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Spatial mapping and development of a WebGIS application of wetlands of Pakistan

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K E Y W O R D S

Wetlands
GIS
Web GIS applications
Topographic mapping
Land cover/land use
Spatial data
Watershed and sub-watershed
National inventories
Wetlands of Pakistan

A B S T R A C T

Wetlands are valuable resources for wildlife and provide subsistence to communities. In Pakistan, wetlands are distributed in diverse ecosystems throughout the country. Geographic Information System (GIS) is used extensively in natural resource planning and management, all over the world. The information about the wetlands and their natural resources was patchy and was not compiled and updated systematically. Very little information was available in the form of unpublished reports. To fill the information gap, this study was conducted under the Pakistan Wetlands Programme to systematically map the wetlands resources of Pakistan. The paper discusses the procedures and techniques adopted for topographic mapping, satellite image processing and corrections, land cover or land use mapping, watershed and sub-watershed delineation and WebGIS application of the wetlands of Pakistan. This study is first ever comprehensive attempt to develop the spatial data including vector and raster datasets of wetlands at national level. The land cover, topographic maps and other spatial data is available online for the students, researchers and stakeholders. Online data availability will help to monitor and manage wetlands resources on scientific basis and will reduce data duplication. The data standards and techniques applied for the development of this inventory should be effectively used for repeated monitoring of the wetlands. It is also recommended to also develop national inventories including forest and wildlife datasets.

Introduction

Pakistan has diverse wetland ecosystems with rich biodiversity. These wetland resources are distributed almost throughout the landscape of the country. The degree of extent of these wetland ecosystems ranges from the high mountains (alpine wetlands) in Sindh and Balochistan.

The information about the wetlands and their natural resources was patchy and was not compiled and updated systematically. Very little information was either in the form of unpublished reports or available in the form of a superficial list attached to the draft Wetlands Action Plan (2003). Further, the information was available for only 48 wetlands of Pakistan in the Directory of Asian Wetlands Inventory (Lu, 1990). Globally, national wetlands inventories have been developed by various countries to map the extent and characteristics of wetlands. In order to fill the information gaps in Pakistan, a study of spatial mapping of all the significant wetlands of Pakistan was proposed under the Pakistan Wetlands Programme (PWP).

This paper discusses the first ever attempt of its kind in Pakistan to systematically map the wetlands resources with their biological and socio-ecological significance. For the systematic data handling and upgrading for future monitoring, a GIS based database was also developed which was linked with the online application of PWGIS portal for the information dissemination to government, public, and private organisations/agencies for the utilisation in their decision making for natural resources management and planning.

The specific objectives of this study were to develop spatial data layers including topographic, watershed and land cover information of the significant wetlands of Pakistan and to design and implement a mechanism to disseminate and publish data/ information to be used effectively by the national and provincial or territorial conservation agencies for strategic decision-making, regular updates and future monitoring.

Material and Methods

Spatial Data Development

Geospatial information is data referenced to a place - a set of geographic coordinates that can often be gathered, manipulated, and displayed in real time (NGAC, 2009).

For the systematic data collection, processing and dissemination, GIS team adopted a scale dependent spatial layers and metadata development approach that was managed and stored by adopting hierarchal categorisation. The hierarchical approach to wetlands inventory was adapted from 'A Manual for an Inventory of Asian Wetlands' (Finlayson *et al*., 2002) and was modified for Pakistan's situation which is shown in Fig. 1.

