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Research Article

A GIS based analysis of essential habitat for six commonly caught species in coastal creeks of Sindh, Pakistan

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Abstract

This study was carried out to evaluate natural resources of some Indus creeks using geospatial technologies. The first phase of the study was a detailed monthly water quality and fish stock survey for one year along with associated environmental observations, which was analysed via Landsat 8 imagery for 2014. In the second phase of the study, appropriate indicators were selected in weighted overlay on ArcGIS platform to perform creek productivity analysis. For this purpose, 13 creeks of Indus delta were selected for detailed analysis. These creeks were chosen using GIS techniques based on accessibility, depth and size. Results obtained from a total number of 65,085 fish catch from 252 identified fisheries important species in which 134 species were estuarine, 107 species marine and 11 species belonged to freshwater. Out of these, six species of *Penaeus indicus, Pennahia anea, Stolephorus indicus, Escualosa thoracata, Charybdis* sp. and *Acanthopagrus arabicus* were selected for spatial distribution analysis. It is observed that creeks of west of Jhang River known as Issaro, Waddi Khuddi, Patiani, Mal, Dabbo, Chann, Richhal had higher fish abundance and species richness than those of eastern creeks. The important fisheries species showed strong correlation with mangroves, salinity and temperatures. This study indicated that all parameters were strongly dependent on anthropogenic interventions at the study area and these activities seriously affected fish catch and growth of species mainly because of recent environmental changes. It has been revealed from the creek productivity analysis that the study area is still highly productive and intact as an ecological unit.

Keywords: Geoinformatics, Fish stock, Weighted overlay, Creek productivity, Anthropogenic activities

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Introduction

Pakistan is a quite rich country in geographical diversity and marine resources. It has two coastal provinces Sindh and Baluchistan covering approximately 1,100 km long coast line (FAO, 2009) of which Sindh coasts comprise of 370 km, including creeks in the east to Hab River coast in the west. According to Noshirwani (2013), 71% of Pakistan's fish resources are found in Sindh. A large number of living and non-living marine resources are directly linked to Sindh creeks (Khan, 2011). These creeks are formed by great Indus River delta, which is one of the largest deltas of the world covering an area of 600,000 ha along Pakistan's coasts (Snedaker, 1984; Harrison *et al*., 1997; Shah *et al*., 2007; Government of Sindh, 2008). These creeks are dominated by world's sixth largest mangroves forest (Khan, 2011). Mangrove environment provides excellent habitat for larvae and juveniles of many marine species to spend early stages of life (Ahmed, 1988). According to FAO (2009), Pakistan's mangroves cover an area of between 100,000 to 500,000 hectares. In last 50 years, a significant loss of mangrove forest has been observed by local authorities (Shah *et al*., 2007). Declining mangrove areas is not the only reason for decreased of fish catch in creek areas of Sindh. Other factors such as climate change, use of banned nets, catch of juvenile fishes and marine pollution may also contribute to declining fish catches (Ilyas, 2014).

With a very high accessibility of EEZ in the Arabian Sea, the role of fishing industry in national economy of Pakistan cannot be overlooked. There are mainly four groups of fisheries important species found in creeks areas of Sindh: permanent inhabitants, partial residents, tidal visitors and seasonal visitors. About 400 aquatic species belonging to 21 orders, 9 suborders and 118 families are recorded (Ahmad, 1988). Out of these, 40 species are commercially viable and highly exploited (Majid, 1988). According to studies of Khan (2004) and Noman *et al*. (2017) total marine fisheries share amounts to 1% of the GDP and total marine fish catch is almost 400,000 tons of which 20% are exported to different countries.

Although fisheries is a major source of protein all over the world, in Pakistan the per capita consumption of protein through fish consumption is one of the lowest, about 1.9 kg (Cai *et al*., 2019).

Use of modern technology to monitor fishing potentials is highly essential for growth of fishing industry of Pakistan. In this context, this paper is an attempt to demonstrate application of geoinformatics for evaluation of fisheries in Pakistan at geographical scale of creeks.

Geoinformatics and Fisheries Management

The term geoinformatics mainly comprises of fields of satellite remote sensing (SRS), geographic information

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system (GIS), and photogrammetry and global positioning system (GPS). The use of geoinformatics is rapidly increased because of its new powerful statistical techniques in GIS system, which helps to predict suitable habitats for fishes in many parts of the world. GIS may help to display geographic distribution of fish species and that may be combined with SRS based oceanographic and environmental features in a spatiotemporal scale in order to acquire essential information from creek habitats (Meaden, 2000; Valavanis, 2002; Valavanis *et al*., 2004). As compared to conventional methods, SRS techniques provide new avenues for gathering of data and multi-spectral images. On the other hand, it is considered as an inexpensive and efficient method for obtaining detailed information from any area (Mirza *et al*., 1988). GIS and spatial analysis methods are used to assess overall contribution of creeks habitats in marine fisheries. Geoinformatics is an emerging technology in Pakistan, which is used in this paper for evaluation of marine fisheries. Geospatial technologies deal with new techniques and methods that help to assess environmental impacts and study prospective effects of anthropogenic activities, natural hazards, and aquaculture at coastal environments (Mirza *et al*., 1995).

Materials and methods

Study Area

Study area consisted of creek zones (essential habitats) located in south of Sindh coast, comprised of two districts, Karachi and Thatta (though a recent district of Sujawal has emerged but we considered it as part of Thatta District, due to data collection limitations, Fig. 1).

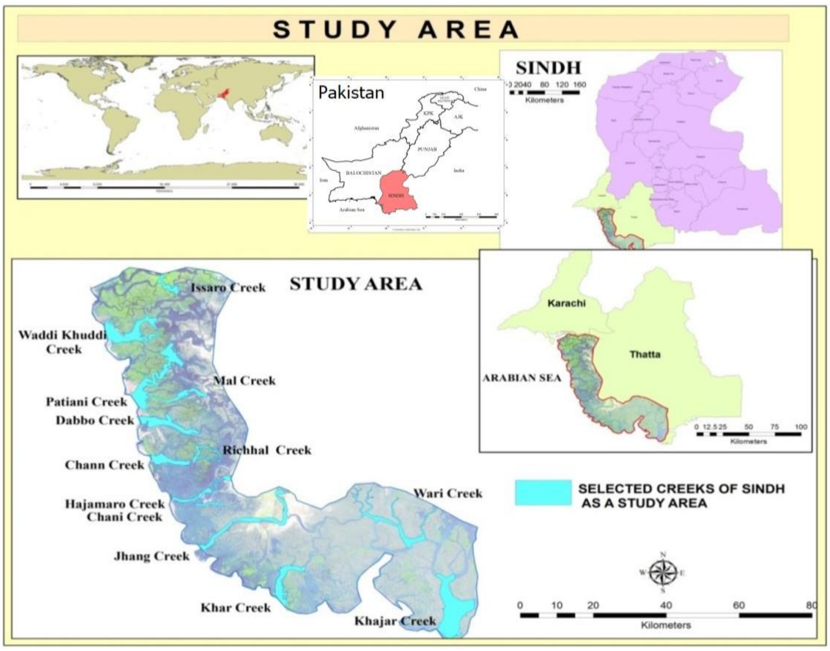

Figure 1: Map of the 13 selected creeks in the study area.

