REPORT
ON
PRE - FEASIBILITY STUDY
ON
RESTORATION OF BADKHAL LAKE, FARIDABAD

MANAV RACHNA

MANAV RACHNA INTERNATIONAL

GLOBAL

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Government of India
New Delhi

FOREWORD

Badkal Lake, Faridabad, once a major attraction of ecotourism has subsequently gone dry. It has adversely affected the ecology of the lake area. It was an environmental issue among the nature loving people of Faridabad along with the local administration. The revival of Badkal Lake will go a long way for the upcoming of smart city of Faridabad. Various steps are already being taken up to revive the lake in isolation.

The present report on "Badkal Lake", undertaken by the subject experts is a sincere attempt to understand the geomorphological setting, drainage pattern and hydrogeological scenario of Badkal catchment. The scientific studies have helped in identifying possible causes of drying up of lake and also proposed various feasible measures for its restoration. The sustainability of water in the lake could be enhanced through construction of subsurface dyke in the catchment area. The officers of CGWB & other reputed scientists have also contributed significantly to the scientific studies.

I hope the recommendations proposed would culminate into an implementable plan for the revival of the lake.

K.B.BISWAS

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Foreword

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Executive Summary

Badkhal Lake, a tourist attraction, came into existence in 1960 with the construction of a dam by joining two hills to arrest a fourth order stream at Badkhal village and became a tourist spot in 1967 and continued to be so till 2006. The drying up of the lake was witnessed silently without protest which was happening because of intensive pumping for mining activity and commercial purposes. It, being, now realised that the revival of Badkhal Lake is important as it is now government priority as Faridabad is aspiring to be a smart city and Badkhal Lake to be an integral part of the smart city. In order to work on the revival of Badkhal Lake, different scientific studies become necessary to comprehend the aquifer system below the lake area and also to identify the possible sources of water for its restoration. These studies included the detail geophysical survey, infiltration test for rate of seepage and the remote sensing for treatment of Badkhal catchment.

The earlier studies by different scientists and the organisations clearly pointed out that the mining activities impacted the flow of water to the lake and intensive groundwater withdraw have been major reason for drying up of the lake. The blasting as integral part of the mining activity over the years disrupted and denuded the catchment area besides opening of the joints, soil erosion, and creating environmental hazards. Although the regulatory measures for groundwater withdrawal for commercial purpose and Hon'ble Supreme court direction should have prevented the lake getting dried up. Not taking into consideration the status of groundwater development taking place, legally or illegally, different types of scientific studies have been carried out to justify possible sources of water for filling up the lake and making it sustainable.

The remote sensing and GIS study provided the information on the drainage pattern of the Badkhal catchment and its geomorphologic analysis will help in deciding the location of the different type of water conservation and recharge structures by utilization of monsoon runoff. In the present scenario four subsurface dykes, have been recommended to prevent the outflow of the groundwater. The infiltration tests show that the specific yield varies from 10% to 15%. Therefore while computing the water requirement for filling up the lake, seepage losses has been calculated based on these values.

The following options have been considered for different sources of water which would not only meet the water requirements to fill the lake upto 6m but can also for keep the lake alive.

1. Transfer of water from nearby water bodies created in deep mining pits
2. Transfer of Yamuna Flood water and storm water of Bhuria nala
3. Development of deep aquifers in the vicinity of Faridabad
4. Treatment of Badkhal Catchment
5. Impoundment of treated wastewater

After appraisal, it is observed that the first three options are not feasible because of the constraints like Riparian issue of River Yamuna; the short period within which the water is to be managed for transfer, quality status of River Yamuna; inadequate source and its annual increment of water bodies. For groundwater development area is notified and not adequate availability to meet a part or whole of requirement, etc etc.

The following two options are viable and do not involve any legal issue or otherwise

1. Treatment of the Badkhal catchment
    a) Construction of four sub surface dyke to check the out flow from the aquifers under the lake area
    b) Restoration of drainage channels leading to the lake area.
2. To use the treated wastewater with desired quality checks using state of art technology.

It is estimated that 1825.8 ML will be required to fill the lake upto 6m depth covering an area of 30.43ha. In order to meet the total water requirement as indicated above, it is proposed to install STP of capacity 10 MLD of treated wastewater for impoundment. Out of 10 MLD of impounding water, 2.63MLD will be make up water towards evaporation and percolation losses. Therefore it will take approximate 300 days for the first filling up of the lake upto the desired depth. Subsequently the water requirement will be reduced and it is estimated that 960 ML per year will be required to meet the requirement of makeup water. The excess water during second and subsequent year can be made available to the industries and the infra structure development at a cost to meet the part of expenditure towards STP functioning.

While planning the use of wastewater, the aspects considered is the Source of wastewater, available quantity of wastewater, quality parameters required of treated wastewater, technology options, capacity of plant, location of treatment plan. The various technologies dealing with the wastewater have been compared considering the design parameters such as Principle of operation, Hydraulic retention time, MLSS, BOD, TSS, Odor, operation and maintence, process performance, power consumptions, and land area requirement. The use of treated wastewater will have the advantage of preventing the lake from getting silted. Considering the quality of waste water available and comparison of various technologies in vogue, MBR and FBAS technologies seem to be more relevant and suitable for the present application. It is opined that considering the hydrogeological aspect and climate change scenario, the base of the lake should preferably be kept as unlined to allow the seepage after scaling of the overburden of about 1m in thickness. The rise in the water table will reduce the power input for pumping, indirectly amount to reducing the emission of green house gases, as the power plant in Faridabad is coal based.

The above options for water resources to revive the lake also meets, the requirements of the smart city which provides for the recycling of the wastewater and water conservation practices.
As a sequel to this study, the detailed project report can be prepared based on the recommendations as the basic information required for the DPR is contained in the report.

Contents

CHAPTER 1

INTRODUCTION

1.1 Introduction

Badkhal Lake, a tourist attraction, came into existence in 1960 with the construction of a dam by joining two hills to arrest a fourth order stream at Badkhal village for irrigation purpose. From 1967, onwards the area was developed as a recreation centre and continued to be tourism attraction till 2006. The lake has a catchment area of 1025 ha and the initial area of submergence was 42 ha. However, because of the mining activities and groundwater extraction, the flow to the lake began reducing gradually and the area of submergence reduced each year, and by the year 2008, the lake became almost dry.

