Hydrological assessment of significant lakes in Broghil and Qurumbar Valleys, Northern Alpine Wetlands Complex

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K E Y W O R D S

Broghil lakes
Bathymetry
Water quality
Thermocline
Aquatic productivity
Migratory waterfowl species
Land use and climate change
Qurumbar Lake
Surkheng Lake

A B S T R A C T

Vital hydrological investigations about significant lakes of Broghil and Qurumbar Vallies were made, which mainly comprised of bathymetric, water quality, aquatic flora and micro-fauna. These were the first intensive and technical assessment ever made for wetlands of the area and its buffer zones. The major explorations include: maximum, average depths, lake volume and surface to volume ratio and discharge. Apart from bathymetric investigations, the water quality of lakes was also being monitored in correlation with lake's morphometry, and topography was developed to envisage their status of vulnerability to land use change and climate change. The hydrological parameters were mostly observed as habitat for waterfowls and their extent of biological aquatic productivity. Qurumbar Lake is one of the highest biologically active water bodies present on earth and there have been sightings of a broad spectrum of biological life, from phyto and zooplankton to important migratory waterfowl species, but, enigmatically, no fish. The investigation revealed that the valley has been bestowed with unique ecosystems, which still up to some extent are virgin and needs attention from conservation agencies. The information being gathered is preliminary and, therefore, further investigation are required for developing management plans and conservation strategies.

Introduction

Broghil valley is located at a distance of 250 km from main Chitral town and is the northern most valley of Chitral district in Khyber Pakhtunkhwa province of Pakistan (Fig. 1). By virtue of its strategic location having both internal and international borders, Broghil is one of the most important valleys in the region. Towards the north, the valley is connected with famous Wakhan strip of Afghanistan through the famous "Broghil Pass". Another important pass "Darwaza" connects Broghil with Afghanistan in the northwest. Broghil pass for the large part of the year remains open for the back and forth motion of the communities, as the population from both sides have familial and tribal relationship with each other since centuries. In the southeast direction, the valley is connected with Yasin valley of Gilgit-Baltistan region via Darkot Pass. Towards east, the valley joins the Qurumbar valley through famous Qurumbar pass towards Ghizer district of Gilgit-Baltistan. In the south, Broghil joins the main valley of Yarkhun towards Mastuj and Chitral town. The valley runs narrowly from southwest to northeast along the Broghil River with high mountains on both sides. The stable and somehow open slopes on both sides of the river provide space for settlement and agriculture practices. The valley is comprised of high mountain peaks, wide plains, steep slopes and deep canyons inhabited by "Wakhi" people. It covers a total area of 124,964ha. The history of Broghil dates back to centuries when communities from different tribal backgrounds i.e. Wakhan, Tajikistan, China etc. started pouring into the Broghil valley while searching for rich pastures and safe refuge (Cited in Said *et al*., 2007).

The area mostly comprises of mountainous tracts. The elevation of the area ranges from 3,280m at Kishmanjah village to 4,304m at Qurumbar Lake in northeast. The terrain of the area is undulating comprising of steep mountains, wide stretch grassy plains and narrow valleys. Broghil valley is characterised by snow clad mountains, narrow passes and fairy meadows. There are more than 30 small and large lakes in the valley and the total area covered by peatlands and lakes is almost 3,400 ha (PWP, 2010).

All large and small streams drain ultimately into the Chitral River that itself originates mainly from Chiantar glacier and Qurumbar Lake's adjacent glaciers and watersheds.

The Broghil River collects numerous tributaries from Chiantar to Darband, locally called Xerao meaning stream. The most important Xeraos (stream/tributaries) that feed into Broghil River from Lashkargaz (last village of Broghil valley) to Kishmanjah (first village) are Rabat Xerao, Kahsherdoor Xerao, Ganj Xerao, Yok Xerao, Warsing Xerao, Kishmanjah Xerao, Chokzard Xerao and Sakhir Xerao (Cited in Said *et al*., 2007).

The climate of area is characterised as Dry Temperate. It is hot in summers (July-August), ranging from very hot in lowlands to warm in the uplands and cool in the higher elevations. Located at height above 3,000 m, the Broghil is haunted by harsh climatic conditions. The temperature remains below freezing point for larger part of the year. The average precipitation in the area has been recorded about 1,000mm.

The unique climatic conditions and extreme variation in altitude and geographic aspect has resulted in diverse ecosystems and vegetation zones in Broghil valley. This diverse range of vegetation and ecological zones also support a rich floral and faunal diversity. The Broghil valley is of high importance in maintaining a great diversity of wetlands including high altitude alpine lakes and ponds, peatlands areas, alpine pastures, riparian areas, Birch, Salix and Juniper forests and riparian vegetation. Beside the habitat of other wildlife species, these resources collectively provide breeding ground to waterbirds and staging ground to waterfowl mostly in autumn and spring seasons. The Pakistan Wetlands Programme's Northern Alpine Wetlands Complex under the mandate to establish the NAWC conservancy, proposed the area to the custodian Khyber Pakhtunkhwa (KP) Wildlife Department for an appropriate protected status. After the baseline studies of the wetlands resources conducted in 2007 and 2008, the valley was explored as one of the potential area for a national or even for an international protected status. Through the joint efforts of the KP Wildlife

Department, the Pakistan Wetlands Programme and the custodian community organisation (Chiantar Welfare Society, Broghil), the Broghil Valley was notified as National Park under the KP Wildlife (Protection, Preservation, Conservation and Management) Act, 1975. The final notification was made on August 25th, 2010, and was circulated to all the concerned departments/organisations from the office of the Environment Department, Government of KP. In future, this wetlands based National Park will be managed by the Wildlife Department of KP with the active participation of the Broghil valley community in Chitral district. After the Chitral GoI National Park, this is the second National Park in Chitral district and the phenomenon is very new to the lowest educated Wakhi community of the district. This designation of the area has also served as a benchmark for the trans-boundary protected area initiatives which resulted in the notification of Qurumbar National Park by the Government of Gilgit Baltistan, and has the potential to link other regions of the bordering Wakhan corridor in Afghanistan at international level (Said *et al*., 2007).