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Indus delta, seasonal streams and mangrove forest of creeks of Sindh coast provide highly productive fishing areas that are extremely important in terms of both biodiversity and economic activity. The initial step of the present study was to decide on the creeks to be used for a detailed study as Indus delta comprises more than 50 creeks, and it was not possible to visit all creeks for the survey. This process was done using QuickBird imageries from Google Earth, because the tools provided exactly the same size and distance from coast as on the ground. Therefore, after evaluating the extent and environment of each creek in QuickBird imageries, 13 creeks were selected based on their size and accessibility (Table 1). These creeks were then vectorised using polygon tool in Google Earth and saved as kmz files, which were imported into ArcGIS to perform further analysis.

Table 1: Area of the selected creeks in the study area.

Creek Name	**Issaro**	**Waddi Khuddi**	**Patiani**	**Mal**	**Dabbo**	**Richhal**	**Chann**
Area (Km^2)	9.98	49.02	57.68	14.90	30.06	10.26	18.35
Creek Name	**Chani**	**Hajamaro**	**Jhang**	**Khar**	**Khajar**	**Wari**	**Total**
Area (Km^2)	4.24	15.24	37.22	27.61	89.65	36.23	**400.44**

Demarcation of field stations at each creek

At the second stage of this survey, a well-maintained and equipped research trawl vessel named *Dolphin boat* was selected for the creeks survey by a joint survey team of FAO, MFD, WWF, NIO, Department of Geography and University of Karachi. There were totally six trips, around 15 to 20 days in a month. A Specific identification (Id) was given to each creek and the entire database contained these Ids. Fisheries samples were collected from each creek in different stations from where environmental data were collected (Table 2). All collected data contained geographic latitude and longitude.

Table 2: List of studied creeks with Ids and stations.

Creek Name	**Issaro**	**Waddi Khuddi**	**Patiani**	**Mal**	**Dabbo**	**Richhal**	**Chann**
Id	9130	9131	9132	9133	9134	9135	9136
Stations	4	4	5	3.00	4	4	4
Creek Name	**Chani**	**Hajamaro**	**Khar**	**Khajar**	**Jhang**	**Wari**	**Total**
Id	9137	9138	9139	9140	9141	9146	
Stations	3	4	4	4	7	5	51

Phase I

Water quality and bathymetry data

A cast-away CTD of Yellow Springs Instruments (YSI) was used for measurement of water quality and bathymetry. It provides maximum accuracy level for salinity and temperature measurements because it is specially designed for monitoring applications along with coastal profiling

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within the depth of 100m (YSI, 2010). This instrument provides data of any single location and incorporates it with GPS, sensors and data logging. Hydrographic profiling was consisted of temperature, pressure, salinity, conductivity and depth during March 2013 to May 2014. All mentioned parameters were used to map water quality and bathymetry of studied Indus creeks. For this study, we selected temperature, salinity and depth. The resulting files were in CTD format for temperature and salinity and CSV files for depth. Both datasets were different in terms of information as water quality parameters contained more detailed seasonal information than bathymetry data. The data received in CTD were classified in four seasons, and then imported into Microsoft Excel, which was then exported into ArcGIS 10.7 as ESRI shape file, where point values developed by adding XY coordinates. In ArcGIS software two water quality variables of temperature and salinity were treated separately to perform Inverse Distance Weighted (IDW) interpolation. The other file format, CSV, was compatible with Microsoft Excel to map depths. Totally, 342,860 points were received from each creek for different months. This process was quite difficult to handle, as there were thousands of points with duplicate values and were spatially overlapped. By using, remove duplicate tool in Microsoft Excel all overlapped values were deleted as they could provide false results or create error while applying interpolation technique in ArcMap 10.7.

Fisheries data

For collection of fisheries data, pelagic and bottom trawls were used. Catch data of each trawl was written on a form that was created by the survey team. After collection, samples were taken to laboratory to measure weight, length, and frequency characteristics. To develop a database the fish samples were organized using Nansis software. Apart from fish, the catch mostly consisted of shrimp larvae, estuarine and marine postlarvae, plankton, gastropods, and molluscs. Length was measured as fork length (FL), mantle length (ML) and total length (TL) for fish, and for crabs and shrimps length, total length, and Carapace Length (CL). All measurements were taken in centimeter except weight, which was in gram. All data were recorded in geographic coordinates during the field, which was easily incorporated into GIS system in order to get spatial information about species. Monthly catch data from April 2013 to March 2014 were taken from the field which was sufficient to explain seasonal and spatial behavior of fish stock at the study area. Out of 252 species, six species were considered for the detailed analysis and spatial distribution (Table 3). Major groups at the study area were estuarine and marine along with one small group of fresh water species.

Table 3: List of selected aquatic species.

Selected Aquatic Species			
Environment	**Fish/Crustacea**	**Family**	**Species**
Estuarine	Fish	Clupeidae	*Escualosa thoracata*
		Engraulidae	*Stolephorus indicus*
	Crustacea	Portunidae	*Charybdis* sp.
		Penaeidae	*Penaeus indicus*
Marine	Fish	Sciaenidae	*Pennahia anea*
		Sparidae	*Acanthopagrus arabicus*

Spatial distribution of fisheries species

An extensive data of species was gathered in postgresql file format from June 2013 to May 2014. This file format was acquired in PgAdmin III, freely available software that develops tools under the license of postgresql, and is highly compatible with PostGIS. Authors imported the database in PgAdmin III that contained eight tables having different information regarding the samples. To acquire the required datasets, we performed join function for identical columns available in the PgAdmin III and typed scripts about the data that were needed. This data then was exported to ArcMap and using graduated symbols, spatial distribution maps were generated accordingly.