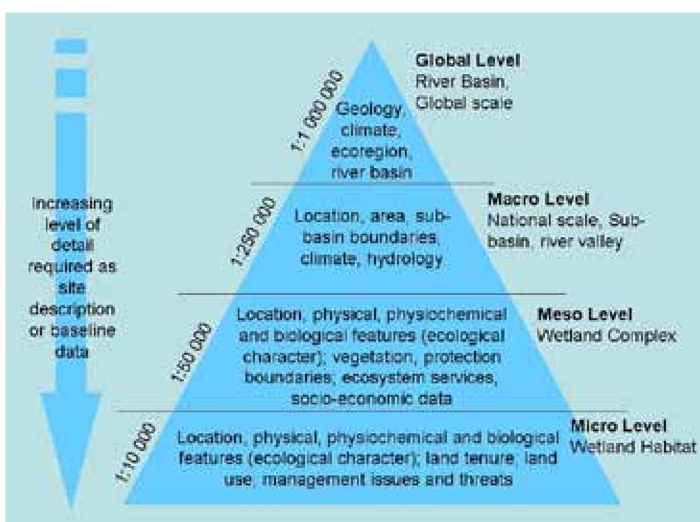


Figure 1: Hierarchical approach to wetlands inventory

Topographic Data Development

Topographic layers such as elevation, aspect, slope, accessibility (road/tracks) of the area, important watersheds/drainage pattern, settlements were established in ArcGIS using 1:250,000, 1:50,000 scale Survey of Pakistan (SoP) map sheets and 1:100,000 scale Russian topographical sheets of Pakistan for the different wetland areas of the country (Fig. 2). This activity was undertaken through scanning and digitisation of each layer. All base layers were stored and formed the baseline GIS. In addition to the topographic sheets, Digital Elevation Model (DEM) of Shuttle Radar Topographic Mission (SRTM) of 90 meter spatial resolution and stereo-pairs of Advanced Spaceborne Thermal Emission Radiometer (ASTER) were also used to collect terrain information of the wetlands area (Lu, 1990). ArcGIS 9.3® and Silcast software were used to generate topology and to develop various types of topographic maps.