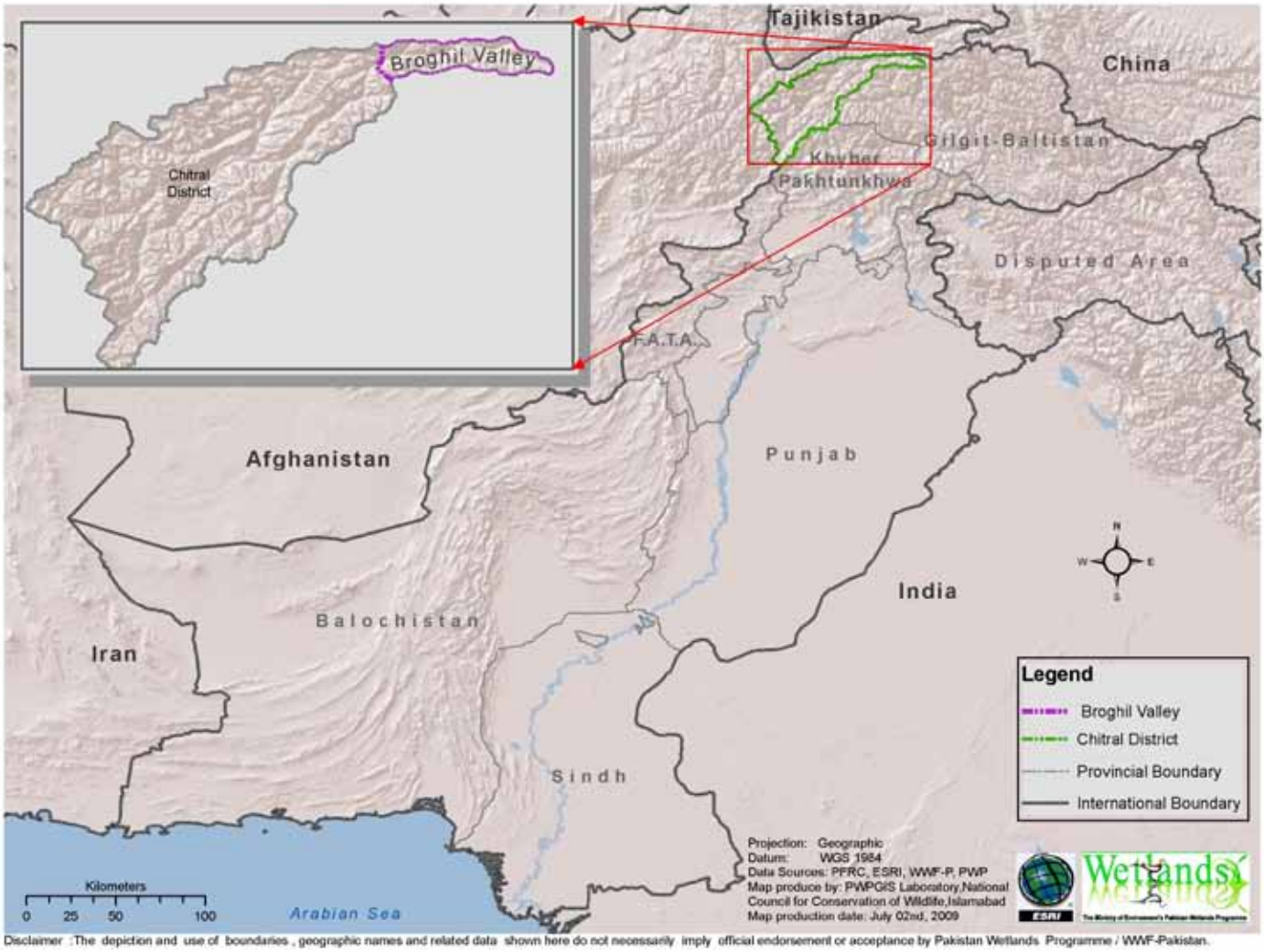

Figure 1: Location map of Broghil Valley, Northern Alpine Wetlands Complex

Material and Methods

Bathymetry

Bathymetric maps are maps that show the topography of the bottom of a lake. The topography is shown in the same way that topographic maps describe terrestrial landscape with contours. The maps are based on depth soundings taken from a boat floating on the surface of the water body. These maps are used to calculate a variety of parameters for a lake such as area, perimeter, maximum depth, littoral area, and volume. Bathymetric maps are used for a wide variety of environmental assessment purposes (BC MoE, 2009).

State of the art incarnations like GIS, GPS and Sounder technologies provided means to record the bathymetry of all selected lakes of the region. For further traversing on the surface of lake, Depth Sounder and GPS assembly were installed on the *SOAR* inflatable boat, which was powered by an eco-friendly four-stroke *Yamaha 4 HP* outboard motor. Transect lines were cruised on the surface area of selected lakes with 50m resolutions which took us approximately five days for each lake (Khan, 2010).

