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Remote sensing applications to identify devastated lagoons of the Indus Delta Pakistan

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ABSTRACT

A reduction in river flows is a major cause of the shrinking of river deltas. The Ramsar protected Indus Delta is one such example. Due to a consistent reduction in the flows of the Indus River, 15 out of 17 allied creeks facing back flows from the sea, while the remaining two are flowing during flooding years only. The connected wetlands and lagoons of these creeks have turned brackish, resulting in the devastation of associated habitats and ecosystems. This situation also increased seawater intrusion and coastal erosion. This study spatially detect the devastated lagoons, employing the Arc-Hydro tools in ArcGIS, conduct community meetings and draft evidence-based recommendations to revive the abandoned wetlands. The study identified 130 waterbodies using maximum likelihood and supervised classification methods on Landsat imagery. Through ground trothing 20 abandoned waterbodies have been visited and verified with community engagement. The revival of wetlands will improve biodiversity and coastal habitat, along with the re-plantation of mangrove, which provides a shield against tsunamis and cyclones and is also home to hundreds of species of shrimp. The sustainable wetlands may also provide immediate drinking and agricultural needs for the local population, as well as repel seawater from intruding inland.

1. Introduction

Originating from Himalayas, draining parts of Hindukush and Korakoram, crossing across the length of Pakistan, from North to South the Indus River travels around 3,000 kms to form Indus Delta over 6,000 sq. kms. The delta is shrinking due to climate change impacts and mainly due to damming and diverting the river flows. Indus River drains through 17 major creeks in Delta, due to acute shortage of water, the creeks backflows with seawater resulting devastation of lagoons and wetlands.

The dwindling river flow had already led to the loss of about 86% of mangrove cover [1]. Keeping in view the huge ecological and environmental loss, the Indus Delta was designated a Ramsar wetland of international importance on 5 November 2002.

The justified distribution and allocation of the minimum flows to ensure ecological and environmental balance is of great concern. In past studies have been conducted on Indus River to allocate the minimum flows to sustain ecology and environment and to retreat the seawater intrusion [2]. Lot of efforts and research is made to increase re-forestation of mangroves, release of more river water to revive the delta and its habitat, and introducing / adapting to saline agriculture [2, 3, 4], but no scientific research is made to geo-reference and quantify the number of total devastated wetlands which is important to measure the losses and revival ratios. The research conducted by government agencies is either not public or not available freely. This research will provide a baseline information for future research for wetland revival projects and the recommendations on revival strategies which were the outcomes of the green solutions, folk wisdom and local coping mechanisms through focus group discussions (FGDs).

During the ground trothing process, (FGDs) were conducted in adjacent communities to know the ground realities and their adaptive measures. Naturally, these waterbodies were developed in the flow path of historical river courses and seasonally recharged with river water or by rainfall runoff. The development of extensive irrigation networks upstream have reduced river water over the last 50 years for environment flows. On the other hand, climate change affects rainfall patterns and concentrations. The shallow lakes and lagoons in the Indus Delta have not been replenished due to unavailability of fresh water supply, thus occupied by seawater due to natural tidal movement. When the high tide recedes, the seawater which trapped in the shallow lagoons seeps down with time and deteriorate the groundwater quality. The inhabitants have occupied these lagoons and shallow patches to catch sea fish trapped in the lagoons after receding tidal seawater.

In view of the current situation, management of available water resources is essential to address the future impacts of climatic change. The present research has focused on the identification of the devastating natural lagoons, and flow paths most of which are occupied or vanished. These lagoons, after identification, have been recommended to revive and serve as recharge basins through optimum utilization of surplus rainwater, interconnecting them with the river network, and adjacent lakes for recharging shallow groundwater. The research will serve as a decision support tool to formulate wetland revival plan to sustain Ramsar protected Indus Delta.

A similar concept was adopted in Iran [5], where floods were diverted to seepage layers and artificially recharged groundwater. Managed aquifer recharge (MAR) is a widely used technique for recharging groundwater. [6]. The management of coastal recharge basins can improve the quality of shallow groundwater and can be an effective way to repel seawater.