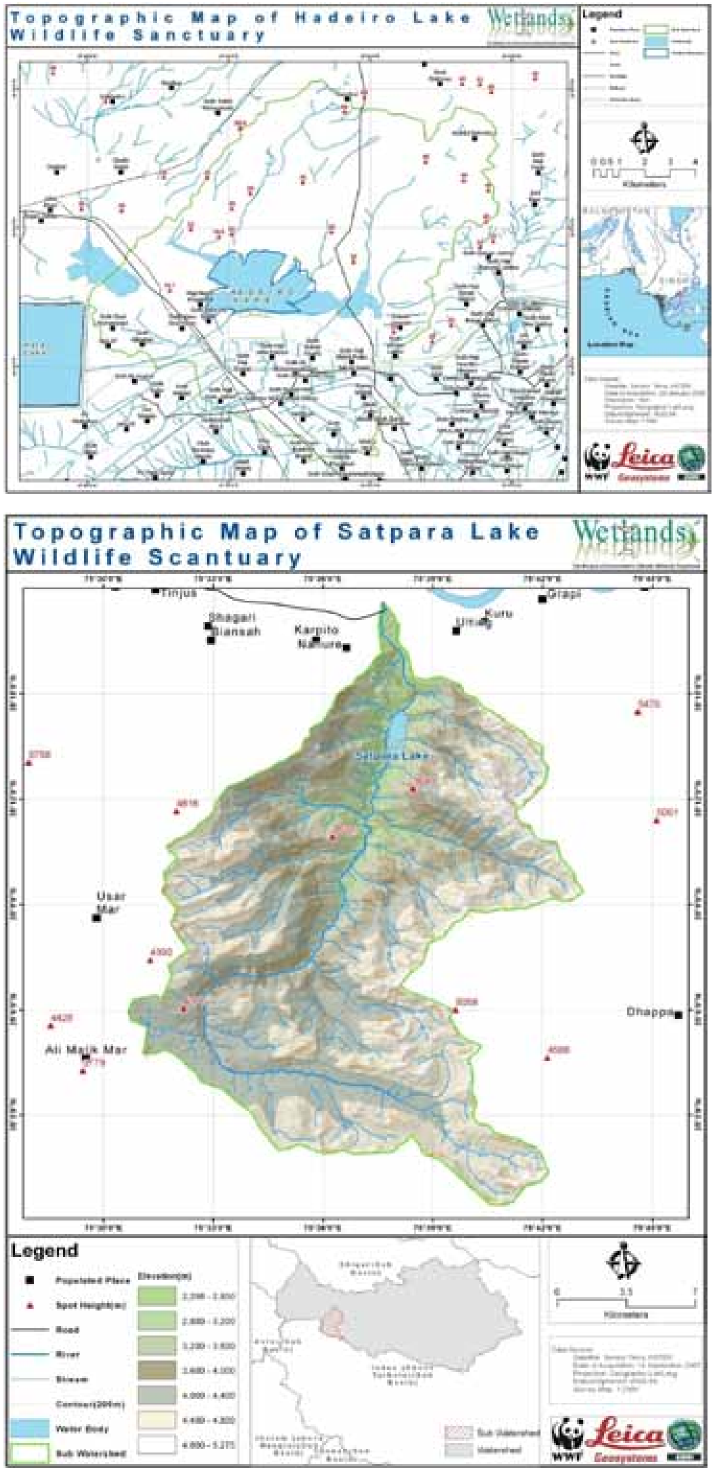


Figure 2: Vector and raster based topographic maps

Raster Data Acquisition and Processing

Suitable and accurate spatial data saves time and cost, and gives accurate and target oriented results (Heipke, 2004). Considering this, all the available satellite images were evaluated and procured on the basis of image quality, season/date of acquisition and cost. The purchase of the images were done on the basis of scale of mapping of different wetlands e.g. medium resolution images (Landsat, ASTER, ALOS) were used for the Wetlands Complexes at 1:50,000 scale; while high-resolution images (SPOT – 5, QuickBird, GeoEye) were used for the micro-level mapping at 1:10,000 scale of the wetlands. One of the achievements was the acquisition of satellite images of the high altitude wetlands areas as most of the northern region of Pakistan were not captured by the satellites or the image quality was poor in those areas due to shadow/snow/cloud. For the new acquisition, a Scientific Team Acquisition Request (STAR) was developed and it was accepted by United States Geological Survey (USGS). As a result, more than 70% of Pakistan was captured by the TERRA satellite on the defined dates and season by WWF – Pakistan. ASTER, placed at TERRA spacecraft is a multi spectral optical sensor with 14 spectral bands that range from visible to thermal infrared band. VNIR has two (2) near infra red bands which have similar wavelengths, those are 3n (nadir looking) and 3b (backward looking). The 3b band is used to achieve the backward looking, with setting angle between the backward looking and the nadir looking is designed to be 27, 60° (Lin, 2002).

To enhance the positional accuracy of the images, all the images were orthorectified that increases positional accuracy and removes terrain distortions. The quality of the images was improved by high resolution merging with the available panchromatic layer of better resolution. Figure 3 highlights the high-resolution (0.6 m) multispectral image with improved/greater level of details which is to be integrated with GIS layers.

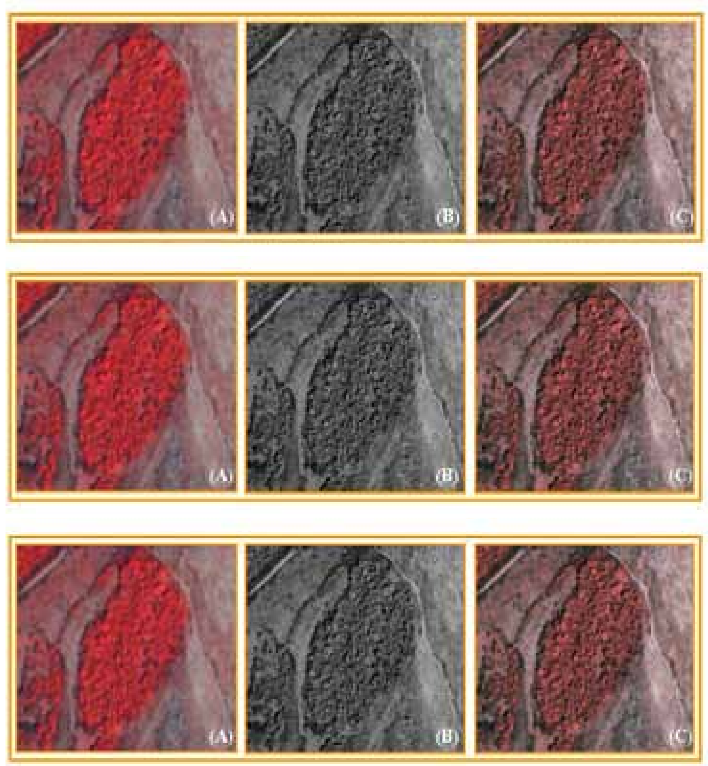


Figure 3: Zoomed parts of multispectral (A), panchromatic (B) and high resolution merged (C) imagery