Outline maps of selected lakes

Outline maps of each lake were developed using *Google Earth* images and polygons from previous surveys. Outline information maps were uploaded to Depth Sounder's memory for display in the screen for navigation purposes. Depth data were acquired using transducer and automatically logged in the built in data-loggers in the system (Garmin Sounder Map 298). The logged data were being downloaded on daily basis using *MapSource* software. For data enhancement, we processed and cleaned the information using *MapSource* and *Microsoft Excel*. Later on, the partially processed data were further transferred to GIS interfaces e.g. *ArcGIS 9.2.1*.

Boat and Sounder Requirement

A self-propelled vessel called SOAR canoe was employed; the most common setup is a boat of minimum draft (i.e. inflatable) fitted with a short-leg outboard (petrol) motor for safe operation on the lake. The configuration was suitable for use in relatively shallow water conditions when near the shoreline but also large enough to handle any weather and water conditions. *SOAR Canoe* was chosen and the transducer was mounted in a way that it remained at a constant depth (which was later on accounted during the data manipulation phase) and was also far enough away from the propeller to avoid turbulence and potential interference in the sonar signals. The sounder/GPS unit was also capable of digitally logging (recording) the collected X, Y (surface location), and Z (depth) data for subsequent downloading and import into a GIS package. The positioning system was configured to record the coordinates in a standardised format that can be easily translated into UTM co-ordinates (BC MoE, 2009).

Boat and Sounder Operation

Excessive speed was avoided during surveys for not causing turbulence under the transducer, which could result in poor soundings. Many other good rules-of-thumb were followed like not cruising too quick near the shoreline as it increases the likelihood of damaging the boat, motor, or transducer by striking the lake bottom (rocks), submerged flora, or other debris and going too close to the shore is also counterproductive because the sounder will often lose the signal in shallow water.

The following principles were followed for using the sounder equipment:

a. The unit was tested before going in the field to become familiar with its operation and to ensure that the unit is tracking and recording both the location and depth data correctly;

b. The operating frequency of the sounder was wet in order to provide the best resolution and detail in the soundings. PWP's unit feature dual frequency 50kHz and 200kHz. The 200kHz setting would be for water less than 100m deep and the 50kHz setting for deeper water because it has a wider cone angle. The instrument was set with 200kHz as the lakes are less than 100m deep;

c. The sensitivity (also known as gain) was tested in order to ensure that enough echoes are being picked up by the receiver. If the sensitivity is set too low, the signal from the bottom of the lake will be weak; if the sensitivity is set too high, the receiver will collect too much noise and it may be difficult to differentiate detail from the signals. In setting the sounding frequency, a good rule of thumb was followed i.e. recording rate of one data point per second;

d. Manually spot soundings were also conducted at the beginning of the survey and also calibrated the sounder accordingly. Spot soundings are depths taken manually using a metre stick or weighted measured line, depending on the depth (Khan, 2010)

Field Procedure and Data Collection

Shoreline Cruise

In the beginning of the depth sounding process, we cruised around the lake shoreline and formed an electronic outline of the lake on the sounder screen. We tried our level best to get as close as possible to the shoreline without hitting bottom or submerged rocks. During shoreline cruise, we noted all the key limnological features like inlets and outlets and marked them on the GPS (Khan, 2010).

E-line

After shoreline cruising, we traversed the lake doing sounding crossing the middle by cruising horizontally and vertically in the lake, which is termed as E-line. These E-lines were used as reference point for transects coverage (Khan, 2010).

Transect Coverage

As the shoreline cruising completed, we began doing transects back and forth across the lake, perpendicular to the E-line and working from one end of the lake to the other. Exact locations of transects were not needed to be predetermined, but some general rules was ensured to have good coverage of the lake. This in turn affects the quality and quantity of the data gathered and, therefore, the final bathymetric map. The following guidelines were observed when planning the layout of transects:

a. Transects were roughly parallel to each other and as close to perpendicular to the shore as possible;

b. The distance between transects was discretionary, but was always close enough to allow for reasonable interpolation by the 3-D surface generating application during the final mapping process;

c. The more transects, the more accurately the depth contours can be mapped. Generally, the smaller the lake, the closer are transects. In the case of an irregular lake like Surkheng Zhui, more transects are required to determine the shape of the lake bottom and water volume;

d. All areas of the lake were mapped.

Data analyses and presentations

Bathymetric maps

Final bathymetric maps were produced using series of techniques. Data were downloaded from Sounder's internal data logger into a laptop machines using *MapSource* package. The dataset were then imported into MS Excel spreadsheet where data were sorted based on the Depth Valid field and then deleted all the false values and the Position Valid Field was used for deleting all bad recorded data. This exercise reduced the number of rows in the sheet. Formulae applied for converting coordinates system into UTM and decimals.

The depth values were converted from positive meters to negative values and added a 20 cm for transducer depth technically called *the Draft*. The sheets were saved on the lake name.

For developing a 3-D model of the lake, the collected three dimensional coordinates (x, y and z) were used as basic information for a very specific, special and spatial model called TIN *(Triangulated Irregular Network)*, which is generally used in GIS for representation of irregular distributed physical land and sea or lake-bottom. This model actually arranges irregular distributed lines or nodes with three dimensional coordinates and shape them in a network of non-overlapping triangles. GIS infrastructure provides ample means and ways for more in depth and accurate information (BC MoE 2009).

Lake volume computation

Mean depth of the lakes was multiplied by the lake surface area. Mean depths were obtained by averaging depth soundings. For a reliable average, the soundings were spaced in a uniform grid pattern. Depth soundings for very shallow water (e.g., close to shore) was omitted as it is very common source of error in this method.