The remote sensing is an operational tool, in terms of cost and time saving, for the identification and zoning of groundwater potential areas [7, 8], and suitable areas for rainwater harvesting [9, 10]. Land image archive records are the best source for identifying temporal land use changes. Abro et al. [11], identified dried and devastated wetlands through applications of remote sensing on the Keenjhar and Haleji wetland complex at the right bank of the Indus River. [12] Combining GIS and remote sensing data, identified groundwater recharge potential areas in the similar climatic region of Morocco.

The application of GIS and remote sensing tools were also employed by [13] on Kuronagi River in Japan. They created digital basins of Kuronagi River and calculated the rainfall runoff in the river basin. The main basin was further divided into 27 sub-basins and calculated slope, the average slope gradient and the length and slope of river section in each sub-basin. ArcGIS (ArcView 8.3, Spatial Analyst extension module) was employed utilizing 50m DEM of the area.

A related research [14] proved that even a small amount of rainfall has positive impact on groundwater quality. Under this study the periodic groundwater samples were collected through installing a battery of nested piezometers and testing the water samples. Similar data trends were also found from the SCARP monitoring observation (SMO) wells installed by WAPDA and PCRWR (Pakistan government departments) during field survey of current research.

All the above studies are only based on application and modification of remote sensing tools, none of the studies re-confirm through physical ground trothing of the remotely sensed data. The current research incorporated ground-trothing as well as Google earth as a tool with fine resolution archival images for confirming the signature sites for classification purpose. Additionally, the Normalized Difference Water Index (NDWI) result image was employed for the disintegration of paddy fields and water bodies through maximum likelihood classification with the support of google image base-map as a re-modified tool for flawless results.

1.1 The Study Area

The study area is Ramsar protected Indus Delta of Pakistan, located downstream of the Kotori barrage and flanked by the Indus River, which passes through the Sujawal and Thatta districts. (Fig. 1). The delta receives average annual rainfall around 220 mm, while the average temperatures for the delta region range between 23.8 OC and 28.7 OC [15]. The delta provides natural habitat to a variety of bird species, reptiles, fish and shrimp species and mangrove forest [16]. Due to the extension of irrigation network and hydraulic structures upstream the drastic reduction in the flows of Indus River resulted in the continuous devastation and shrinking of fertile Indus Delta and increase of seawater intrusion and land erosion [17]. The unplanned diversion of freshwater and neglecting attitude to delta resulting in the drastic decrease of Indus River water from 130 million acre-feet (MAF) to 0.02 MAF [18].

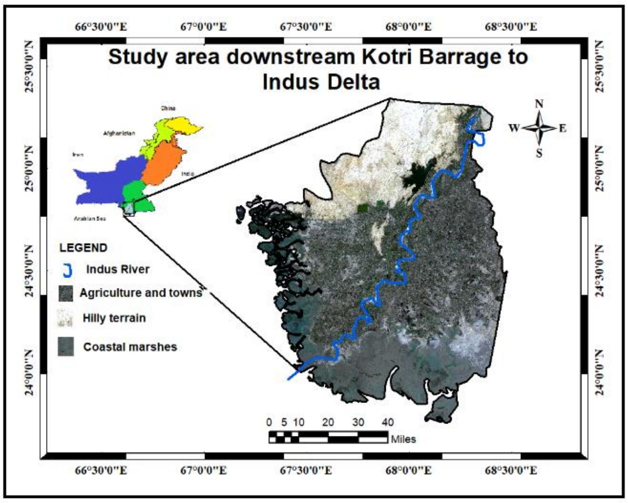

Fig. 1. Study Area Downstream Kotri Barrage To Indus Delta

2. Methodology

2.1 Geospatial Data Employed

This study was conducted by applying remote sensing tools and ground trothing techniques. ArcGIS 10.3 licenced software has been engaged to accomplish the required objective. The satellite imageries were downloaded from USGS earth explorer web public portal. The shapefile of district Thatta (formerly it was one district, later in the year 2004 divided into two districts Thatta and Sujawal) has been digitized from the PDF map of district Thatta available publically on Sindh government web portal. The physical verification (ground-trothing) was conducted two times for the study.