Watershed and Sub-watershed Mapping

A watershed is defined as the entire area drained by a river system or by one of its main tributaries (Revenga *et al*., 1998). Watersheds play a critical role in the natural functioning of the Earth thus considered as one of the primary planning units in the field of natural resource management. The automated extraction of topographic classes from DEM is recognised as a viable alternative to traditional surveys and manual evaluation of topographic maps, particularly as the quality and coverage of DEM data increases (Garbrecht and Martz, 1996).

In this study, sub basins and watersheds (Fig. 4) have been delineated on the basis of corrected SRTM DEM acquired from CGIAR data download center. Sub watersheds were delineated based on the DEM derived from ASTER images of which the vertical accuracy approaches to 25 m, but in area with less vegetation coverage, the accuracy can rise approximately to 9-11m (Goncalves and Oliveira, 2004; Selby, 2004).

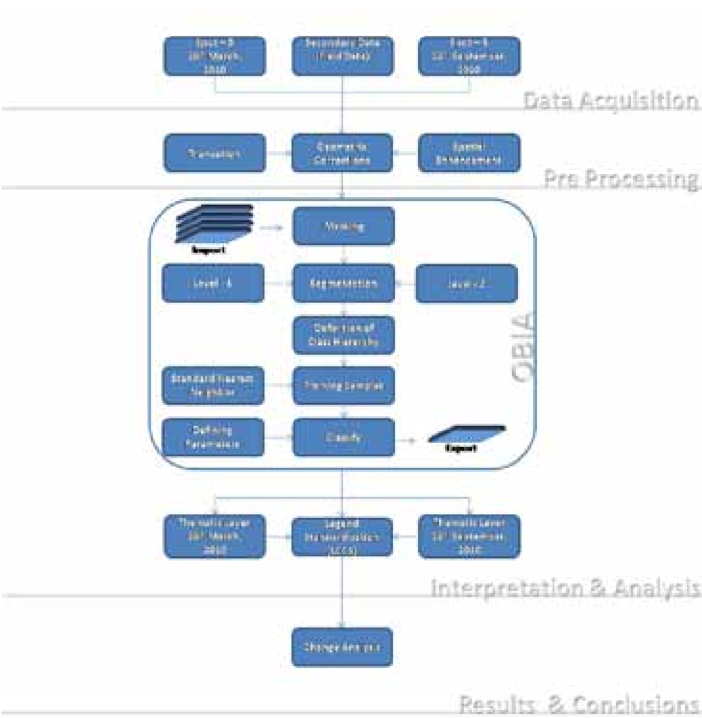


Figure 4: Watershed and Sub-watershed mapping flow diagram

Depression less DEM was prepared by calculating the sink depth and then applies the fill function. In another iteration process, the flow direction was calculated using D8 method that leads to determine all other functions like flow accumulations, stream links, and then finally watershed and stream network (Garbrecht and Martz, 1996). *Flow Length* command was used to calculate the length of the longest flow path within a given basin. Ninety meter spatial resolution DEM was used to determine the watershed boundaries with the help of flow length (Upstream). However thirty meter spatial resolution ASTER based DEM were used to determine the sub watershed boundaries.

Land Cover / Land Use Mapping

In a satellite image, it is possible to assemble groups of similar pixels into classes that are associated with the informational categories of interest to users of remotely sensed data and it is referred as image classification (Richards, 1999; Weng, 2007). The objective of image classification is to extract information from a satellite image. There are number of techniques to classify and quantify features which come under supervised and unsupervised method. In this study, supervised classification techniques were used to classify the satellite images of major wetland areas which specifically include Maximum Likelihood Classification (MLC) and Object Based Image Analysis. MLC was applied on medium resolution satellite images and the wetland areas.