1.2 Location

Badkhal Lake is located in Faridabad town of Haryana State about 30 km south of Delhi and falls in toposheets no 53 H/7. **(Figure 1.1)** The lake, thus formed, has a maximum length of 2.13 km and Maximum breadth 0.43 km**.** The maximum storage capacity of 28.75 X10 -5 m3 at highest flood level of 216.70 m with the depth of submergence is 11.1m. The detail of the Lake characteristics is given in **Table 1.1.**

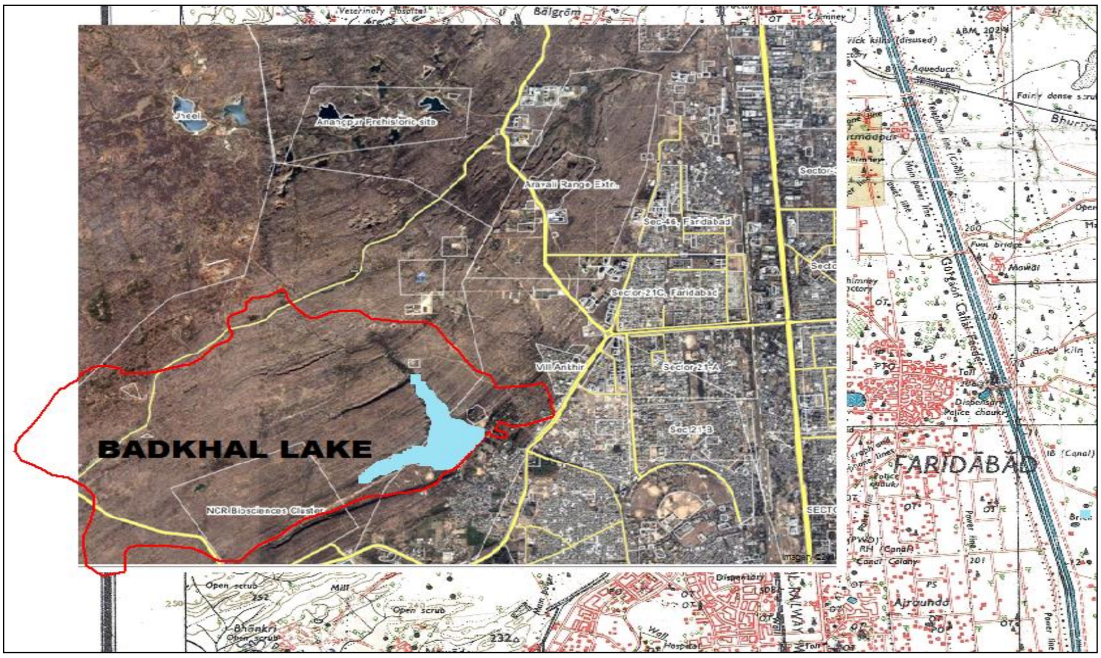


Figure 1.1: Location Map of Badkhal Lake- Faridabad

Table 1.1: Morphometric and hydrological characteristics of Badkhal Lake

Source : . (K.M.M. Dakshini and S.K.Gupta 1984).

1	Geographical Location	$77^0$17'Long $28^0$26'Lat
2	Maximum length(km)	2.13
3	Effective length (km)	1.10
4	Maximum breadth (km)	0.43
5	Maximum depth(m)	11.1
6	Surface area(ha)	30.43
7	Lake volume(*104) m3	28.75
8	Length of shore line (m)	3615
9	Development of shore line	1.8
10	Highest flood level (m)	216.70
11	Catchment area (Sq.km)	13.0
12	Ratio between surface and catchment areas	42.7

1.3 Literature Survey

A review of the publication by Geological Survey of India (Hari Singh & B.K. Jain, 1989, H.S. Saini and S. A. I. Mujataba, 1998) and Groundwater Board (Shekhar S, et al 2010, CGWB Report 1998, 2011) and Siddiqui, R., Mahmood G, Syed Rehan Ali (2012) was made pertaining to the geology, mining, hydrogeology, GIS and geo-environment earlier have been investigated for the Badkhal catchment and the Badkhal Lake area. It has generally being agreed that the mining activities and dewatering are mainly responsible for the decline in the runoff from the catchment to the lake area.

1.4 Periodic Google Earth Images of Badkhal Lake

In order to study the change in the submergence area of Badkhal Lake over the past 10 year the satellite images was studied for the Purpose. The submergence area in 2003 was about 14 ha, gradually decreased to 8 ha in 2006, and the consequently the area dried up in 2008. **(Figure 1.2)**

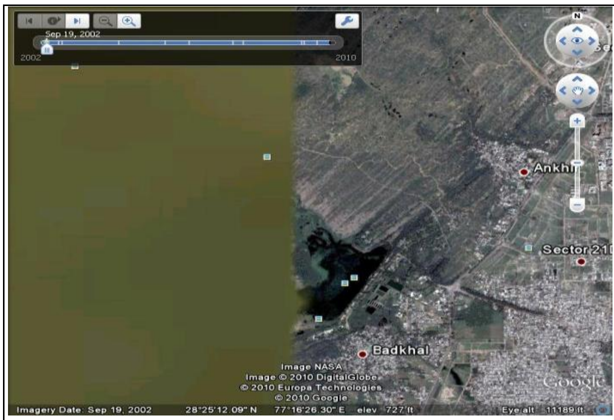
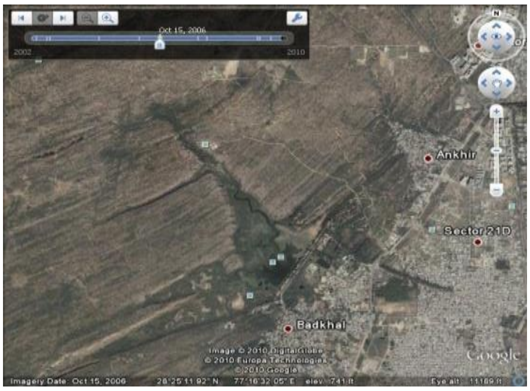
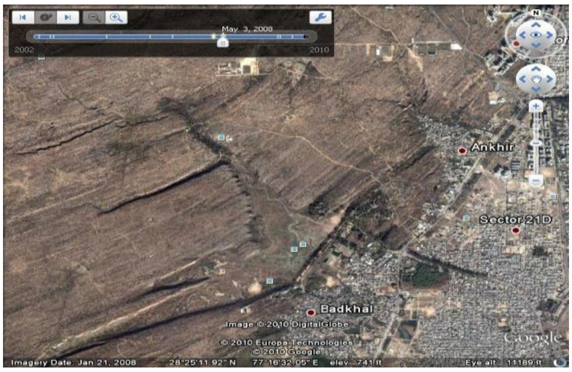
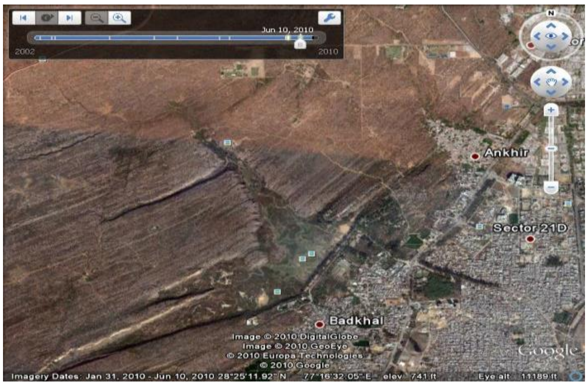
3/02/2003(submergence area 14ha)	9/10/2004(submergence area 14ha)
10/2/2006(submergence area 8ha)	15/10/2006 (submergence area 8ha)
3/5/2008(submergence area 2ha)	10/6/2010(dry)
3/11/2013(dry)	27/8/2015(dry)