2.2 Digital Elevation Model (DEM)

Advanced Space borne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model (ASTER-GDEM) was downloaded from open sources and used to develop the elevation profile. The shape-file of district Thatta was masked over DEM file to extract the single band DEM information of the study area. The masked and extracted (.tiff) file later applied for watershed delineation through Arc-hydro tools. The DEM was utilized to create the elevation profile which was further utilized to delineate watersheds and drainage network in the masked area.

The study area was divided into different watersheds with different catchments. The watershed near to coast was selected to further scale-down the area of experiment, mainly due to availability of seepage from the riverbank and seawater intrusion from coastline. Selected watersheds were further investigated to study the behaviour of topology including the slope, flow direction, flow accumulation, stream segmentation, and the drainage network. The shapefile, drainage line and elevation profile layers have been created and saved.

2.3 Normalized Difference Water Index (NDWI)

Landsat 8 imagery having sensor ID, OLI–TIRS (Operational Land Imager-Thermal Infrared Sensor) in GeoTIFF format was acquired from Earth explorer. The study area (watershed newly created) was extracted from the single tile of path 152 and row 43, having 6.05 % cloud cover on land, has been downloaded with the courtesy of the US Geological Survey. The respective depressions, water bodies, and lagoons in that watershed have been identified and mapped using NDWI in ArcGIS 10.3 by extracting and masking the Landsat-8 imagery from the shapefile of the selected watershed. Using Raster calculator in ArcGIS, band 3 (green) has been subtracted from band 5 (NIR) to highlight the reflection of water bodies.

NDWI = (Green - NIR) / (Green + NIR) ------------(1)

2.4 Supervised Classification Over NDWI

Further supervised classification using “Maximum likelihood algorithm” has been applied to map the water bodies through supervised signatures. The identification of water signatures was helped through adding a base map of world imagery having a resolution of 1 meter over “ArcMap” interface. The selected signatures of visible water bodies having similar reflections were merged in each other. Apparently, 5 to 6 signatures of each type were selected and merged. The main objective was to identify the water bodies, to acquire this, the supervised classification was conducted on the raster image acquired after the NDWI process. The Randomly selected 5 identified water bodies have been physically verified for the ground trothing process (2 in Thatta and 3 in Sujawal district). Google Earth Pro was used to clarify the selected 5 water bodies and preparing their shapefiles, the actual peripheries of waterbodies were outlined through Google earth pro archives of heavy rainfall periods. The outlines were saved into layers and the layers were converted into shapefiles for further studies. The signature of water was highlighted and extracted from the rest of the signatures by giving water value one (1) and others as zero (0).

2.5 Ground Trothing Of Remotely Sensed Data

The remotely sensed and analysed data for the current study has been physically verified two times for ground trothing. The initial visit was conducted in the month of August after NDWI analysis of the imageries and identification of the wetlands through supervised classification incorporating google earth base map and archival record. Three wetland sites of the discrete study area were visited, using participatory rural appraisal (PRA) transect walk tool. The second ground trothing visit was in June next year which was relatively a dry year. The purpose of this visit was to clarify the current status of the previously visited wetlands. Three separate focus group discussions (FGDs) were held in each wetland to discuss shrinkage around the wetlands and their sustainability measures.

3. Results And Discussion

The modified method of acquiring supervised classification on a raster image of NDWI and getting help through Google Earth pro with finer resolution to distinguish between rice fields and shallow lagoons found a simple and accurate tool to highlight the water bodies. The archival record of Google Earth pro was found helpful to demarcate the extended boundaries of the devastated and occupied lagoon as the imageries of heavy rainfall years provide the actual perimeters of lagoons. The technique can be replicated over large watersheds too. The method is more accurate to distinguish between water bodies and inundated areas like rice fields and fishponds.