The MLC tool considers both the variances and covariance of the class signatures when assigning each cell to one of the classes represented in the signature file (Kamble and Dule, 2012). With the assumption that the distribution of a class sample is normal, a class can be characterised by the mean vector and the covariance matrix. Given these two characteristics for each cell value, the statistical probability is computed for each class to determine the membership of the cells to the class. The default parameters of the software were specified according to our area of interest, each cell is classified to the class to which it has the highest probability of being a member. If the likelihood of occurrence of some classes is higher (or lower) than the average then the weights for the classes with special probabilities are specified in the a priori file. In this situation, a priori file assists in the allocation of cells that lie in the statistical overlap between two classes. These cells are more accurately assigned to the appropriate class, resulting in a better classification. This weighting approach to classification is referred to as the probability of the assigned class to the brightness values. Consequently, classes that have fewer cells than the average in the sample will receive weights below the average and those with more cells will receive weights greater than the average. As a result, the respective classes will have more or fewer cells assigned to them. When a MLC is performed, an optional output confidence raster was also produced. This raster shows the levels of classification confidence (iterations). The level of confidence, coded in the confidence raster as one, consists of cells with the shortest distance to any mean vector stored in the input signature file; therefore, the classification of these cells has highest certainty (Esri Development Network, 2008). This classification technique was applied on the medium resolution satellite images or the wetlands area that cover more than 50 km^2 land area.

In this study, some of the wetlands which requires high level of acccuracy depeneding upon the level and size of the wetlands and ultimately resolution of satellite images, Object Based Image Analysis technique was used. It is an advanced and most recent classification technique specially meant for processing and analysing high resolution satelitte images. Digital Image Processing software i.e. Definiens developer® has been purchased and used for the analysis.

The object-based classification starts with segmentation of the image into highly homogeneous image regions (or objects) (Antonio *et al.,* 1998). These image segments correspond to the approximations of real world objects which can be characterised by shape and texture. Multiresolution filter was prefeered out of Chessboard, Quadtree, Contrast Split and Spectral Difference Contrast Filter due to its capacity of including texture, sixe, scale and weightage values of the image objects.

Field Surveys

Seventy five field surveys were conducted to various important ecological wetland areas (Fig. 5) The main objective of the field surveys was to process and also verify satellite image interpretation with ground reference data. For this purpose, A3 and A2 sized field maps of satellite images in False Colour Composites (FCC) and Natural Colour Composites were developed for field data collection activities at various scales depending on the size of the wetland. Garmin Map 76 GPS Receiver, digital camera and binocular were used to record different number of ground control points and respective field observations. The land features that appeared as spectral abnormality in the satellite images were the prime focus of the field surveys. Accessible localities were surveyed while the inaccessible areas were verified through the information from government officials and local communities. In addition, the classification processes of the images were further validated by visual inspection of high resolution images available on the World

Wide Web. GoogleTM Earth combines different resolution images and updates them on a rolling basis (Conchedda *et al*., 2008).

Development of WebGIS Application

The database designed in this study was deployed in Web – based information architecture. Web based applications are the applications that require just a browser to function. The server – side application logic runs on a centralised web server in the data center.

For this purpose, PostgreSQL which is an open source, highly robust SQL 92 compliant database system was used. It contains almost all of the features that one can find in other commercial or open source databases along with some additions (Stones and Mathew, 2001). Each web page, like the screens of traditional applications, presents information to the user. The information normally comes from a Postgre SQL database server and enabling the user to view, modify or delete the authorised contents. This application was built on the same client server architecture which significantly support geographically distributed organisational structure of the Pakistan Wetlands Programme. The present PWGIS integrated database built in PostgreSQL/PostGIS will provide platform to develop a need specific online GIS by integrating it with web mapping services of UMN –Mapserver through PHP and JavaScript. This comprehensive application allows viewing, editing and analysing the spatial and non – spatial data of Pakistan Wetlands Inventory through http://pwi.pakistanwetlands.org.

Figure 5: Field photographs during wetlands surveys

Results and Discussion

This study is the first ever attempt of its kind in Pakistan to systematically map the wetlands resources with their biological and socio-ecological significance. One of the main objectives of the present study was to enhance the role of spatial data in decision making by developing and sharing it globally.