Land use and land cover classification

Another important part of this study was image classification. Image classification was applied on each of the 13 creeks separately, for this purpose selecting a radius distance of 0.7 km around each creek buffers were created in ArcMap 10.7. The reason to choose this distance was that some creeks were close to each other. Each creek was extracted from Landsat 8 in ERDAS IMAGINE using polygon tool in raster option according to the size of creek's buffer. All extracted AOIs from Landsat 8, for each creek was saved in IMG format. Landsat imageries of creeks were then separately treated for further analysis. First step was to set band combinations and it was 6-5-4 for Landsat 2014, as it made it easier to visualize the satellite data. Second step was to enhance the study area imageries, which made it more clear and crisp by using simple bright and contrast method in raster option. Under the classifier tool, unsupervised classifier was chosen to classify the images separately into 100 classes, which were than recoded as eight classes. Number of classes varied according to land-cover and land-use of particular creeks. The area of each class was calculated by adding an area column in raster attribute. Classified images were then transformed into IMG format. Finally, classified images were imported to ArcMap 10.7 where cartographic techniques were applied.

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Phase II

Creek productivity

In order to find the most productive creek at the study area, creek productivity analysis was performed in ArcMap 10.7. To complete this task, all parameters such as fish stock data, water quality and most influential variables from Land use and land cover analysis (LULC), such as mangroves and mud lands were overlaid in ArcGIS to get productive site at the study area. All parameters were placed into a single table according to their final results at each creek, then converted to Raster and reclassified to set an evaluation scale which is common for all parameters. After evaluating the scale, all raster files were added to the weighted overlay tool in spatial analyst. The cell value for each input raster in the analysis was the assigned value from the evaluation scale. This made it possible to perform arithmetic operations on raster files that were originally dissimilar types of values. At the end, influence was selected for each parameter at different percentage according to the parameter. Therefore, cell values of each input raster were multiplied by the raster's weight, or percentage of influence. The resulting cell values were added to produce final output raster.

Results

Land use and land cover analysis (LULC)

Results of land use and land cover showed visible contrast in distribution of selected classes of each creek. Study area was divided into 13 classes of LULC, two classes of agricultural land and built up land were human use of land, the rest of the classes came under land cover. Although both classes comprised of a small area at Indus creeks, 0.29% and 0.08% respectively but have a significant role in alteration of creeks. Table 4 shows the total area of classes at the study area, wet mud land occupied most of Indus creeks 26.14% followed by deep water which was 25.09%. Additionally, another important class was mangroves, which was divided into dense mangroves, mangroves, and sparse mangroves, the total area covered by these three classes was only 10.84%. To find out the significance of habitat for fisheries important stocks detailed LULC was done separately on selected creeks at the study area. Figures 2 and 3 indicate distribution of each class separately over selected Indus creeks. It was observed that creeks at west of Jhang River were occupied with more mangrove cover than creeks in the east. The Jhang River is part of mighty river Indus and it regulates the flow of fresh water at creeks zone. Agricultural land was only found along Jhang River with only 1% mangrove cover, which can be an indicator of impact of human activities.

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Table 4: Area of LULC at buffers of the study area in 2014.

LuLC-2014	Hectare	%
Deep water	2327.6	25.09
Shallow water	4282.83	4.61
Turbid water	13508.12	14.56
Bare sand	3734.97	4.02
Dry mud land	12531.06	13.51
Wet mud land	24251.04	26.14
Saline land	380.16	0.40
Sparse mangroves	105.075	0.11
Mangroves	5838.05	6.29
Dense mangroves	4121.57	4.44
Agricultural land	274.3425	0.29
Other Vegetation	370.7775	0.399
Built up land	79.695	0.08
Total	**92751.56 ha**	**99.93**

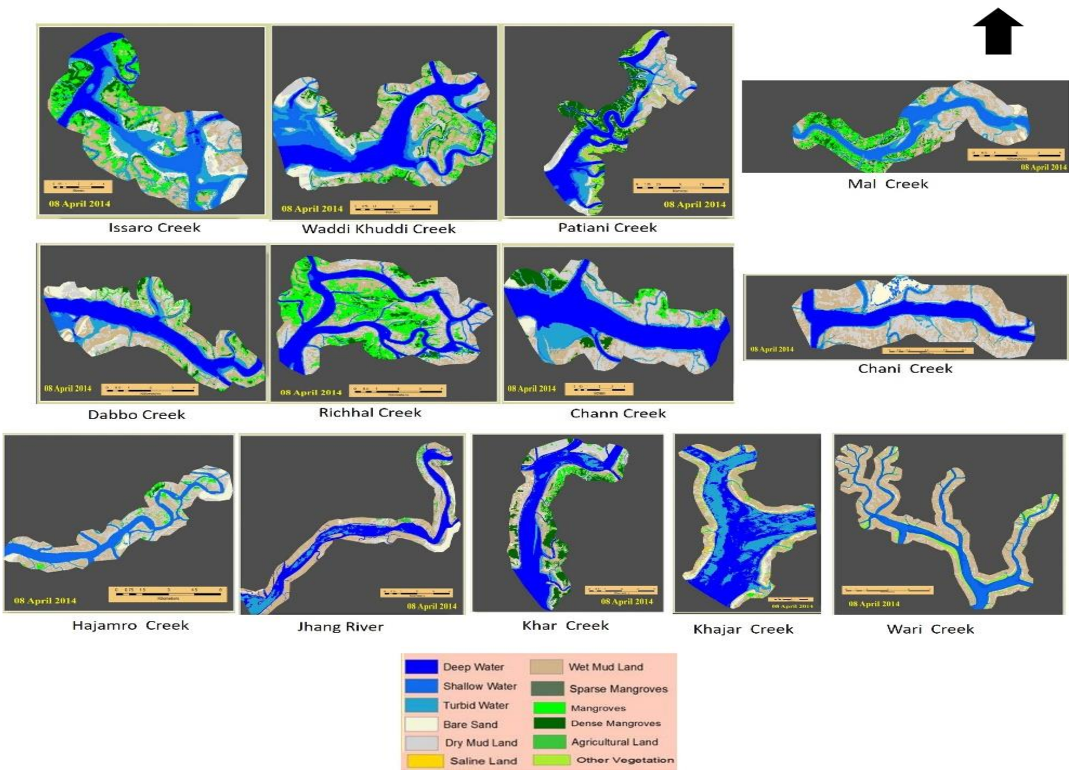

Figure 2: LULC of buffers of each creek at the study area.