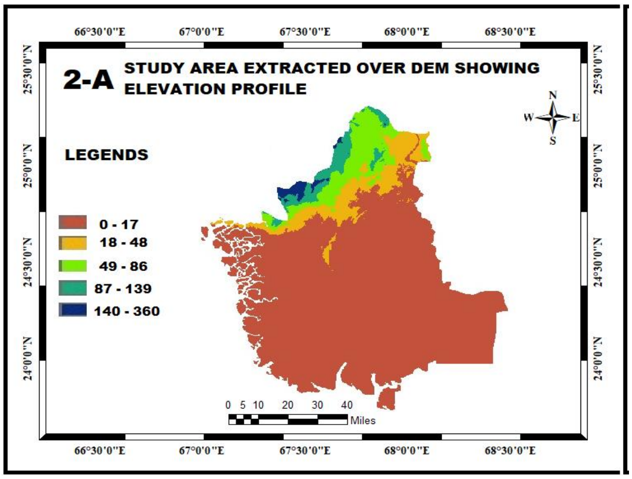

Fig. 2-A. Watershed Delineation Tools Applied On Extracted Masked DEM Of Thatta And Sujawal Districts

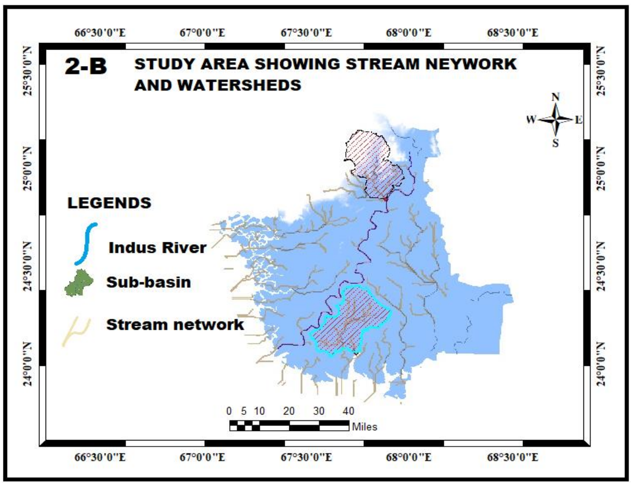

Fig. 2-B. Watershed Delineation Tools Applied On Extracted Masked DEM Of Thatta And Sujawal Districts

Fig. 2 (A and B) indicates the extracted DEM of Thatta and Sujawal districts, for downsizing the image area for clear resolution. Various processes in watershed delineation using ArcHydro tools have been applied to carve out the sub-basin to further reduce the study area for quick processing. A similar method can be replicated to any extent of the area.

Fig. (2-A) demonstrates the elevation pattern after filling sinks in the DEM data. The fill DEM mentions the elevation difference of 0 to highest 359 meters over the top left areas. The same area was physically visited to re-confirm the elevation. The specific area falls under Jhampir tehsil of Thatta district and is the mountainous/rocky area. The elevations were also re-confirmed through Garmin handheld GPS device. Total aerial length of the elevated area to the sea level is 190 km which was measured through drawing and measuring a polyline in Google Earth Pro. The crescent-shaped object encircled red (Fig. 2-A) is a mountainous area of Makli hills. The fill sink processed map was further classified into 5 classes to distinguish the elevation differences. Fig. 2-A indicated that 100% area of Sujawal district falls within the range of 0-17 meter elevation, while the geographical area of Thatta district falls around 50% within the range of 0-17 meter and rest is mountainous above 17 to 360 meters of elevation. On the basis of flow directions, the streamlines and drainage network have been identified along with the longest flow path (Indus River), which divided district Thatta and district Sujawal. Fig. (2-B) displays the sub-basin selected on the basis of assigning drain points in the Project setup tool. The selected basin having an area of about 1,087 km2 and the perimeter around 233 km is taken further for study on Landsat 8 imagery.