The first step of the study was spatial data development including topographic data and land cover maps. Landcover maps of the wetlands complexes at 1:50,000 scale and the significant wetlands at 1:10,000 scale were developed using medium and high resolution data respectively. The land cover maps of Central Indus Wetlands Complex (CIWC) and Taunsa Barrage (that is within the CIWC) at different level of details is shown in Fig. 6 and Table 1.

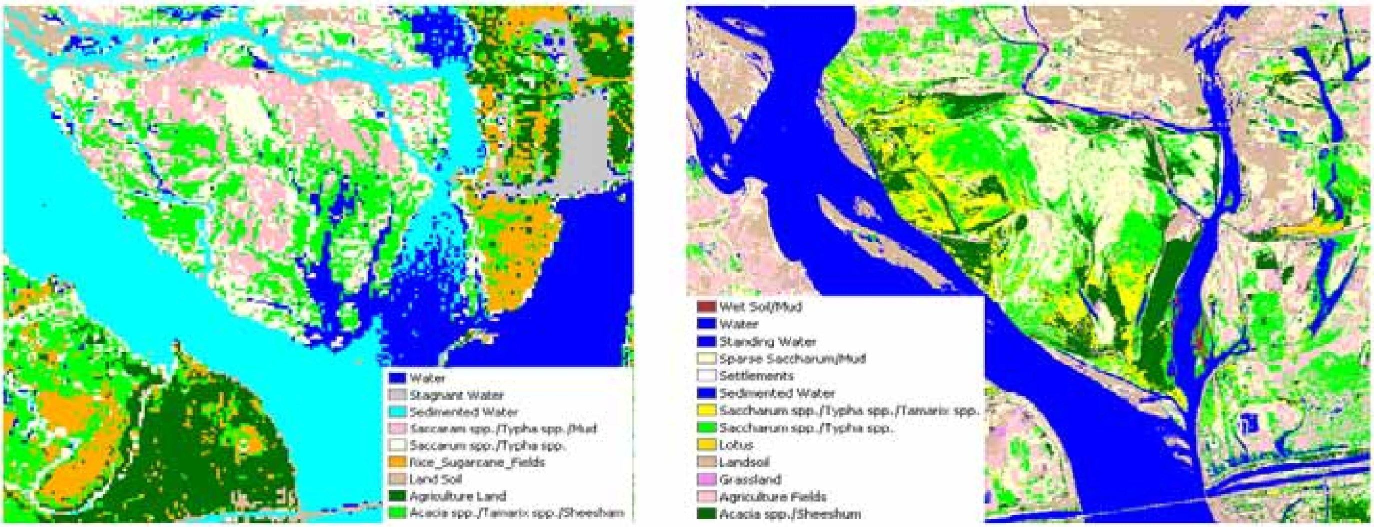
This study suggested method and techniques to delineate watershed boundaries and drainage network at multi scale. At smaller scale (1:10,000,000) three basins were delineated i.e. Dasht, Hamun-i-Mashkhel and Indus (Fig. 7 & 8). In addition, 46 sub basins and 287 watersheds were identified at national level. These watersheds and sub-watershed boundaries are useful to compile baseline information of the respective areas and their *in situ* conservation activities.

Table 1: Identified basins, sub basins and watersheds of Pakistan

Sr. No.	Basin	Sub Basin	Watershed
1	Indus	35	171
2	Dasht	8	37
3	Hamun-i-Mashkhel	3	82

Over the past decade, web-based GIS have become an integrated tool for storing, manipulating, visualising and analysing spatial data. Under the study, a web-based GIS data portal was developed which comprised of all the GIS data layers of the wetlands of Pakistan. The information system is accessible through World Wide Web to government, public, and private organisations/agencies for the utilisation in their decision making for natural resources management and planning. Pakistan Wetlands Inventory, at national level, has provided a standard platform where the relevant departments and agencies from any part of the country can share and access the relevant data and information.

Current study is first comprehensive attempt to analyse the extent and characterisation of the wetlands of Pakistan. Thoroughly documented standards and techniques applied for the development of this inventory can also be effectively used for repeated monitoring of these wetlands. This national level study also provides the basis for developing other key national inventories including forest and wildlife.