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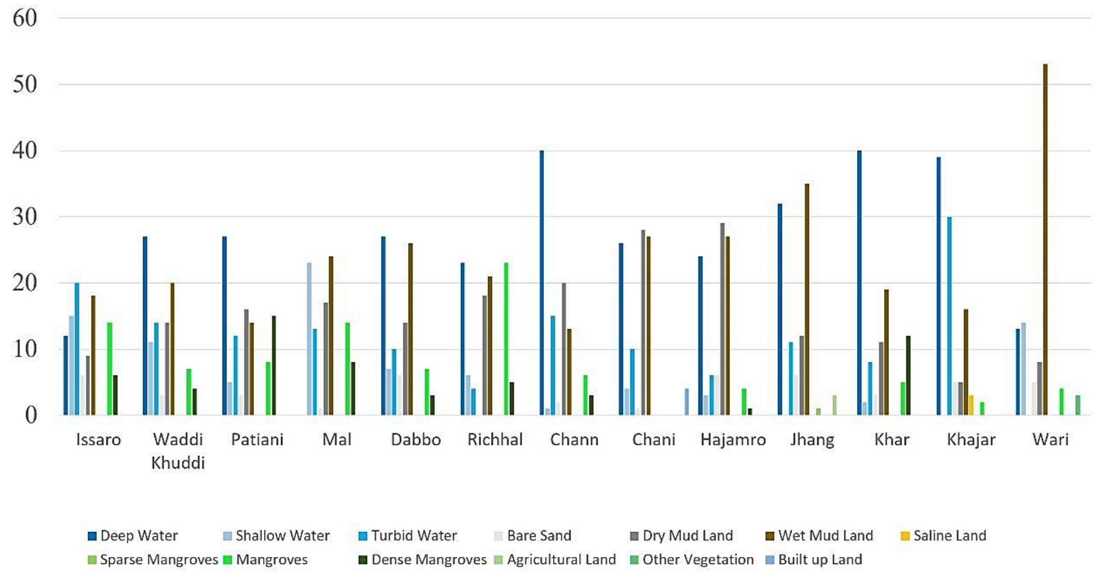

Figure 3: Percentage of LULC classes of each creek at the study area.

Similarly, Hajamaro Creek, which is very close to Jhang River on the west, has less mangrove cover with only 5%, which can be due to illegal cutting. Nevertheless, the creeks on the west, including Issaro, Waddi Khuddi, Patiani, Mal, Dabbo, Richhal and Chann were found in more stable condition in terms of mangroves mainly because of availability of fresh water and planting of mangroves near Keti Bunder. Almost 541,176 mangroves were planted at Keti Bunder with support of Sind Forest Department (SFD), coastal communities and volunteers (WWF, 2009). While no mangrove cover was found at Chani Creek in 2014 with the built up land, which is called Jetty, it is proved that no effort was made to plant mangroves here due to construction in previous years. Whereas, creeks on the east of Jhang River, Khar, Khajar and Wari were not only difficult to access but faced great sea water rise towards the land because of shortage of fresh water in those creeks. That resulted in saline land at Khajar Creek with 3%. However, Khar Creek had 12% dense mangroves cover and 2% mangrove cover that was as a result of efforts of SFD in 2013, with collaboration of International Union of Conservation of Nature (IUCN), they had set a world record by planting 750,000 mangrove sapling at Khar Creek in a day (Ousat, 2013).

Other important classes were water classes and mud lands. They both were shown a very close relationship. In the creeks where sea water level rises occurred, including Khar, Khajar, Waddi Khuddi, Dabbo and Chann creeks there were decrease of mud land. Because it caused sea intrusion and erosion resulted loss of mud lands, which is considered an important part of fish habitat. Little percentage of bare

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sand was found at the study area, which was highest at 6% in Issaro, Dabbo, Hajamaro and Jhang River and lowest at 1% at Chani Creek. Bare sand habitats in coastal areas support large numbers of juvenile fish species (Bennett, 1989). Other vegetations, including bushes and halophytes, were only found at Wari Creek in 3%.

Water quality analysis

Temperature

Seasonal changes in sea temperature of the study area was analyzed which ranged from 14.5 - 31.1ºC in year (Fig. 4). Temperature levels varied not only among creeks but also within creeks as well. However, temperature variation was almost constant during mid-May to mid-September in all creeks, varying between 29.6 to 31.1ºC. This may be due to seasonal effect of monsoonal heavy rainfalls in north increasing the flow of fresh water in Jhang River, Hajamaro and Chani creeks. On the other hand, during mid-September to November (Post Monsoon), temperature was slightly lower than during monsoon, ranging from 23.2 to 29.4ºC. During December to February, low temperature ranges were identified while temperature range also varied within the study area.

The creeks on west of Jhang River showed moderate temperatures during winter whereas the Jhang River and the creeks on east had low temperature ranges comparatively. It is clear from Figure 4 that temperature range during March to mid-May was almost the same as that during mid-September to November, ranging from 24.8 to 29.5ºC.

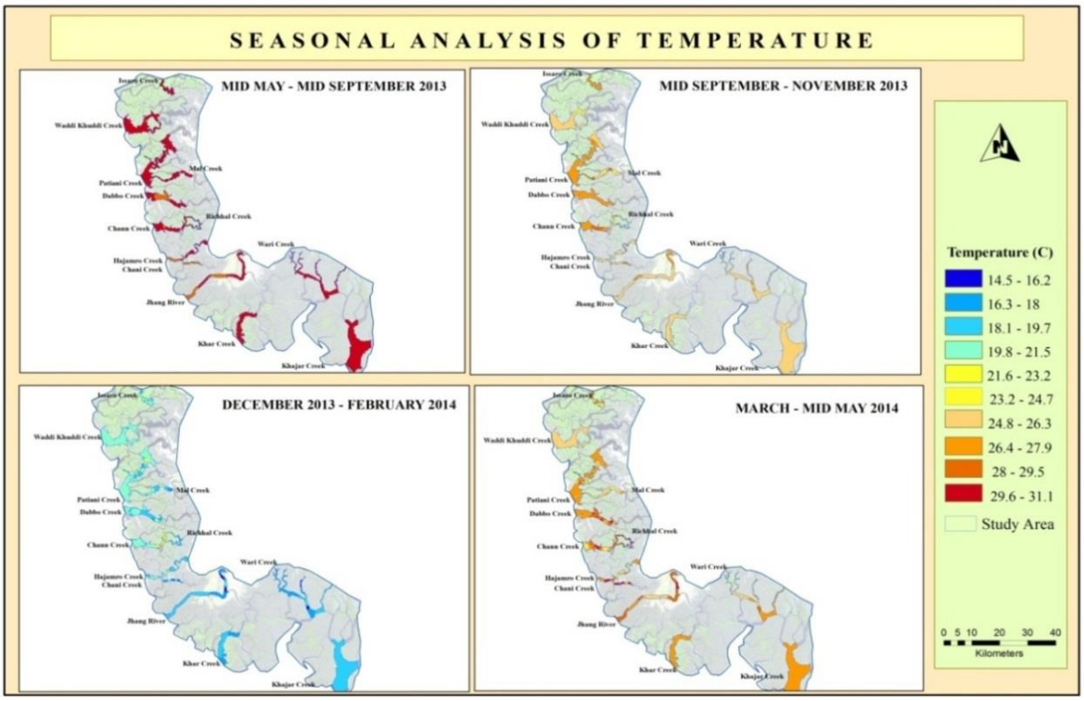

Figure 4: Seasonal analysis of temperature.