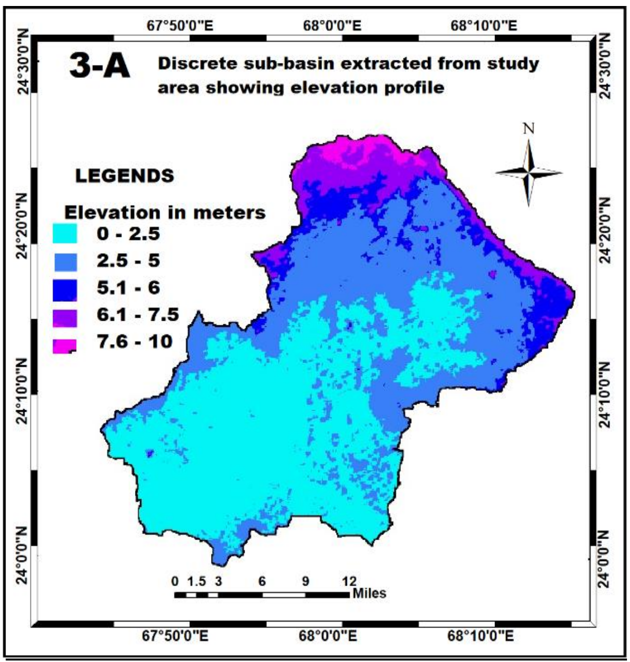

Fig. 3-A. Elevation Profile Of Extracted Sub-Basin

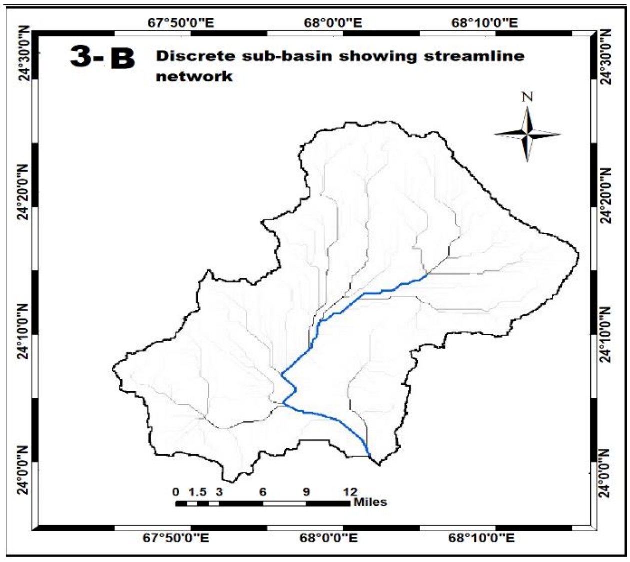

Fig. 3-B. Stream Flow And Drainage Network Of Extracted Sub-Basin

The sub-basin is extracted from the watersheds of district Sujawal imagery. The sub-basin further produced into the layer and finally a shapefile prepared for extended work. The sub-basin shapefile has been masked over the DEM data and the DEM extracted over the shapefile of sub-basin. The sub-basin again processed through watershed delineation tools to classify the elevation differences, flow direction, and stream and drain network.

Fig. (3-A) divides the study area from 0 to 10-meter elevation, which displays that around 50% area falls within the elevation of 2.5 meters. The selected sub-basin falls within the area of Indus delta. Fig. (3-B) establish the stream flow and drainage network of sub-basin.