Figure 1.2: Periodic google images shows change in submergence area

1.5 Rainfall & Climate

The climate of Faridabad district can be classified as tropical steppe, semiarid and hot which is mainly characterized by the extreme dryness of the air except during monsoon months. The area falls under semi arid climate. The normal annual rainfall in Faridabad district is 564 mm and average number of rainy days is 27. The annual rainfall from 1960 to 2014 for Faridabad station has been analyzed to know the rainfall trend. The mean annual rainfall from 1960-2014 of Faridabad is 646 mm and 75% dependable rainfall as per the data of 55 years is 523 mm. Thus the frequency of deficit/scanty rainfall is 36% in the area i.e. once in every three years. The rate of evaporation and monthly rainfall data as observed in the adjacent Delhi area given in **Table 1.2 and Figure 1.3.**

Table 1.2: Year wise rainfall data (from 1960-2014)

Source: Metrological Department

Year	Rainfall In mm	Year	Rainfall In mm	Year	Rainfall In mm
1960	638	1978	841	1996	824
1961	911	1979	421	1997	598
1962	521	1980	571	1998	735
1963	652	1981	580	1999	444
1964	1043	1982	709	2000	597
1965	533	1983	747	2001	618
1966	578	1984	605	2002	353
1967	941	1985	845	2003	1202
1968	523	1986	412	2004	634
1969	570	1987	308	2005	592
1970	650	1988	842	2006	466
1971	743	1989	398	2007	483
1972	638	1990	782	2008	742
1973	663	1991	641	2009	355
1974	456	1992	470	2010	558
1975	997	1993	811	2011	605
1976	840	1994	827	2012	323
1977	781	1995	792	2013	618
				2014	495

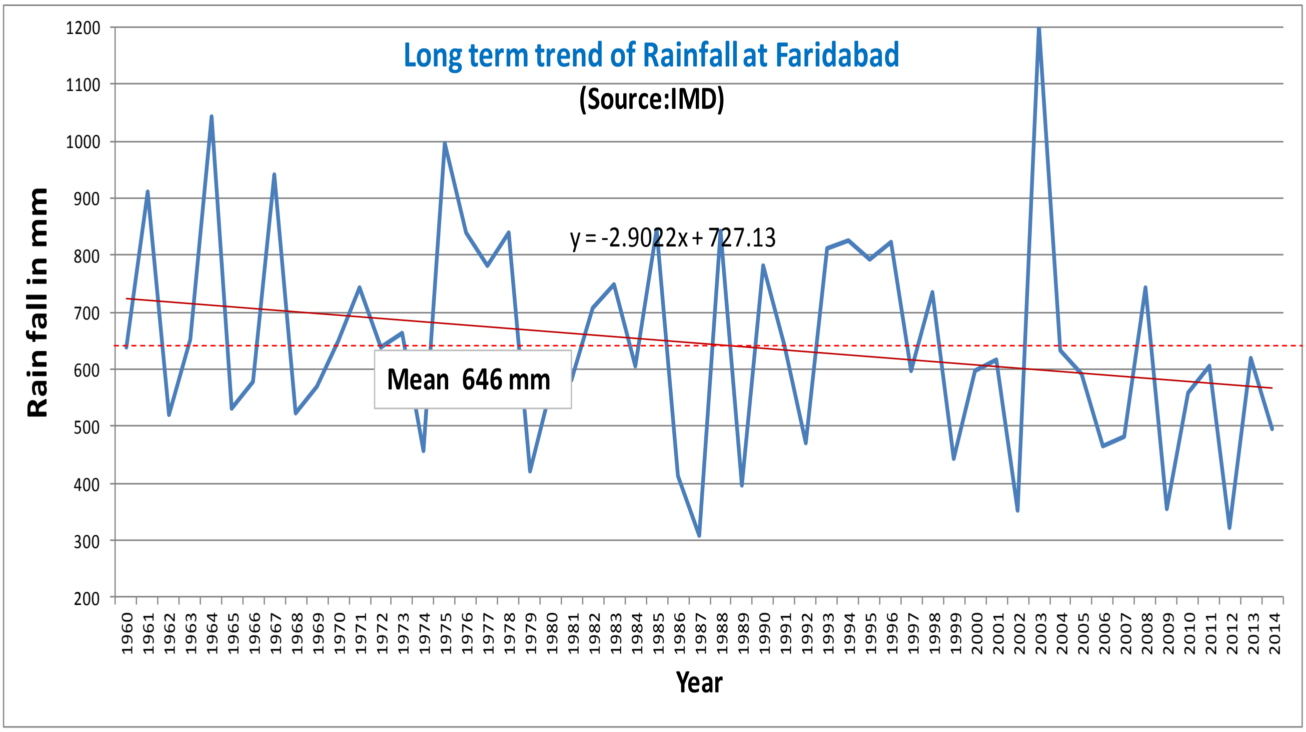


Figure 1.3: Rainfall trend Graph

The rainfall data is an important input to calculate the runoff in the Badkhal catchment and also for each of the micro watersheds within the Badkhal catchment.

1.6 Mining activity in the area and its Impact

In the Aravali Ridge area, open cast mining for silica sand, quartzite and other construction material was rampant till 2009 when the Hon'ble Supreme Court gave directions to stop it. During 2001-02, extractions of silica sand, ordinary sand and stone were 0.21, 9.47 and 6.48 Million metric ton respectively. The mining of silica sand was mainly carried out below water table by pumping of ground water. Mining was being carried out in highly unscientific manner and the huge amount of debris-generated block the flow of rainwater into the lake. The deeper mines were 40-60m in depth and are exposed the ground water table thus depleting saturation. In Anangpur mining area, pumped water from pits was being discharged in Burianala whereas in Pali and Manger area pumped water was discharged in Badkhal and Dhauj Lake through artificial channels that connect to natural drainage. The mining activity has caused irreparable environmental damages. It is estimated that evaporation losses from exposed water bodies is 0.89 MCM.