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Salinity

Figure 5 shows seasonal change in salinity at the study area. It is revealed from the figure that there was smaller effect of seasonal shift at western creeks of Issaro, Waddi Khuddi, Patiani, Mal, Dabbo, Richhal, Chann, Chani and Hajamaro than eastern creeks and Jhang River.

During mid-May to mid-September (Monsoon), the highest salinity values are recorded at Issaro and Waddi Khuddi creeks ranging from 32.9 to 36.9 psu. At Patiani and Mal creeks salinity during monsoon was from 28.8 to 32.8 psu and slightly higher in some parts of these two creeks up to 32.9 to 36.9 psu. Salinity was from 28.8-32.8 psu at mouths of Dabbo and Chann creeks while the rest of the creeks including Richhal showed a range of 24.8 to 28.7 psu, at mouth of Hajamaro and Chani creeks, salinity was from 24.8 to 28.7 psu while at the rest of the creeks it was from 20.7 to 24.7 psu. The lowest salinity level was identified at Jhang River during monsoon from north to south the salinity at Jhang River was from 0.176 to 24.7 psu. Wari and Khar creeks also showed low levels of salinity ranging between 8.35 to 16.50 psu.

On the other hand, a little variation in level of salinity was identified in the creeks in other seasons. But salinity levels were slightly higher during winter, December to March, and pre-monsoon, March to mid-May. Therefore, during mid-September to November (Post monsoon) all creeks on west of Jhang River showed salinity levels between 32.9 to 36.9 psu and from 20.7 to 32.8 psu at east of Jhang River creeks of Wari, Khar and Khajar. During the same season at Jhang River lowest level of salinity was recorded at the north ranging from 0.176 to 4.26 psu and changes continued till the mouth of Jhang River that was from 32.9 to 36.9 psu.

During December to February and March to mid-May the same levels of salinity were recorded at Issaro, Waddi Khuddi, Patiani and Mal creeks, ranging from 37 to 41 psu and Hajamaro and Chani creeks, from 32.9 to 41 psu. While, at Dabbo, Chann and Richhal creeks different levels of salinity were measured during these seasons ranging from 32.9 to 36.9 psu during February and March (winter) and 32.9 to 41 psu during March to Mid-May (Pre-Monsoon). A significant variation was observed in salinity level of Jhang River during March to mid-May as compared to all seasons, the complete River showed high salinity level ranging from 32.9 to 36.9 psu. High levels of salinity during this period may be associated to low or no rainfall in 2014 before and during these months which caused high values of salinity. On the other hand, salinity levels also increased during March to mid-May in Wari and Khajar creeks, from 41.1 to 45.5 psu (Fig. 5).

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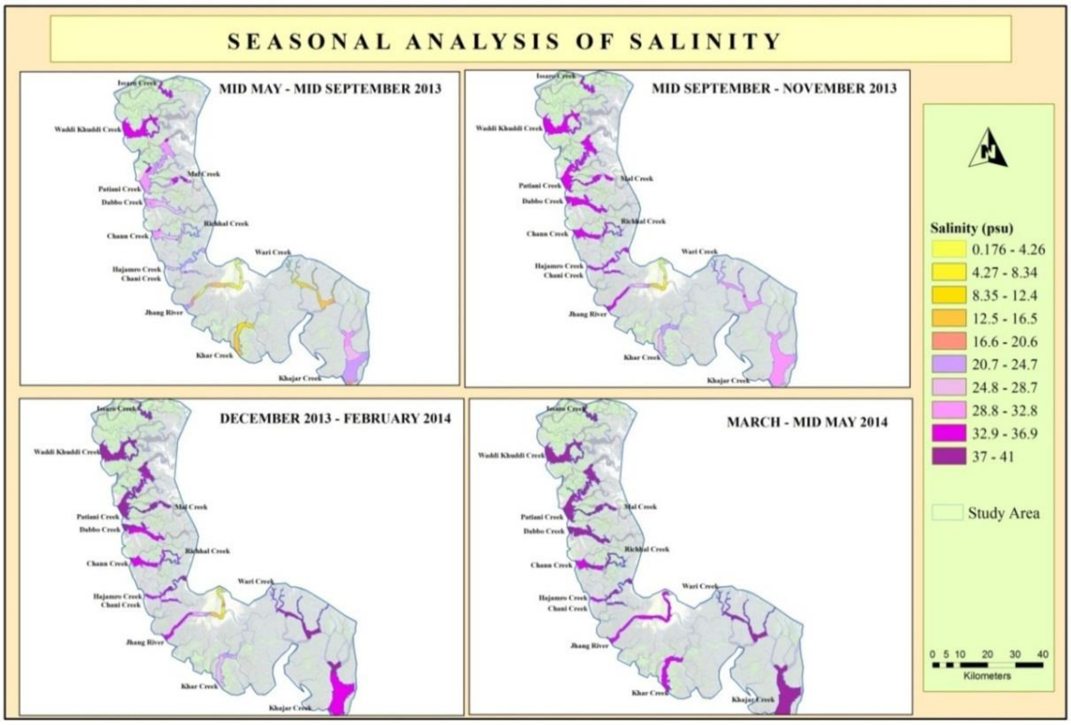

Figure 5: Seasonal analysis of salinity.

Bathymetry

Bathymetry is a key indicator in evaluation of fish resources. Figure 6 shows average depth at the study area, seawater depth in the creeks is important to maintain the balance of aquatic life. Some species are sensitive to depth and are found at particular depth ranges. Depth range at the study area was between -1.68 to 33m. Deepest depths were found in some parts of Waddi Khuddi, Patiani, Mal and Wari creeks, ranging between 27.3 to 33 m. Low depths were found at Jhang River ranging from -1.68 to 9.98m. While depth range at Issaro Creek was -1.68 to 27.2m, Waddi Khuddi Creek 4.11 to 33m, Patiani Creek -1.68 to 33m, Mal Creek -1.68 to 33m, Dabbo Creek 4.11 to 27.2m, Chann Creek 4.11 to 21.4m, Richhal Creek 4.11 to 21.4m, Hajamaro Creek -1.68 to 15.7m, Chani Creek 4.11 to 9.98m, Khar Creek -1.68 to 15.7m and Khajar Creek -1.68 to 15.7m (Fig. 6).