(a) (b)

Figure 6: Land cover slice of CIWC developed using (a) ASTER and (b) QuickBird satellite images

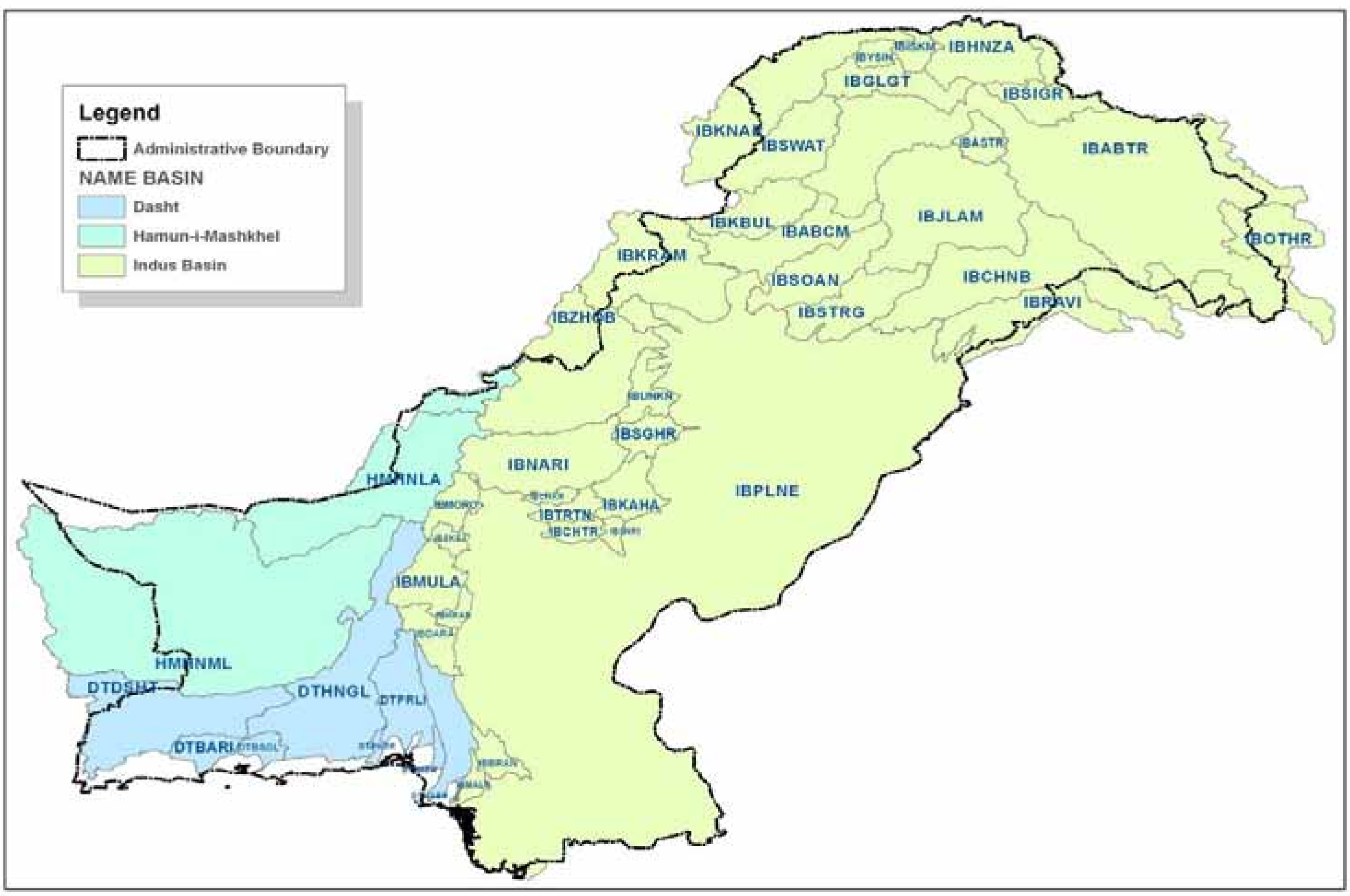


Figure 7: Extent of Indus, Dasht and