1.7 Legal Aspects

A Public Interest Litigation (PIL) was filed against mining and stone crushing in the Aravali citing the drying up of these water bodies in the area. In October 1996, the Hon'ble Supreme Court directed that "No construction of any type shall be permitted then onwards within 5 km radius of the Badkhal lake and Surajkund" lakes in Haryana. During the Hon'ble Supreme Court hearing on 18th of March 2009, the court appointed Central Empowered Committee brought in notice of the apex court the condition of Badkhal Lake and showed the satellite images of the lake to the justice Bench showing dried up lake bed.

Hon'ble Supreme Court gave a direction on 9 May 2009, to suspend mining activities in Aravali Hills. On a special bench comprising Chief Justice remarked, "We hereby suspend all mining operations in the Aravali Hill range falling in the State of Haryana within the area of approximately 448km2 in the districts of Faridabad and Gurgaon including Mewat till Reclamation Plan duly certified by State of Haryana, MoEF and CEC is prepared".

1.8 Groundwater regulation

In order to regulate the development of the Groundwater resources, Centre Ground Water Authority issue directions in this respect, Notification issue 1998 is given below.

CENTRAL GROUND WATER AUTHORITY

(Constituted under Section 3(3) of Environment (Protection) Act, 1986)

MINISTRY OF WATER RESOURCES

Jamnagar House, Mansingh Road, New Delhi -110011

NOTICE

Whereas the Central Government has constituted the Central Ground Water Authority, here in after referred to as the 'Authority'; pursuant to sub-section (3) of the Section 3 of the Environment (Protection) Act, 1986, for the purposes of regulation and control of ground water development and management.

And Whereas in order to achieve the objective, the Authority, based on the study conducted by the Central Ground Water Board, Ministry of Water Resources and the guidelines framed by the Authority in this regard, has identified whole of the Municipal Corporation of Faridabad and Ballabhgarh in Faridabad District in the State of Haryana as 'critical areas' in view of depletion in ground water resource, due to over-exploitation and presence of the traces of chemical contaminants, due to industrial activities in the region.

And Whereas the Authority considered it expedient and necessary to protect and preserve the ground water resource of the above said region, proposes to prohibit and put restrictions for carrying on the operation of drilling, construction, installation of any abstraction structure for extraction of ground water in whole of the Municipal Corporation of Faridabad and Ballabhgarh.

Now therefore the Authority in exercise of its powers and function as provided in clause (v) of sub-section 2 of section 3 of the Environment (Protection) Act, 1986, after considering the need for protecting the ground water resource and to ensure further development activities in consistence with protection & preservation of the ground water resource, hereby declare the whole of the Municipal Corporation of "Faridabed and Ballabhgarh" in the District of Faridabad, Haryana as "critical areas" and imposes prohibition and restriction in the region on the construction, installation of any structure for extraction of ground water resource, to avoid its further depletion and deterioration in its quality, and authorises the Deputy Commissioner, Faridabad to take action as deem fit for prohibition and restriction on the construction, installation of any ground water abstraction structure in the above-said notified area.

Person/Organisation/Agency (Govt. or Non-Govt.) having ground water abstraction structures, already in existence, are advised to get registered with the Authority at the Office of Deputy Commissioner, Sector-15, Faridabad, Haryana with in a period of ninty days from the publication of this Notification.

Further, henceforth, no Person/Organisation/Agency (Govt. or Non-Govt.) shall undertake any scheme/project of ground water development & management in the above said region without permission of the Authority.

(D.K. Chadha)
Chairman

Indian Express, 14.10.98

District of Faridabad, in Haryana in critical areas and imposes prohibition and restriction in the region on the construction, installation of any structure of ground water resources

Person/Organization/Agency (Govt. or Non-Govt) having ground water abstraction structures, already in existence are advised to get registered with the authority at the office of Deputy Commissioner, Sector-15 Faridabad, Haryana with in a period of ninty days from the publication of this Notification

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Since the drying up of the lake is being attributed to the extensive development of ground water around the lake area, the groundwater development now needs to be regulated.

1.9 Project Objectives

The main purpose for taking up the pre feasibility study is to collect information based on scientific studies such as detailed geophysical survey, Hydrogeological Investigations, Water percolation test, Remote sensing and GIS based study for Badkhal catchment, etc, for preparation of approach paper for revival of the Badkhal Lake. The information so collected from the various studies will form prelude for the preparation of detailed project report.

CHAPTER 2

GEOLOGY AND REMOTE SENSING & GIS STUDY

2.1 General Geology

The study of geology and its stratigraphical sequence is an important aspect to know the types of aquifers, their extensiveness and to decide on to drilling technique for construction of tube wells.

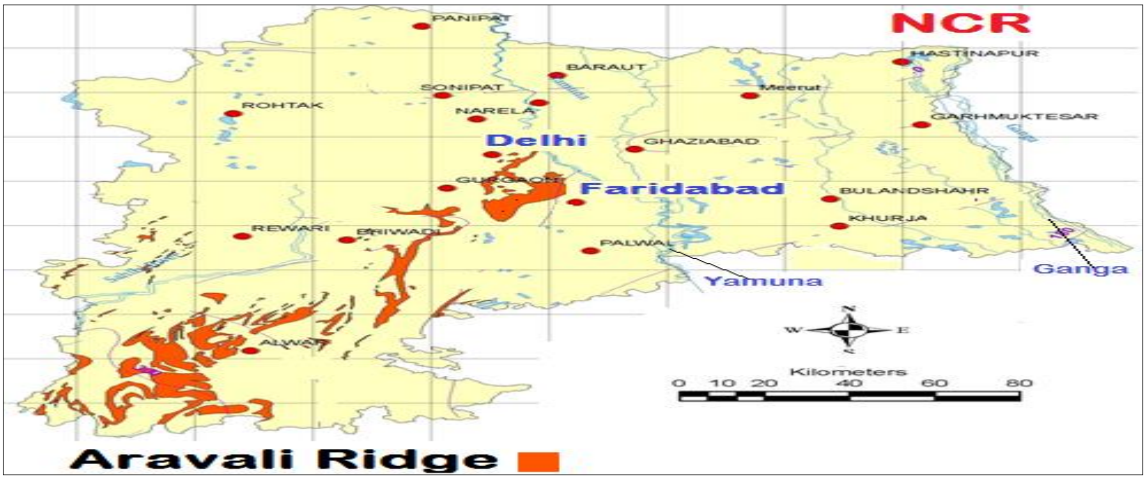


Figure 2.1: Disposition of Aravali Ridge

The Aravali ridge, trending in NNE SSW direction is shown in **Figure 2.1.** The Badkhal catchment is a part of Aravali ridge is mainly composed of Quartzite. The quartzites are of the Pre-Cambrian (Protozoic age represented by Delhi Super quartzite called Ajabgarh Group) and are underlain quaternary sediments consisting of older alluvium sediments.