All soundings of the lake were summed and then were divided by the number of soundings to obtain mean depth. Lake volume equals mean depth times lake area (Taube, 2000).

Lake Volume = Mean Depth X Lake Area
Hydraulic Residence Time of Lakes

Hydraulic Residence Time = Volume / Flow Rate (Holdren *et al*., 2001).

Water Quality (*In-situ* Monitoring)

Hydrolab Multiprobe MS 5 was used for *in-situ* monitoring of water quality. The *Hydrolab* being connected with 25m long data cable and used to lower for vertical profiling of lakes with a meter resolution. The data being monitored were logged in the Toshiba laptop machine using *Hydras 3LT* software. The reading interval was set at 3 seconds and for further QC, three reading were recorded at same depth. The Multiprobe equipment senses and monitor the Water Temperature, pH, Electric Conductivity (EC), Salinity, Total Dissolved Solids (TDS), Sensor's Depth, Oxidation Reduction Potential (ORP), Luminescence Dissolved Oxygen (LDO) and Percent Saturation of Oxygen (% Sat).

The *Hydrolab* unit uses internal and external batteries, both were properly checked and extra backup were taken along for any emergency purpose. For better results, Dura Cell and Energisers battery cells were used as an external power to avoid any inconvenience in the field.

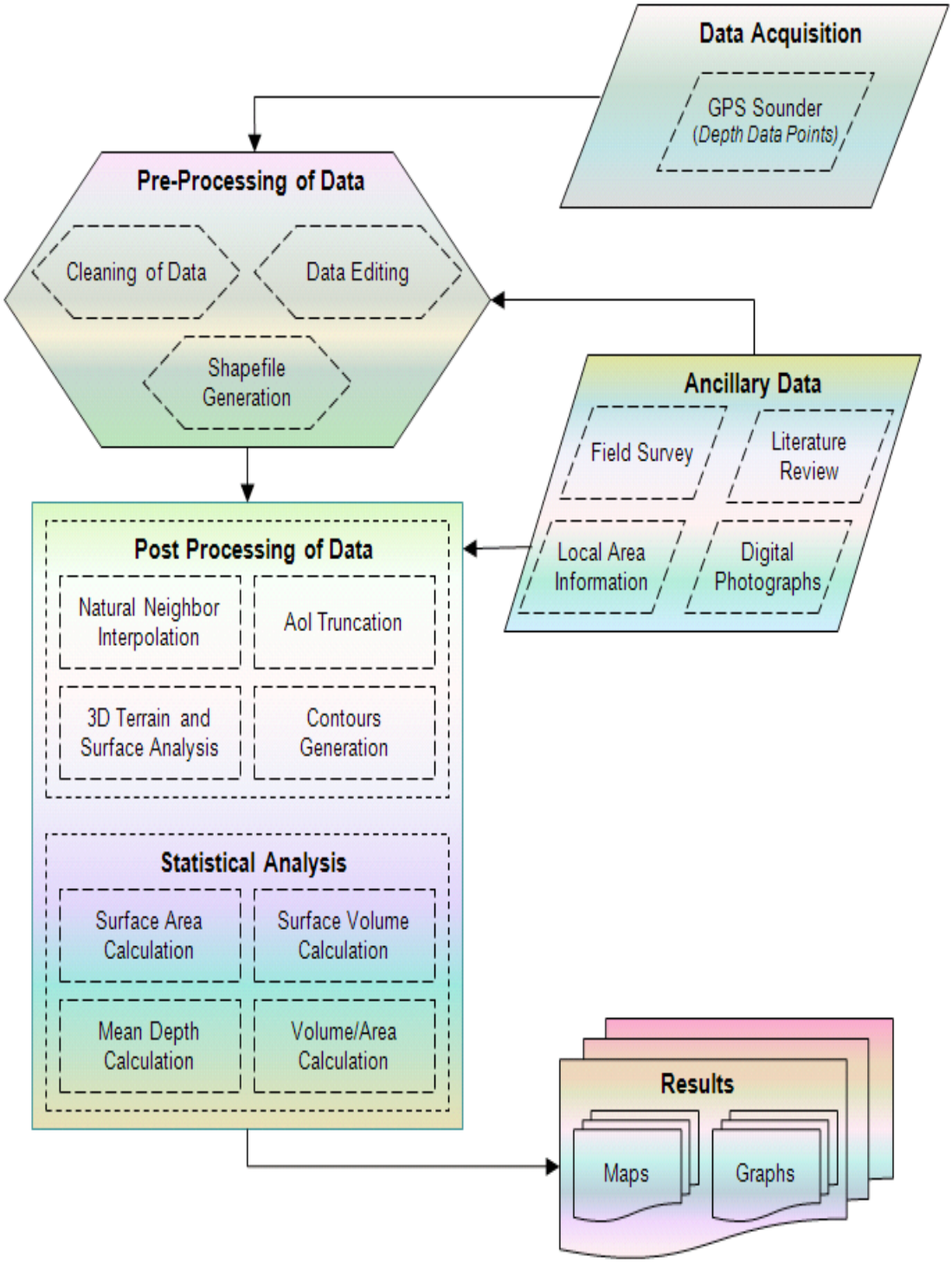

Figure 2: Methodology employed in development of bathymetric maps

Hydrolab Calibration

The *Hydrolab* units used was calibrated with standard solutions after every 25 readings in the field. The standard solution with required parameters and known values were taken along and were used to calibrate all the sensors with regular interval. Even though the instrument was properly calibrated before plunging into field but for safety and QC/QA purposes, the practices being repeated with recommended interval.