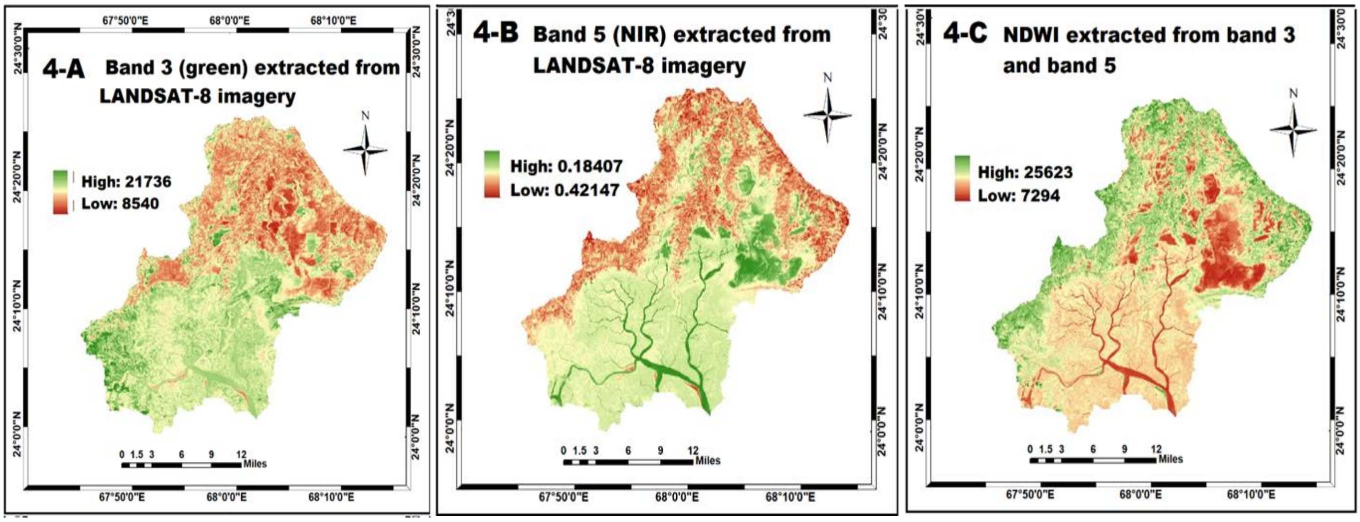

Fig. 4-A, 4-B, and 4-C. NDWI From Band 3 And Band 5 For Selected Watershed

The shapefile of the selected watershed has been masked and the data has been extracted from the imagery bands 3 (Green) and band 5(NIR) from the Landsat 8 imagery. The procedure of the normalized difference water index (NDWI) is widely employed, this method maximizes the reflectance properties of water by minimizing the low reflectance of near-infrared (NIR) and maximizing the reflectance in the green wavelength. Studies reveal that this method yields better results for deeper and worse for shallower parts of the water body [19, 20, and 21].

Fig. 4-A presents the extracted band 3 from Landsat 8, with wavelength 0.53 to 0.59 having a 30-meter resolution. The band wavelength reflects most of the green objects including the vegetation and algae in water bodies, the vegetation in the delta area is also highlighted in the green band. NIR band having wavelength 0.85 to 0.88 with same 30 meters resolution reflects biomass content and shoreline. In this band, the vegetation and water are highlighted in red color. The delta area and creek are visible in Fig. 4-B. Fig 4-C presents the NDWI results of normalized ratio from band 3 and 5. Water bodies are highlighted with clear distinct from vegetation. Further supervised classification is conducted using a maximum likelihood method to again distinguish between rice field areas and water bodies (lagoons, lakes, and depression areas). The image classification is conducted on the NDWI image imposed on a base map of the World image in Arc-map to identify the signatures of similar objects. The base-map interface in Arc-map supports to enlarge the image up to 1-meter resolution for a clear distinction between water bodies and inundated cropped areas. The maximum likelihood classified image resulted in the extracted water bodies.

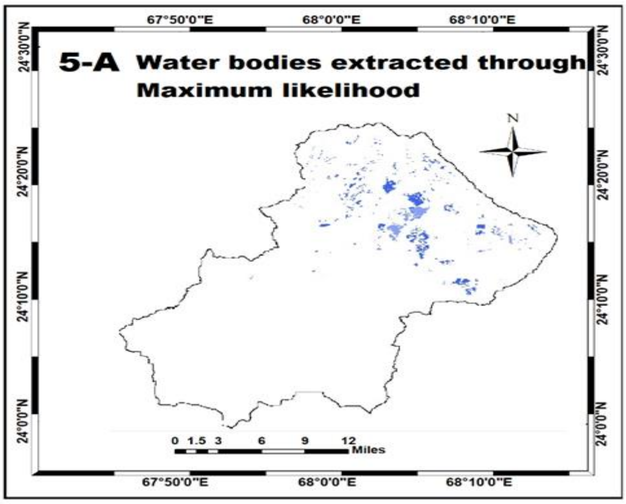

Fig 5-A. Extracted Water Bodies

Fig. 5-A, indicates the result of water bodies identified after supervised classification using the maximum likelihood method. The results of the method have been classified into 1 and 0 values, 1 is assigned to the signature of water samples while the rest signatures have been assigned zero values. The water-bodies assigned value 1 have been distinctive in the image and the layer has been produced.