A generalized stratigraphic sequence of the area is as **Table 2.1**

Table 2.1: Stratigraphic sequence of the area

Group	Age	Geological units	Geomorphological units
Quaternary	Holocene	Newer Alluvium	Low land unit
-- Disconformity --			
Quaternary	Pleistocene	Older Alluvium	Alluvial Up land unit
---Unconformity---			
Pre Cambrian	Proterozoic	Delhi Super Group (Ajabgarh group)	Denudational Hill unit

2.2 Geology of the Area

The Ajabgarh Group of Delhi Supergroup represents the oldest exposed rocks in Faridabad area around Badkhal Lake. The rock type is mainly quartzite and the exposures are confined, in northwestern part of the town.

The quartzites have undergone several phases of deformation resulting in structures such as folds, joints, and fracture. The joints trend in the direction of NE-SW, NS-EW with a dip varying from 35^0 to almost vertical. In the catchment area of Badkhal Lake, the quartzites are dipping nearly vertical with NE-SW and NE-SW oriented lineaments are controlling the drainage in the area. **(Figure 2.2)** The quartzite is grey, creamish and pinkish in color and generally of fine grained.

Figure 2.2: Photograph of Jointed Quartzite exposed in Badkhal Catchment

Thin beds of ash/tuff 0.5 to 1.4 m in thickness are pre sent interbedded with quartzite a few of which are recorded near Balgram and Ankhir in the quarry sections (Hari Singh & Jain op cit) the ash bed has a sharp lower contact and diffusing upper contact small boudinaged lenses of hard quartzitic material may be present within the ash beds.

In certain pockets, the quartzite is highly friable at depth ranging from 5 to 20 m. Pure white/cream friable varieties present only at deeper levels are being mined as silica sand. At places in pockets, quartzites disintegrate to form coarse sandy material locally known as “Bajri/Badarpur”. The sandy material is supposed to be formed by leaching of cementing material.

The Harchandpur Badkhal ridge occurs in the form of an antiform plunging 25^0 SSW at Harchandpur (Prasad et Al. 1994). The fold axis trends along N-S direction in the southern part and bends slightly along NNE-SSW directions in the northern part the eastern limb of fold strikes along NNE direction, in the southern part NE, in the northern part with steep easterly dips between 60^0 and 80^0. As these ridges are strike ridges, their trend and continuity is mainly controlled by geological structures of the rock**. (Figure 2.3)**

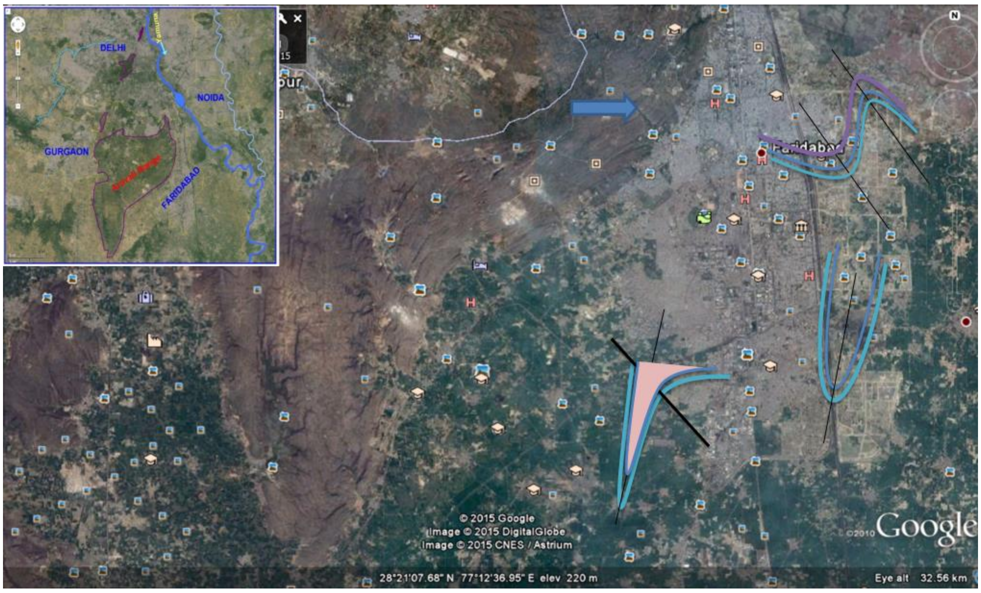


Figure 2.3: Google Image showing the folding structure

In thin section, quartzites consist of tightly packed, recrystalline quartz with minor feldspar, chlorite, garnet, biotite and sericite. Graphite pyrite and chalcopyrite are present at some places. Quartz shows sutured grams boundary and deformational twining. These grains appear to have been formed ruing two generations (Hari Singh & Jain 1989). The Delhi Supergroup unconformably overlain by older alluvium of Pleistocene age.

Older alluvium mainly comprises fine to medium sand with layers of silt and clay with kankar. Lenses of brown to yellowish clay-silt brown and grey sand and calcrete having lateral facies variations. The lithologies are interpreted to be in tectonic contact with the Ajabgarh rocks, the newer alluvium disconformably overlies the older alluvium. The silt with clay is brown to yellowish brown in color whereas sand is of light in colour.

In general, the presence of different grades of sand, silt and clay is given below.

Lithology	Thickness	Elevations of exposed
Brown sand-I	2 to 7m	204-197 a. m. s. l
Yellowish silt-clay	3 to 5 m	197-192 a. m. s. l
Brown sand –II	2 to 5 m	192-198 a. m. s. l
Yellowish silt-clay	Variable	-
Grey sand	-	-

Newer alluvium is confined within flood plains of Yamuna River and disconformably over lies the older alluvium. This is 10 to 20 m thick sequence of grey coloured medium very fine sand to silt which disconformably overlies the older alluvium. The newer alluvium is devoid of calcareous nodules. The drainage here is following these orientations.