Water Quality Sensing Assembly

The water quality sensing unit comprises of Hydrolab MS 5, extra data cable of length 25m, a Laptop and a spray gun of distilled water being set on the SOAR Canoe boat along with two trained persons. We cruised to required depth location and hence *in-situ* monitoring was conducted with aforementioned methodology. For QC/QA purposes, the monitoring were conducted and data was logged while descending and ascending the *Hydrolab* as the unit also log depth of the sensing point, in order to compare both the readings. The Hydras 3LT software package offers the facility to export the readings to an Excel Spreadsheet, which was the easiest way to edit and clean the data on site.

Results and Discussion

Surkheng Zhui Lake

Morphology of Surkheng Zhui Lake

Surkheng Zhui is morphologically a fish shaped lake and located at the border of the Broghil Valley, Pakistan with the Wakhan Corridor of Afghanistan. It is a mountain pass and the local communities use it for going back and forth to Afghanistan. It is a bluish green lake and appears as blue gemstone from the very top of the mountain. The trail is very steep and therefore, very tricky for the horses and donkeys to transport the gears, food stuffs and even the staff.

Surkheng Zhui is a vernacular name; where *Surkheng* mean Reddish and *Zhui* mean Lake. Actually the lake water is not reddish but the mountain towards Wakhan appears as red from the far away distance. It is surrounded by three mountains and study reveals that the lake is 24m deep in south western portion, where the gorge intrudes into the lake. Anthropogenic affects are negligible. The water quality and bathymetric information depict key facts about the limnological aspects of the lake.

Water Quality of Surkheng Zhui Lake

Because of the current law and order situation, access is limited to the area and therefore, the lake is protected and untouched. The *Secchi* Depth recorded is 13 m, which is pretty high transparency and is therefore, can be classified as Oligotrophic. Lake bottom in the littoral zone is rocky and appeared sandy on the western side because of the shore area. Aquatic vegetation observed are emergent such as *Polygonum* and *Juncus* and submerged appeared in few spots are Chara. Thermocline seems have been developed and a unique attribute is that the deepest portion of lake have dissolved oxygen all the way up to 20m. No fish life was observed and amphibians like toad and frog have rarely been sighted. The lake shore was full of larvae and zooplanktons, and therefore, was very attractive for birds. ORP value is pretty high and therefore should be further investigated.

Dynamisms is a beauty of wetlands ecosystems, status of any lake varies across the seasons and even within day period. Apart from the temporal variation, the spatial variation within a lake (horizontally and vertically), are other key attributes that support the dependant biodiversity. Among all selected parameters, DO and temperature are very important for keeping ecological integrity alive within the lake ecosystem. The vertical distribution of temperature and DO up to 20m depth were highlighted of the lake and the results are very supportive for life. The graph in vertical distribution shows that thermocline has been developed from 8 – 12m (Table 1; Fig. 3).

Bathymetry of Surkheng Zhui Lake

Surkheng Zhui Lake is second deepest lake in Broghil valley with the maximum and mean depth of 24m and 6.06m respectively. The surface area is 20.8ha and the total lake volume is 1,019.85 acres feet.

The lake surface to the lake volume ratio is 6.06, which means that each square meter of the lake contain 6.06m^3 of water. The