Spatial distribution of fishing species

Figure 7 shows spatial distribution of selected fisheries species at the study area. Two estuarine species of *E. thoracata* and *S. indicus* are widely distributed and accounted for 19.5% and 9.67% of total fisheries catch at the study area. *E. thoracata* was caught in higher weight than *S. indicus* in creeks. Highest weight of *E. thoracata* was found at Hajamaro 65.6 g/tow (catch effort) compared to *S. indicus* that was 12.07 g/tow at Richhal Creek. The lowest weight was recorded at Chann Creek for both species to be 19.9g for *E. thoracata* and 3.2g for *S. indicus*. Additionally, crabs are also harvested at the study area in large quantities and

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despite their low economic value; they are mostly exported to South East Asian countries. In this study two species of crustacea, *Charybdis* sp. and *P. indicus*, were selected to analyze their distribution pattern. Out of total fish catch, 0.21% was *Charybdis* sp. and 1.05% was *P. indicus*. Although *P. indicus* was widely distributed in most creeks but it was fished in small quantity and low weight. While examining the highest catch by weight, it is found that 4.02 g/tow *Charybdis* sp. was caught in Dabbo Creek and 11.59 g/tow *P. indicus* in Issaro Creek. Similarly, the lowest catches were found at Hajamaro Creek for both species as 0.04% *Charybdis* sp. and 0.5 g/tow *P. indicus*. Generally, the lowest catch weight was recorded for crustaceans in all creeks. Above-mentioned species were permanent resident of creek area, it means they spend their whole life in Indus creeks, whereas the next mentioned species are grouped as marine species that move to creeks at the time of spawning and once they mature they swim back to the ocean. 107 marine species were caught at the study area along with 134 estuarine and 11 fresh water species. Therefore, *A. arabicus* and *P. anea* were selected for spatial distribution. Small quantity of *A. arabicus* was caught at the study area, which comprised of 0.05% of the total fish catch along with 0.16% of *P. anea* catch. *A. arabicus* was only found at three creeks of Sindh, Issaro, Waddi Khuddi and Wari with highest recorded catch weight of 8.78 g/tow at Waddi Khuddi. The highest weight of *P. anea* was also recorded to be 6.83 g/tow at Waddi Khuddi Creek.

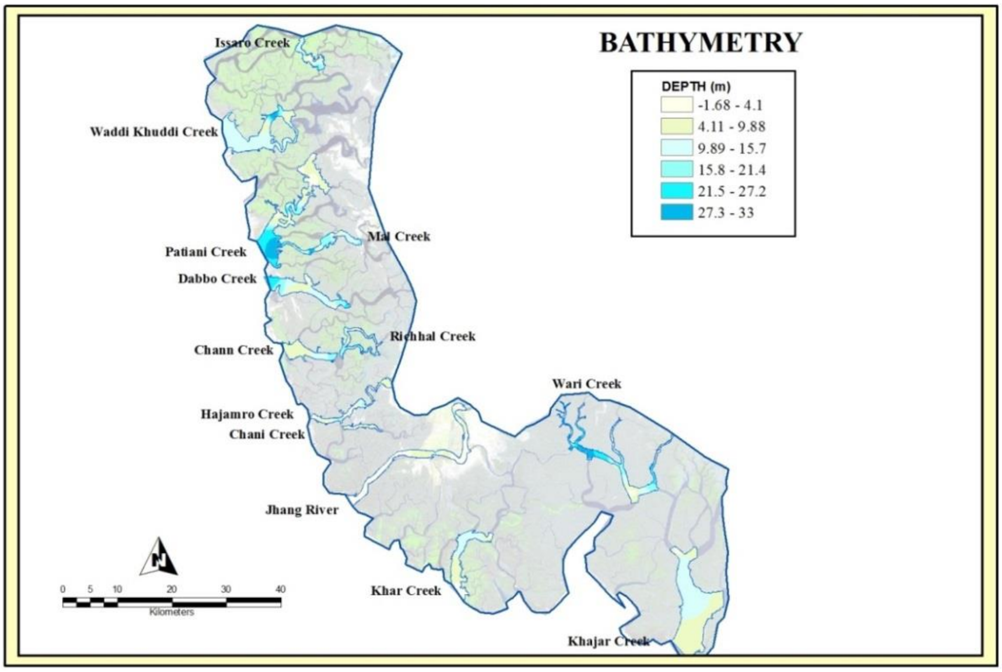

Figure 6: Bathymetry analysis.

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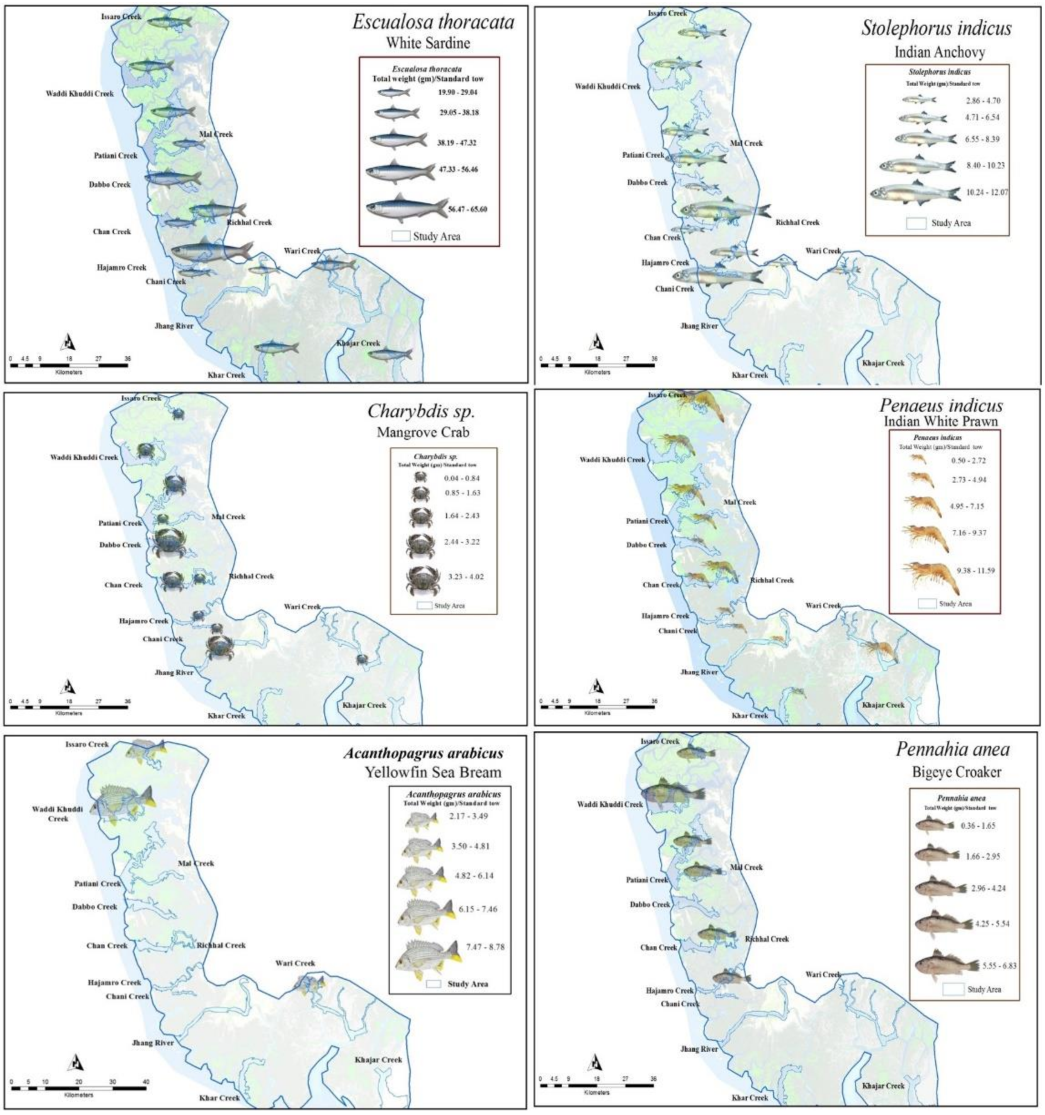