2.3 Local Geology

Based on GIS study and the field geological mapping, a map has been prepared showing the distribution of different Lithological units/rock formation **(Figure 2.4).** The Badkhal lake area has been divided into different lithological units based on the type of sediments present. The area coverage by different lithological units and the topographic gradient is given in **Table 2.2. (**Source: Siddiqui, R et al, 2012)

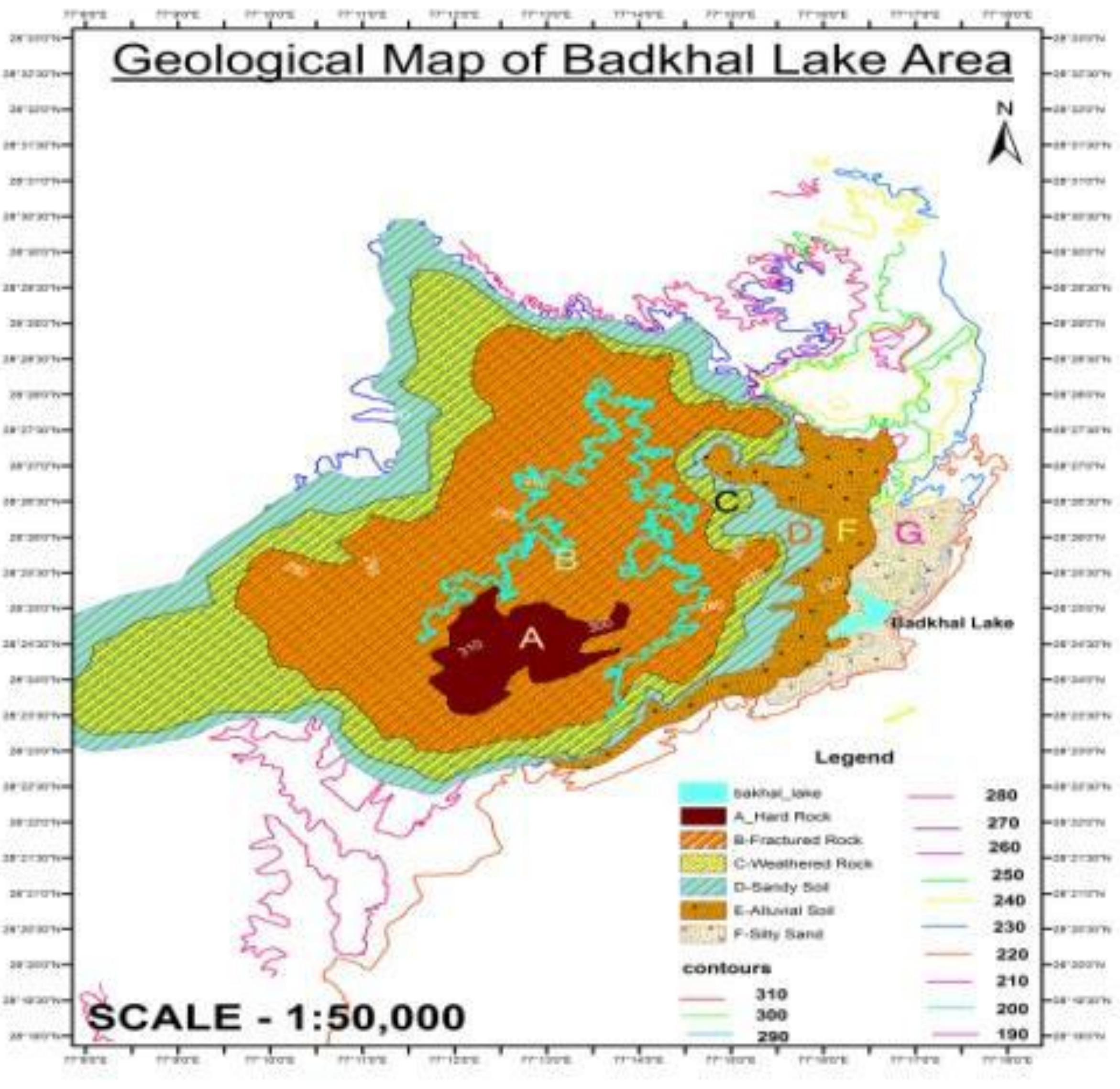


Figure 2.4: Geological Map of Badkhal Lake

Table2.2: Lithological Units of watershed area of Badkhal Lake

S.No	Label	Lithology	Area(Sq.Km)	Relief (In Meters)
1	A	Hard Quartzite	6.64	315-300
2	B	Fractured quartzite	60.41	300-280
3	C	Weathered quartzite	30.9	280-270
4	D	Silty Sand	23.22	270-250
5	E	Sandy silt	11.2	250-240
6	F	Silt	7.51	240-220

2.4 Remote sensing and GIS

Remote Sensing (RS) data and Geographical Information System (GIS) play a rapidly increasing role in the field of land and water resources development. One of the greatest advantages of using Remote Sensing data for natural resource management is its ability to generate information in spatial and temporal domain, which is very crucial for successful model analysis, prediction and validation. Integrating all these approaches can offer a better understanding of groundwater controlling features in hard rock aquifers.

For water management and planning, it is important to study the drainage pattern, ordering of drainage, slope maps and a qualitative analysis of the water level data, water table contour map, which can be pictorially represented so that it gives better understanding of the changing scenarios.

2.4.1 Methodology adopted

The following methodology and procedure is adopted in the present study.