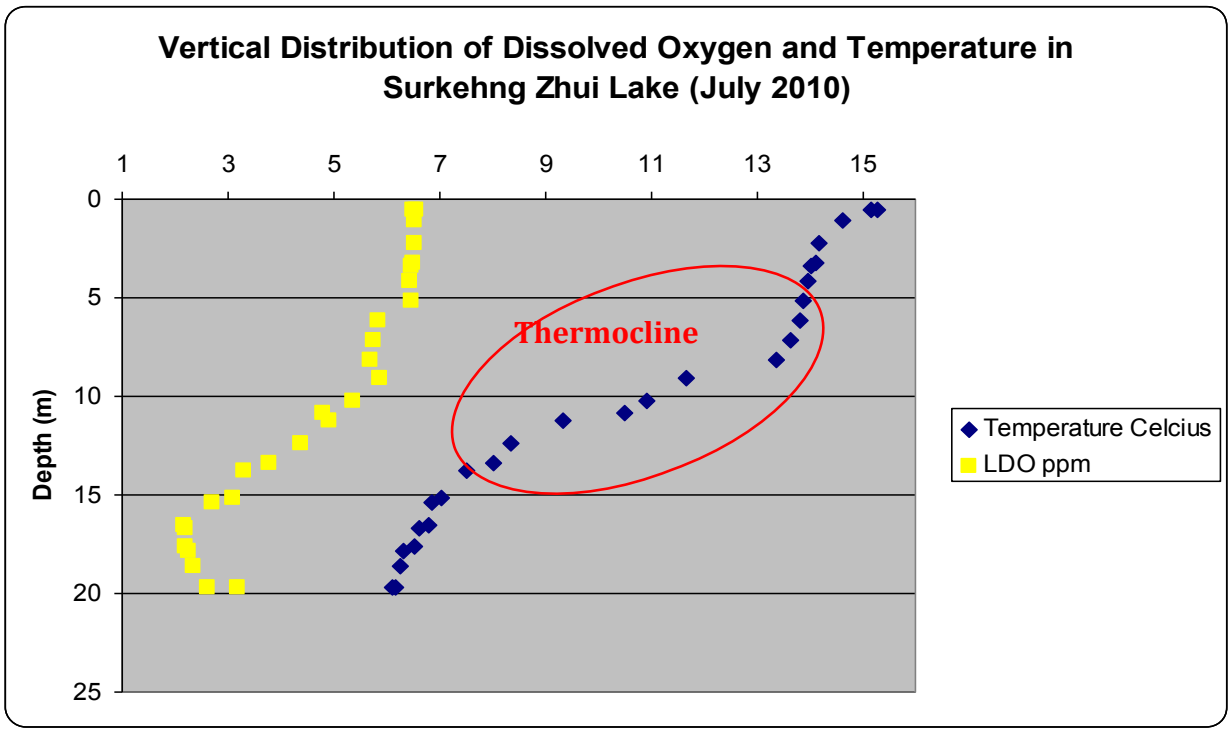

Figure 3: Vertical distribution of Dissolved Oxygen and Temperature in Surkheng Lake

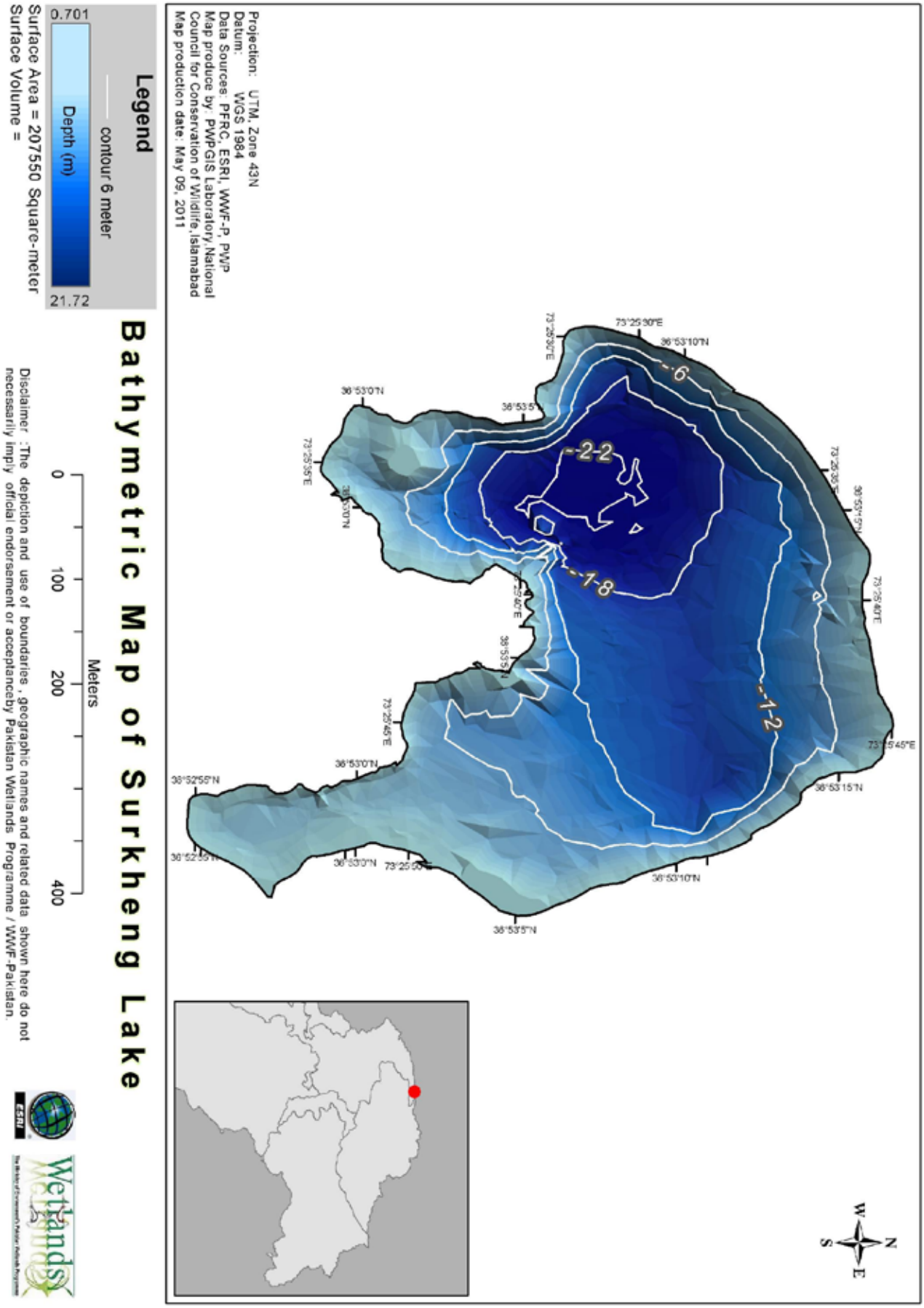

Figure 4: Bathymetric map of Surkheng Zhui Lake

lake's profundal zone is not uniformly distributed but is confined to southwest of the body. The south-eastern littoral zone consist of sand, gravels and rocks, and therefore support aquatic vegetation, both emergent and submerged. Waterfowls were sighted in the marginal zones of south-eastern portion of the lake (Fig. 4).

Qurumbar Lake

Morphology of Qurumbar Lake

Qurumbar Lake's vernacular name, as pronounced by the Wakhi community of Broghil Valley, is *"Qarumbura Zhui",* where *Qarumbura* means "a heap of boulders" and *Zhui* is the word for "lake". This seems entirely appropriate as the forces of glaciation formed the lake during a colder era, scouring out huge depression in the earth, and then filling it with ice. As the climate warmed up, the ice mass melted, leaving a barrier of *moraine* across the valley like a massive dam wall that confined the glacial melt water and formed the lake. *Moraine* is a technical term used for accumulated earth and rocks carried and finally deposited by a glacier. Surrounded by towering peaks, it is a breathtakingly beautiful panorama that rewards any hiker who is intrepid enough to climb up to 4,300m to see it.