Figure 7: Spatial distribution of selected fish species.

Creek productivity analysis

This complete analysis was performed through GIS Model Builder in ArcGIS 10.7. Figure 8 shows hierarchical chart of the performed analysis to evaluate productivity of each creek. To achieve this goal all parameters were set at an identical scale. Average values of salinity, temperature and depth were taken along with data of selected fish species, i.e., fish catch per tow, fish weight and influential classes from LULC, including mangroves, turbid water and dry and wet mud lands. All layers were then overlaid and produced an estimated weight for each creek to assess productivity of the study area (Table 5).

Figure 9 shows resulting map indicating the overall productivity of Indus creeks. For this the study area ranked as scale 1 to 5 from extremely productive to low productive creeks. Subsequently, the only one extremely productive creek at Indus region was Richhal Creek.

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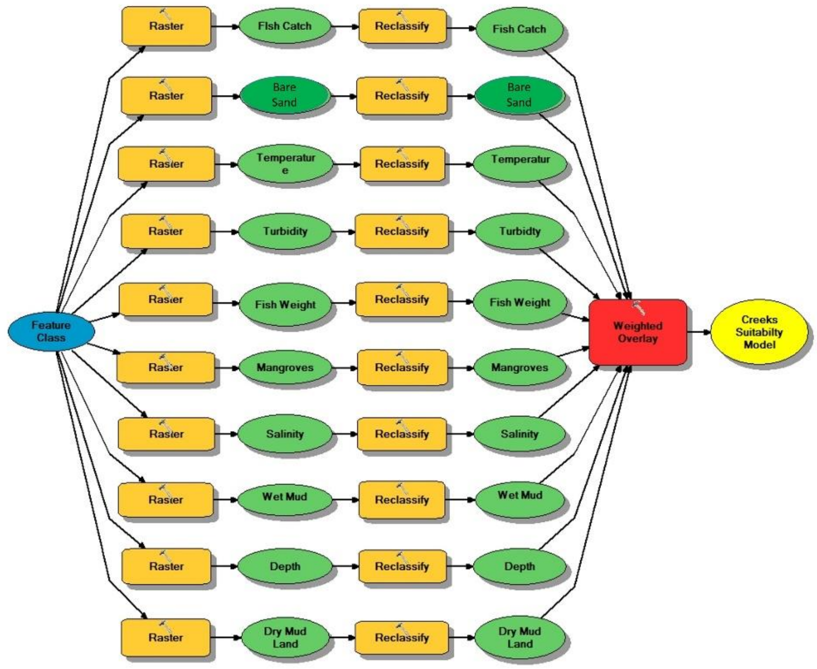

Figure 8: Hierarchical workflow of creeks productivity analysis in ArcGIS 10.7.

Table 5: Estimated weight of each study site through GIS system.

Creeks	Fish Catch	Weight	Bare Sand	Depth (m)	Temperature (°C)	Salinity (psu)	Mangroves	Wet Mud Land	Dry Mud Land	Turbid Water	Weight
Issaro	3.2	4.0	2.0	3.5	5.0	1.0	3.5	4.0	4.0	2.0	32.2
Waddi Khuddi	3.0	3.6	3.0	4.0	5.0	1.5	2.0	4.0	4.0	2.5	32.6
Patiani	2.0	3.5	2.5	5.0	4.5	2.0	4.0	4.0	4.0	3.0	34.5
Mal	3.2	2.4	4.2	3.5	4.0	1.5	3.5	3.5	3.5	2.0	31.3
Dabbo	1.0	5.0	2.5	4.5	3.0	2.0	2.0	3.0	3.0	3.0	29.0
Richhal	3.2	3.5	2.5	5.0	3.0	3.5	5.0	3.5	3.5	4.0	36.7
Chann	2.2	1.0	4.5	3.0	4.5	3.0	2.0	2.0	2.0	2.5	26.7
Chani	3.2	2.0	3.0	2.2	3.0	3.0	0.0	3.0	3.0	4.0	26.4
Hajamaro	3.5	3.5	5.0	3.0	4.5	3.5	1.5	3.0	3.0	4.0	34.5
Khar	3.5	2.0	2.5	2.5	4.0	3.5	2.5	2.0	2.0	4.0	28.5
Khajar	5.0	1.0	3.0	2.0	4.0	3.0	1.0	2.0	2.0	1.0	24.0
Jhang	4.5	2.2	1.5	1.0	4.5	5.0	1.0	2.0	2.0	3.5	27.2
Wari	4.0	3.2	1.0	2.0	3.0	4.5	1.5	1.0	1.0	2.5	23.7

However, highly productive areas were found in the north of Hajamaro Creek. Most of the creeks including Issaro, Waddi Khuddi, Patiani, Jhang, Khar and some parts of Mal, Wari and Dabbo were categorized as productive creeks. While lower parts of Wari and Khajar and mouths of Chann, Hajamaro, Patiani, parts of Mal and Chani creeks were placed under moderately productive regions. Only part of Chann Creek was ranked as low productive region.