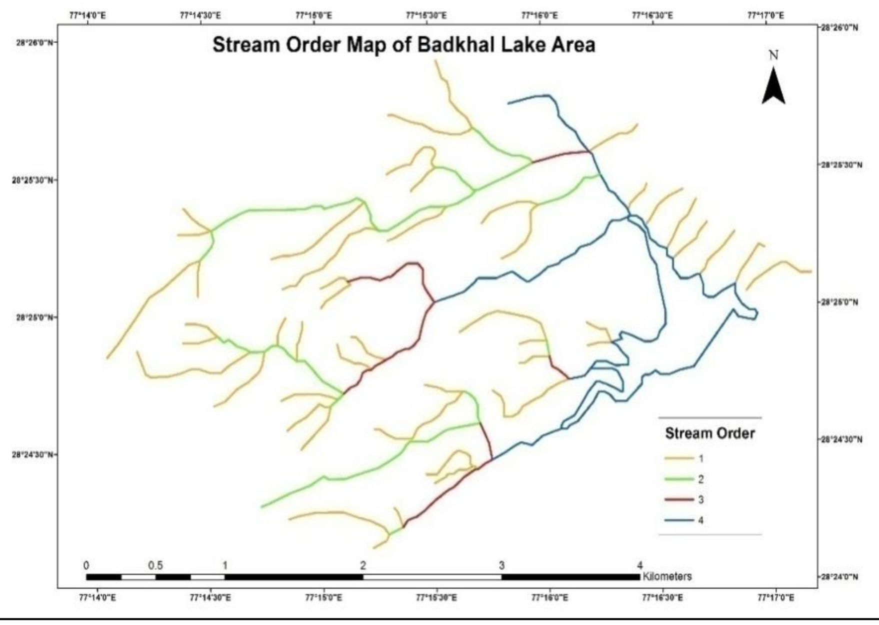
- Collection of satellite data from Google image and Survey of India Topographical maps
- Preparation of different Thematic layers of this spatial data
- Collection of spatial and non spatial data covering the study area
- Preparation of base map on 1:25000 scale using Survey of India Topographical Maps
- Preparation of Drainage map, watershed map, Depth to water map, Ground water contour map, and Surface water bodies

The toposheets covering the Badkhal catchment and the surrounding area are scanned, using ARCGIS 9.3 software; all scanned toposheets are Georeferenced and rectified to create Thematic layers like Drainage network, Stream ordering map, Base map showing lake and adjacent water bodies, Contours.

2.4.2 Drainage Network Map

In order to plan the treatment to the Badkhal catchment it is important to map the drainage network from toposheets and to undertake geomorphic analysis of the drainage system giving details of the stream order. The stream are of four orders, the length of each of the stream is also shown in the **Figure 2.5**

The above data is useful in deciding the type of water conservation structures, which should be constructed across different stream order like Gabion structure across the first order, cement plug and small check dam across the second order, and anicuts across third order, major dam across fourth order stream. The dam for Badkhal Reservoir was constructed across fourth order stream by making an earthen dam across Parsun nadi.



Stream Order	Length (km)
First	20.012
Second	7.74
Third	3.44
Fourth	10

Figure 2.5: Drainage map with ordering

2.4.3 Digital Elevation Model (DEM)

The basic parameter that influences the drainage in any area is the topography of the area. The contours are digitized and contour information is added in elevation column. Using

3D analyst converted contours to TIN (Triangular Irregular Network) Model. Using 3D analyst TIN MODEL converted in to demand to slope map. (**Figure 2.6)** The digital elevation model has been prepared to understand morphological features of the area in 3D.

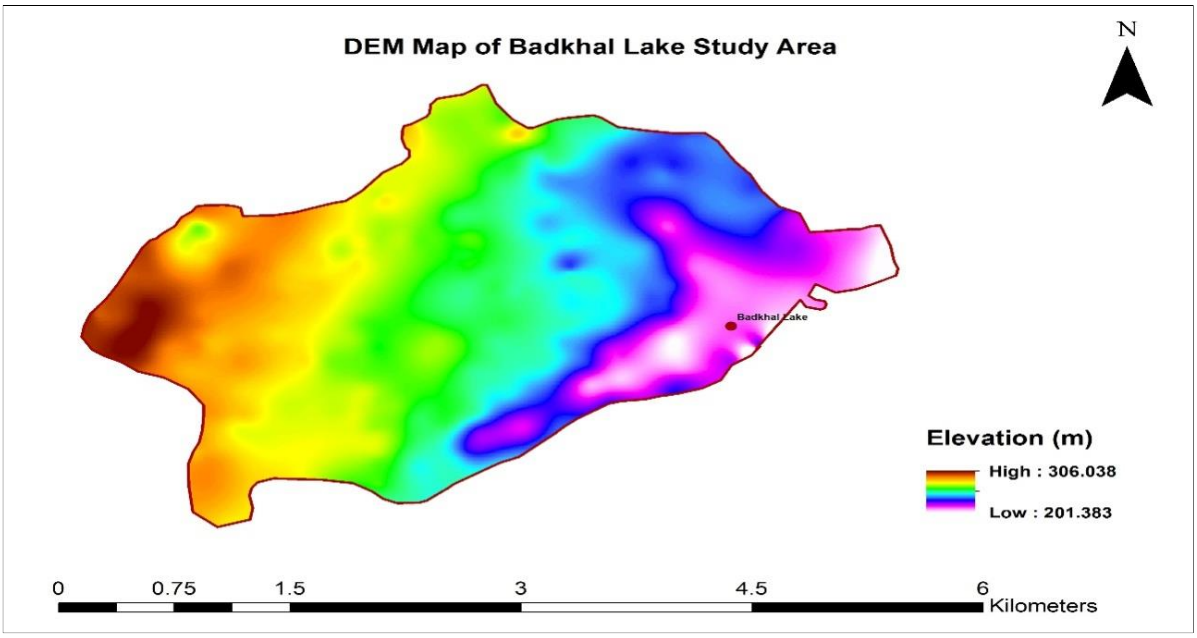


Figure 2.6: DEM Map

The DEM was used for the generation of slope, which classifies the entire Badkhal catchment area in different categories of slope ranges. The ranges so classified will help in calculating the space of the water flow in that particular region. This information is useful in the categorization of the type of structure to be built in that particular zone.

2.4.4 Slope Map

Slope Map is the measure of steepness or the degree of inclination of a feature relative to the horizontal plane. Gradient, grade, incline and pitch are used interchangeably with slope. Here dark blue and green values in the map show steeper slopes and brown areas show relatively gentle slope. All the nearby water bodies are located at steeper slopes as compared to Badkhal Lake.

The slope map has been derived from the DEM into following categories into high and low categories with shows variation in slopes having different colors, which is shown in **Figure 2.7.** The slope map can be used for to know the Flow direction, flow accumulation purpose.