Water Quality, bathymetric and other limnological features

The lake surface water temperature while undertaking the survey varied from 5-8° C daily. The water clarity level was 13.75m (Secchi Disc Reading), which is highest value ever recorded or seen in the available literature of lakes in Pakistan. The maximum and mean depth is 55 m and 17.08m respectively, the lake surface area is 265 ha and volume is 36,695.13 acre feet. The surface to volume ratio of the lake is 17.09 which means that there are 17.09m^3 water under 1m^2 area of the lake. The lake water quality was vertically profiled up to 25m and was strange to observe that the variation in temperature, pH, EC and DO is almost nil. The pH and DO of the lake is 7.08 and 7ppm respectively (Fig. 5 & 6).

Discharge from Qurumbar Lake

Qurumbar Lake has many inlets including glaciers mouth in the lake. The depth and central elongated trench (Fig. 5) also reveals that there is substantial quantity of base flow in the lake. The discharge therefore, is more than the recharge from surface inlets and glacial melt. The actual discharge at the mouth of the outlet was measured and the figure calculated as *3.2 Cusec (m^3/second)*. The time of measurements was 11:30 am, July 25th, 2010.

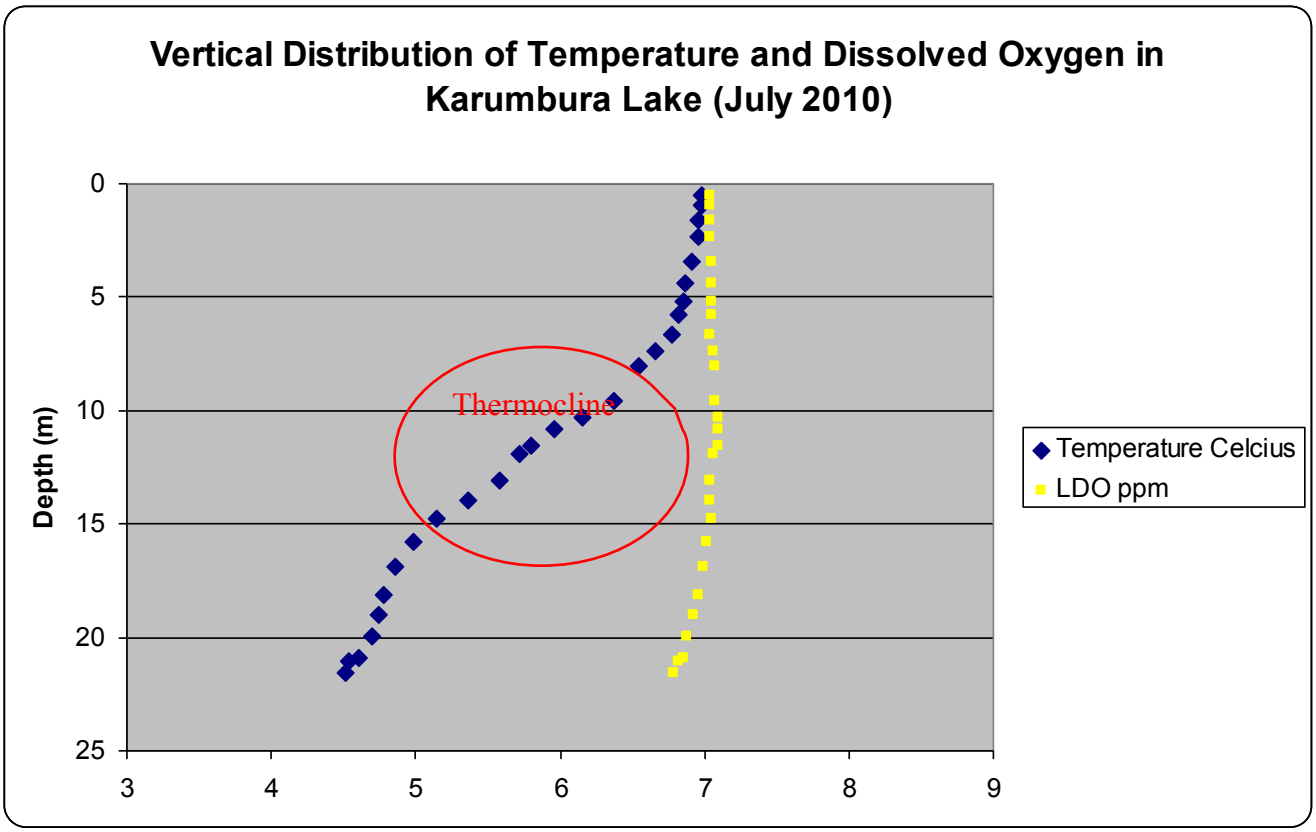

Figure 5: Vertical profile of Temperature and DO in Qurumbar Lake

Table 1: Volumetric and area details of Broghil Lakes

Lake	Lake Parameter	Values	Units	Lake Surface Area into Lake Volume Ratio
Qurumbar Lake	Surface Area	2,648,960	m^2	
	Mean Depth	17.09	m	17.09
	Volume	45,262,782.17	m^3	
Surkheng Lake	Surface Area	207,550	m^2	
	Mean Depth	6.06	m	6.06
	Volume	1,257,967.19	m^3	

