present year 2018. There is not any significant or drastic change in the moisture level when we do a yearly comparison unless the image is of a completely different month and season (as 2011 image is acquired in October), in that case moisture level is quite increased or decreased at specific places due to some extreme events but while viewing on a larger scale with a much broader perspective it is quite clear that the moisture stress have increased a lot in recent years in the overall southern part of Sindh including the command area of Phuleli Canal, specifically Badin district. Intensity of moisture index is quite decreased featuring the reduce water content in the area. By comparing the output results of moisture index maps of present image of 2018 with the image of 1991, it is quite evident that the water in the lower parts like Jubho Lagoon (Badin), Keti Bandar, Kharo Chan, Nurrari Lagoons (Badin) have been drastically reduced, thus increasing the moisture stress level in these areas as well and reducing the moisture values which in due course may cause all the wetlands in the area to be transformed to drylands.

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