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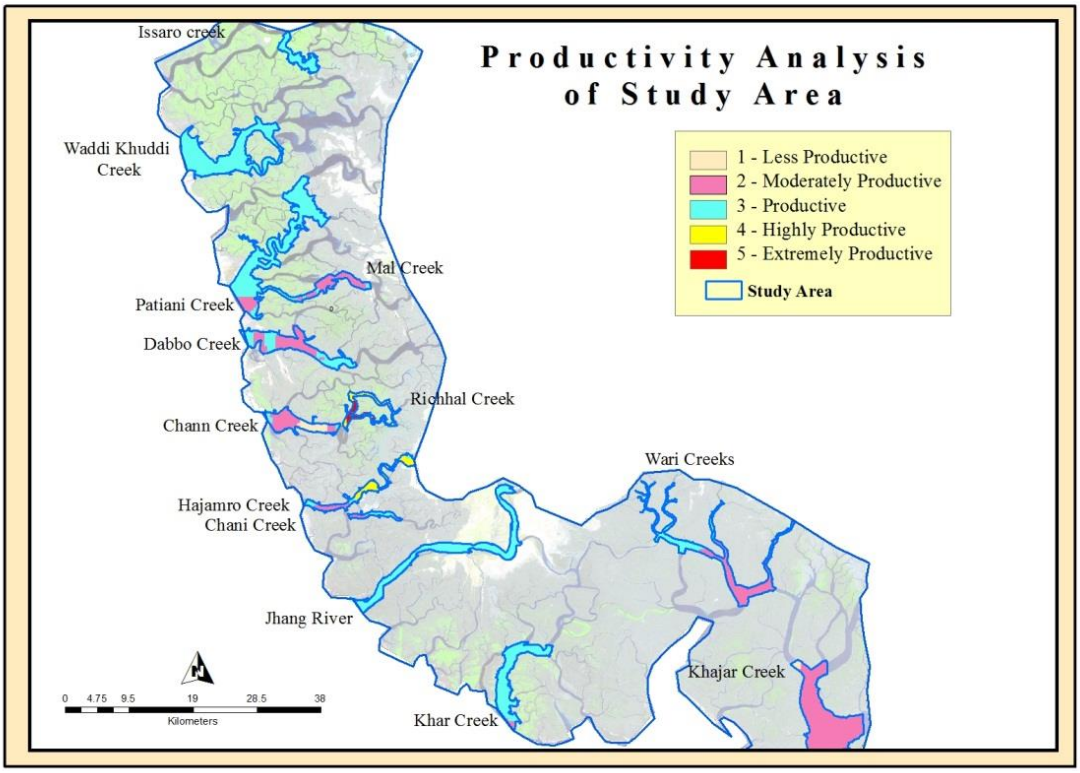

Figure 9: Productivity analysis in different creeks.

Discussion

The results were significant to relate parameters of each creek. Analyses results showed that Richhal Creek, which was termed as extremely productive creek, had reduced salinity level along with moderate temperature and shallow depth (Sarwar, 2015). Ross and Behringer (2019) indicated that mangroves and marshes are main component of coastal ecosystem to control erosion and pollution along with enhancing nutrient to support nursery grounds of invertebrates and fish species. Bell (1986), Clark (1995), and Agbesi (2002) studied oxygen condition, which is an important factor for fish stock distribution, and confirmed a correlation between physical and biophysical environment for essential habitat of fish species. According to Fowler *et al*. (1995), temperature and salinity greatly affect otolith formation in fish species. In this study, seasonal variations of biophysical parameters indicated variations in temperature and salinity not only in different seasons but also within the creeks. Tsuchiya (1981), Blanke and Raynaud (1997) and Agbesi (2002) studies showed that change in water temperature may lead to undercurrents that has high oxygen, which are responsible for dissolved oxygen and nutrients that ultimately affect distribution of fish species. In another study, De la Lanza-Espino *et al*. (2014) reported temperature range of a tropical lagoon to be from 18 to 32ºC depending on the season. In this study,

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overall temperature was ranging between 16 to 31ºC in four seasons. Similarly, salinity was ranging at moderate levels, which is considered ideal for fish production except for few parts of creeks where concentration was higher due to pollutants from urban areas (Sarwar, 2015). Large number of pollutants were found in coastal waters, particularly sewage discharge, waste disposal, oil spills, agricultural and industrial waste that harm fish food (Eng *et al*., 1989), similarly creeks on west of Jhang River showed high levels of salinity and temperature because of being close to urban areas (Sarwar, 2015). Issaro Creek on the west supported the main industrial area of Karachi known as Port Qasim while other creeks including Waddi Khuddi, Patiani, and Mal faced shortage of water and increased contamination levels. Ministry of Food, Agriculture and Livestock of Pakistan (2006) reported that spawning grounds in Indus creek region are adversely affected by industrial waste, land reclamation and sewage waste. It is also responsible for destruction of mangrove swamps causing coastal erosion, shoreline change, and loss of fisheries (Snedaker and Getter, 1985). When contamination increases due to anthropogenic activities, disturbance of the whole food chain and nutrients occurs (Abkenar *et al*., 2020). It may be observed clearly from the results that Hajamaro, Chani and Jhang River received maximum amount of fresh water compared to other creeks, and the catch numbers were in hundreds but with low weight and small length (Sarwar, 2015). These creeks were most affected by the use of banned nets, including encircling net (Katra) and estuarine bag net (Bullo) commonly used in Indus creeks (Ministry of Food, Agriculture and Livestock of Pakistan, 2006; Pitcher and Pramod, 2006; FAO, 2009). Khar, Khajar and Wari creeks on east of Jhang River were ranked as moderately productive zones because they were difficult to access due to strong currents and that is the reason that no or little human activity was observed in those creeks resulting in average high frequency of fish species. However, if fish resources are overexploited, they could not cope or sustain in climatic and environmental change situation of the area (Blanchard *et al*., 2012). Indus creek zone is considered productive and is main spawning ground for fish species and early life stages of fish are less tolerable to any seasonal and environmental change (Post and Evans, 1989; Rijnsdorp *et al*., 2009). It is revealed from the results that RS and GIS techniques in fisheries can be helpful for fisheries management (Meaden, 2000). Based on the findings of this study, it is highly recommended to make GIS mandatory for marine and fish resources in Pakistan to evaluate potential situation of marine habitats.

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