Hamun-i-Mashkhel basins in Pakistan

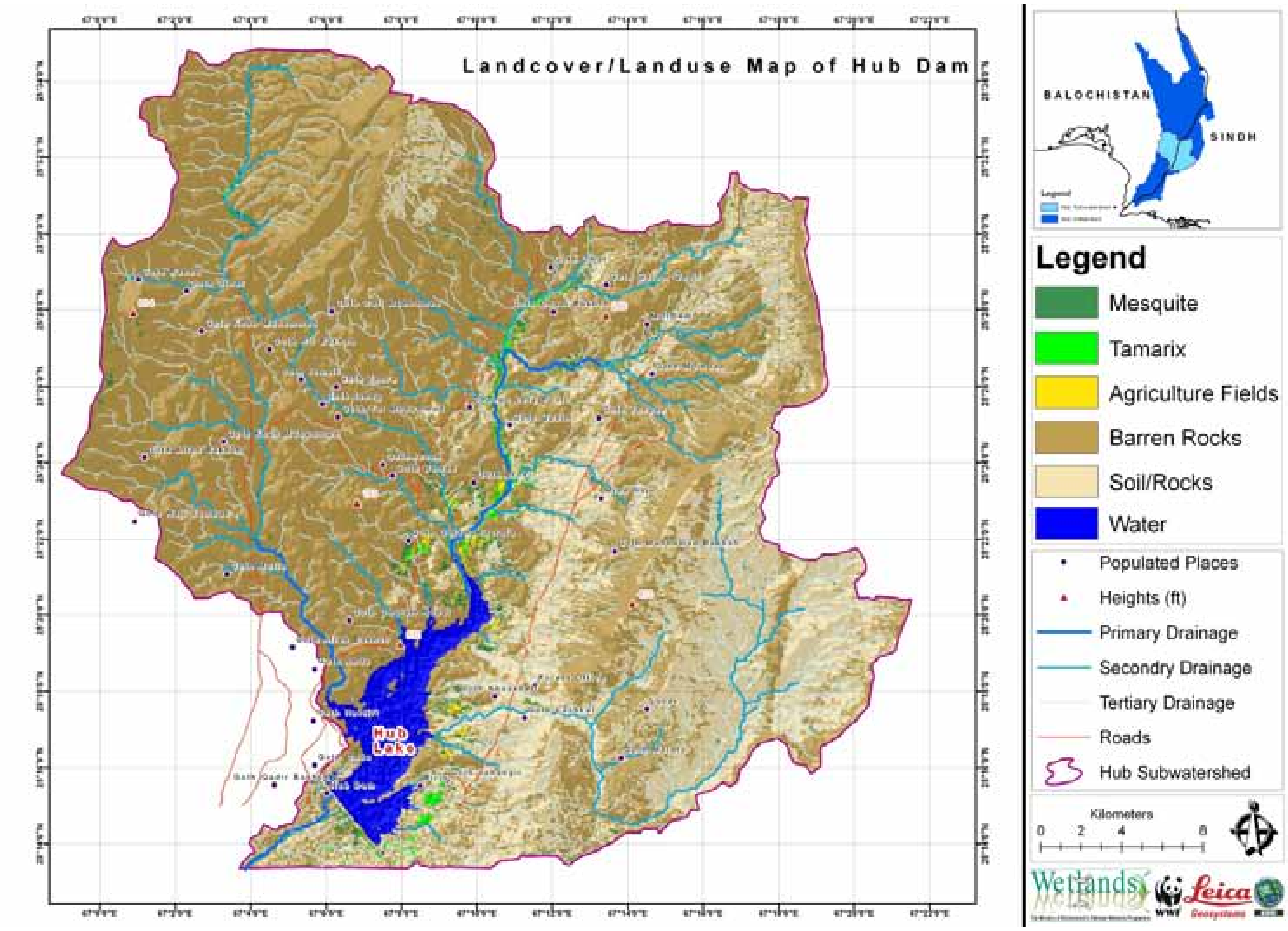


Figure 8: Sub-watershed based Land cover/Land use of Hub Dam

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