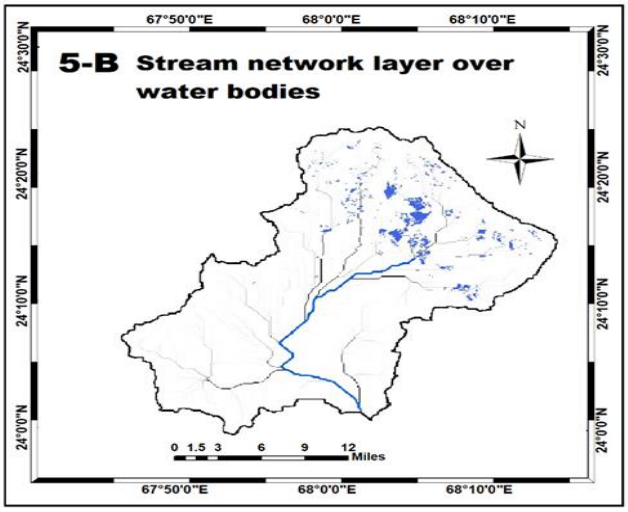

Fig 5-B. Stream Network On Extracted Water Bodies

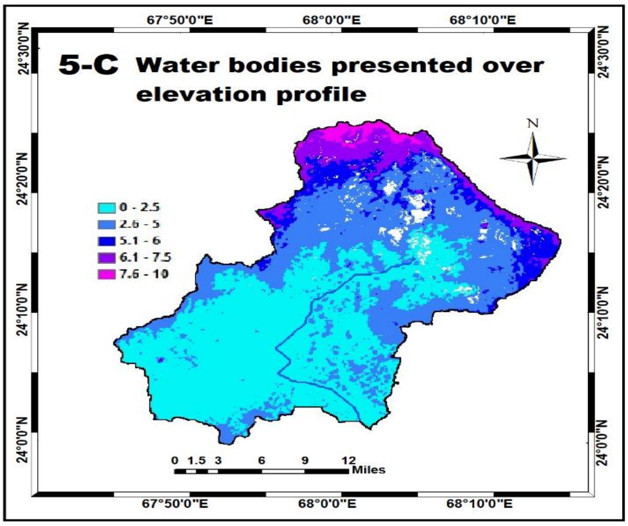

Fig 5-C. Elevation Profile On Stream Network

Fig 5-B displays the masking of water bodies with stream network to present their connectivity and flow towards Delta, and Fig. 5-C indicate their respective elevation from sea level by imposing the water body layer over elevation layer, which indicate that most of the water bodies are present in the elevation ranging 2.5 to 5 meter above sea level. This elevation basically indicated the vulnerability of water bodies to flooding due to high tide in the ocean. The water bodies presented in the elevation region 2.5 to 5 meters are classified “lagoons” having brackish seawater, while six freshwater lakes were also identified in the region from 8 to 10 meters of elevation.

The same technique was later used for whole study area and found numerous waterbodies, scattered in both districts. The highlighted bigger waterbodies were then physically verified.

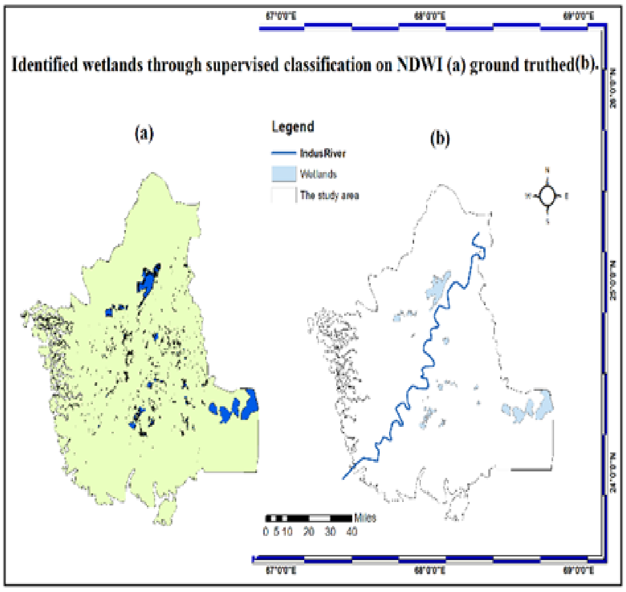

Fig. 6. Maximum Likelihood In Supervised Classification On Whole Study Area After NDWI (A) And Ground Trothed Waterbodies (B)

3.1 Wetlands Identified Through Remote Sensing And Ground Trothing

The remotely sensed data and GIS-based analysis along with ground-trothed verification produce encouraging results. The verified wetlands in the study area were identified as “Chhachh dhandh”, “Serna Gujja dhand” and Gujjo dhandh. “Dhandh” is the local term used for wetland or lake. The other wetlands which were also in close vicinity were known as “Jagir dhandh”, “Matthi dhandh”, “Gungri dhandh”, and “Beli dhandh”. Apart from these considerably bigger wetlands, there were numerous small wetlands which were either lagoon connecting these wetlands or swamplands.