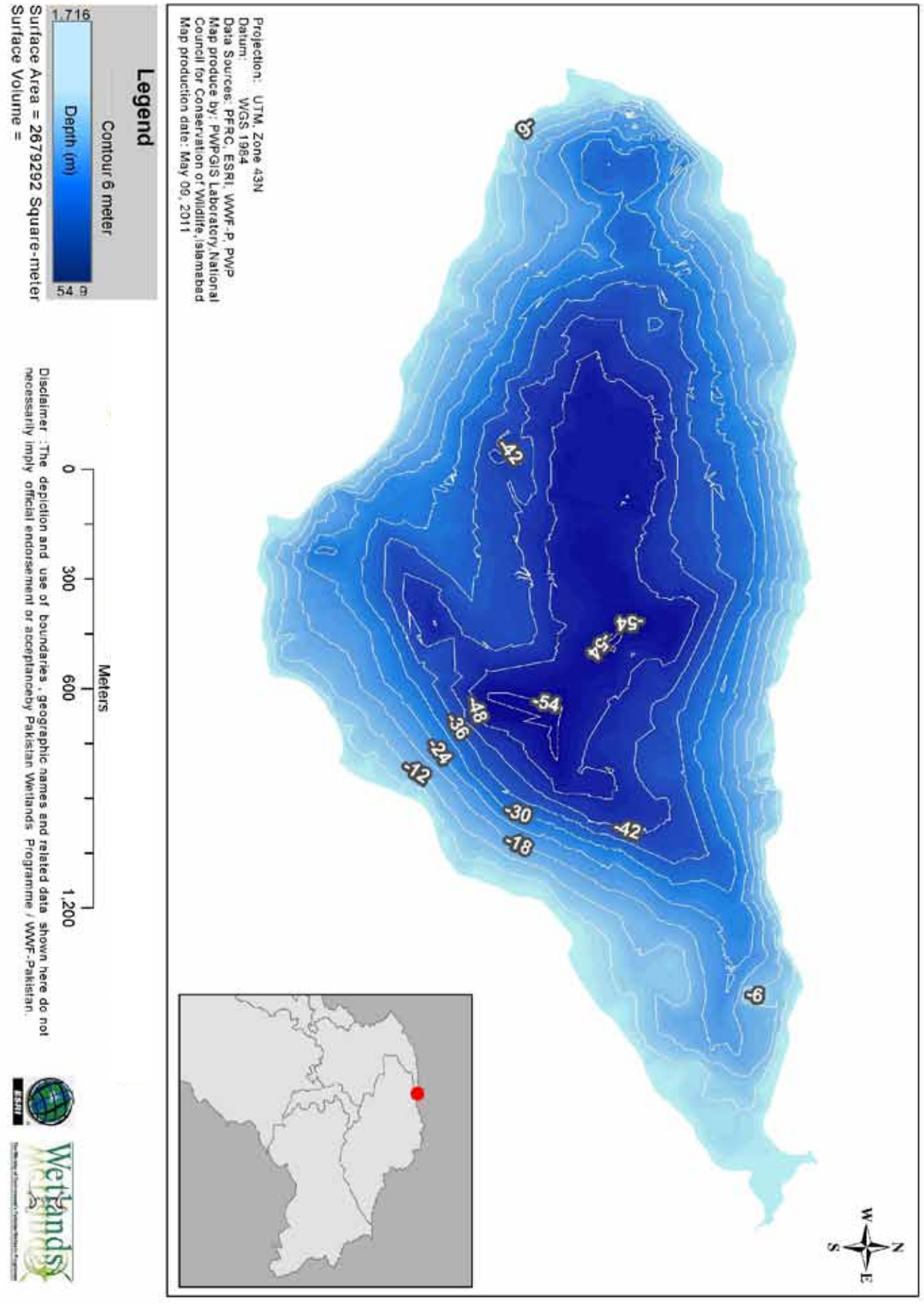

Figure 6: Bathymetric map of Qurumbar Lake

Hydraulic Residence Time of Qurumbar Lake

Average time required to completely renew a lake's water volume is called the hydraulic residence time. If the lake basin volume is relatively small and the flow of water is relatively high, the hydraulic residence time can be so short (10 days) that algal cells produced in the water column are washed out faster than they can grow and accumulate. An intermediate water residence time allows both an abundant time for algae to assimilate, grow and then accumulate. Longer water residence time from 100 days to several years provide plenty of time to algal biomass to accumulate if sufficient nutrients are present. The hydraulic residence time of Qurumbar Lake is 163.7 days.

Lake Surface Area Vs Volume Comparison of Broghil Lakes

Qurumbar Lake is the deepest lake in the valley with a maximum and mean depth of 55m and 17.08m respectively and is spread over a surface area of 26,48,960 m^2 and discharges into Qurumbar valley of Gilgit Baltistan. The discharge is 3.2m^3/second.

Surkheng Zhui Lake is the second deepest after Qurumbar with maximum and mean depth of 24m and 6.06m respectively. The lake surface area is 207,550m^2.

Recommendations

No doubt Broghil is a far flung and very remote area and is not easy to be accessed in most time of the year. Summer is best time for visiting the valley and so is for exploring the unveiled facts and information about the virgin ecosystems. The present study was deficient in assessing number of parameters and specifically recommends the followingl for future studies:

– As there is limited information available on meteorological and hydrological aspects at the country level, therefore, robust, unattended and telemetric based observatories are strongly recommended for long term monitoring. Ecosystems in the valley are very fragile and virgin hence are very prone to climate change;

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