Table 1

Ground-trothed waterbodies in the study area

S#	Name of the lake	Easting m E	Northing m N	Area (Sqkm)
1	Keenjhar	404380.33	2759875.06	134.7
2	Haleji	376728.97	2743745.11	17.4
3	Hadero	384772.05	2746516.20	9.13
4	Serna Gujja	398645.60	2687886.37	3
5	Nikoti	409940.13	2730166.80	10.3
6	Mathi	395025.49	2691483.96	2.1
7	Kangan-Khadi	405479.79	2702681.79	8.30
8	Jagir-Karo	397065.85	2687148.42	2.72
9	Gungri	395125.49	2685538.69	6.27
10	Gujjo	402907.56	2707548.49	0.53
11	Gadap	449840.94	2691212.01	27.4
12	Chhateji	381447.58	2745090.81	0.33
13	Chhachh	407986.65	2683551.70	6.78
14	Amerji	431679.92	2694431.72	2.51
15	Ratol	411695.22	2706925.08	0.43
16	Pateji	472469.07	2687578.40	111
17	Nareri	460583.56	2688930.29	91.2
18	Mehboob shah	409157.68	2706797.86	2.21
19	Kharar	416476.36	2704581.89	0.75
20	Karo Gujjo	410980.10	2706249.29	0.78
21	Kalan Kot	386837.02	2733645.18	1.20
22	Jhal	422241.42	2694573.53	1.98
23	Beli	393563.74	2682606.40	12
24	Gunjo	412712.24	2705552.77	0.45
25	Gujjo lake	393634.59	2696058.91	0.1
26	Dhandh	430121.23	2703643.72	4.52
27	Near Haleji	379816.00	2747769.00	3.21
28	Near Hadero	389804.00	2746224.00	2.41
Accumulated area				463.71 sqkms

4. Conclusion

The above study exposes encouraging results since it identifies several small and medium water bodies, such as lagoons, lakes (dhands), and water ponds present in the study area of the Indus delta. The remotely sensed data, which has been ground-trothed, is recognized as accurate for identification of water bodies. The archived images of Google Earth confirm the availability of water in the wet years, while some of the areas of wetlands were converted into either wasteland or agricultural lands during normal rainfall years, thus reducing the perimeter/area of natural wetlands. The identification of stream networks in the watershed delineation process is helpful to route the interconnectivity of many wetlands within the wetland complex. Revival of those routes will again connect the scattered waterbodies and provide flushing opportunity to reclaim them. The study is also helpful to replicate it on the whole Indus Delta to unfold the extent of potential rainwater harvesting sites and their respective volumes.

The study will be supportive to reclaim the natural waterways, natural depressions and water reservoirs to their original extent for maximum harvesting of rainfall and flood water to sustain the environment and delta ecosystem.

5. Suggestions

The current study will provide the basis to draft a detailed plan to recover the environmental degradation of the Indus Delta and its associated wetlands. This will also help to sustain the biodiversity, ecology, and habitat in their natural environment. The study, however, focused on a distinct watershed within the Indus Delta that has the characteristics of seawater intrusion and the possibility of freshwater recharge to shallow, unconfined aquifers. The study can be further extended to a complete delta. The stream and drainage networks supports the recharge-ability of identified wetlands through either rainwater harvesting or connecting them with irrigation network to feed them through freshwater during floods and rainfall runoff. The last constructed hydraulic structure on the Indus River is the Kotri barrage, which is situated about 276 km upstream from the Indus Delta, which does not serves the purpose to recharge shallow unconfined aquifers.

6. Acknowledgement

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