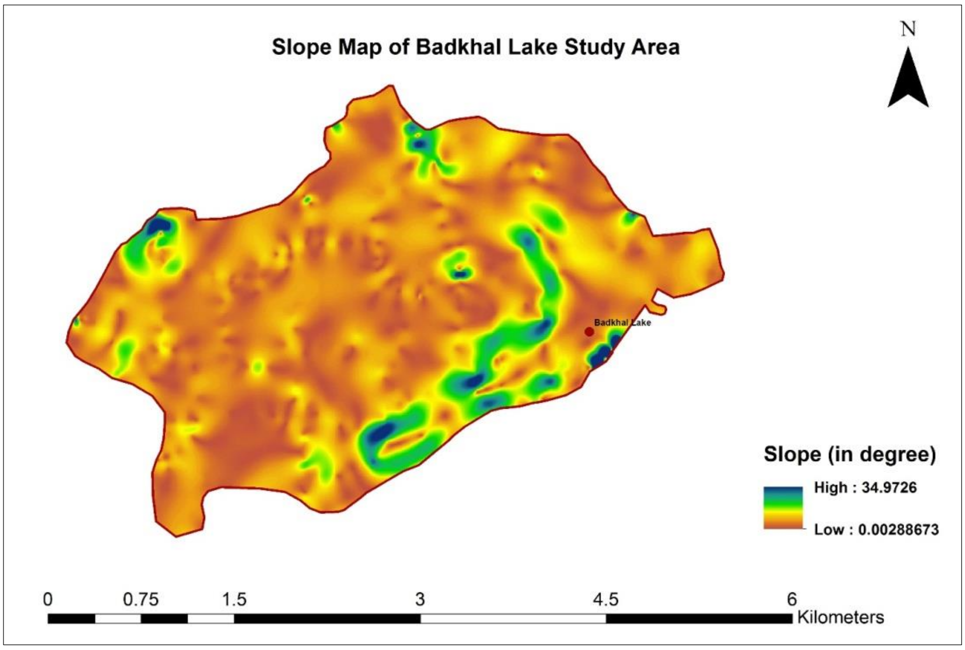


Figure 2.7 : Slope Map

2.4.5 Slope characterization

The mining activities left the pits without rehabilitation and these pits have now been filled up, because of storage of the storm water and also cutting across the water table. These water bodies are at higher altitude compare to the Badkhal lake area therefore it is important to study the slope characteristics either to use the stored water for transfer for water supply or to create a waterfall as part of the tourism. The application of Google earth was made to study the distance and the slope gradient of the water bodies on NNE to Badkhal lake (Lake No 1 to 7) and also the water bodies on the West of the Badkhal Lake (lake no 8 and 9) **Figure 2.8 and Table 2.3.** The slope gradient and distance of the four water bodies on the NNE side is given in **Figure 2. 9A** and the lake 8 and 9 in **Figure 2.9 B.**

Figure 2.8: Regional View of Google image showing water bodies and Badkhal Lake.

Table 2.3: Showing the Distance and Elevation of Different water bodies with respect to Badkhal Lake

Lake_Name	Distance from Badkhal Lake (m)	Elevation (m)	Area (sq. m)
Lake 1	4500	255	62000
Lake 2	4233	253	33328
Lake 3	3800	248	51141
Lake 4	3800	250	25000
Lake 5	4100	257	8900
Lake 6	4400	260	3700
Lake 7	3500	250	6800
Lake 8	4800	260	62000
Lake 9	6000	264	39370

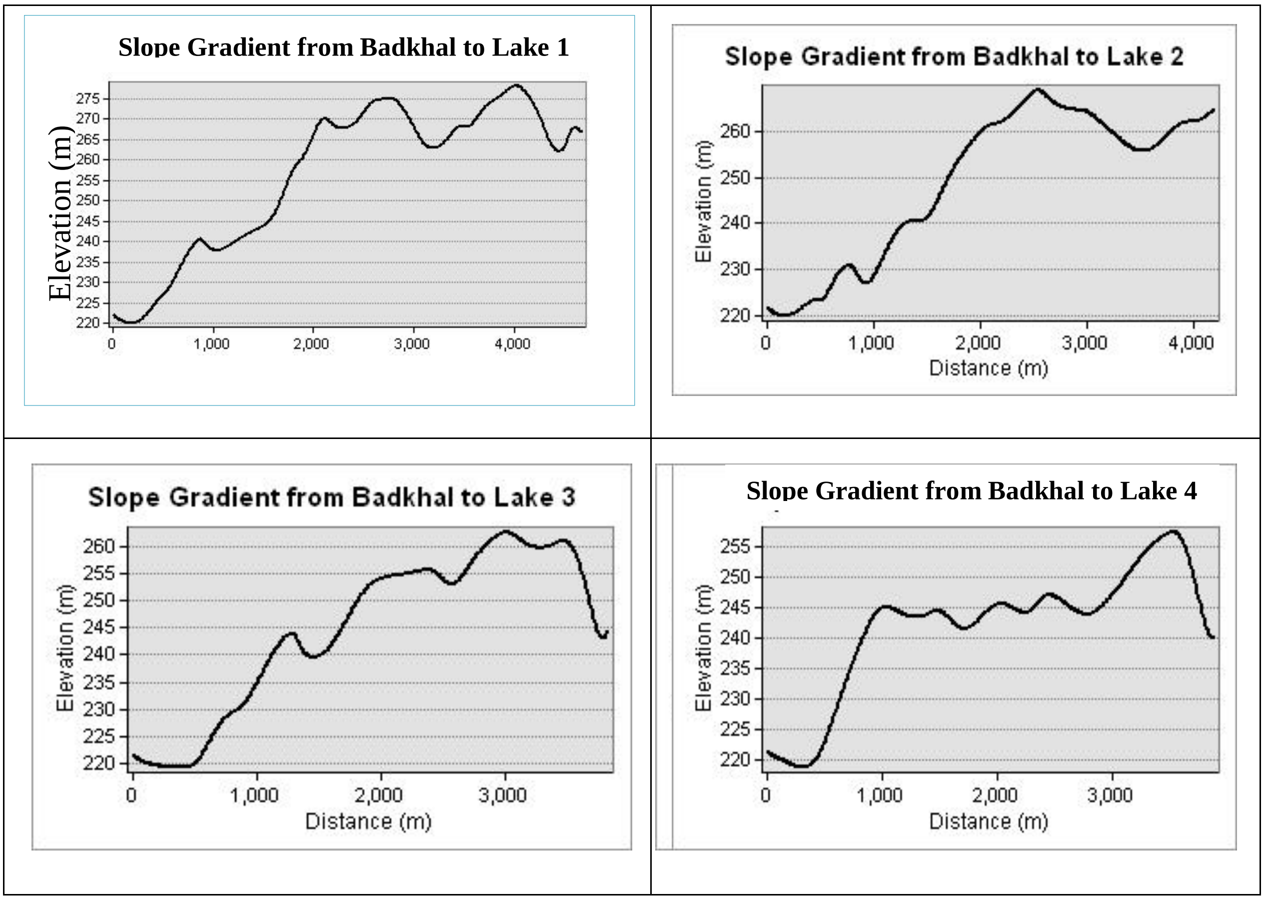


Figure 2.9 A: Slope Gradient graphs from Badkhal To Lake 1, 2, 3 &4

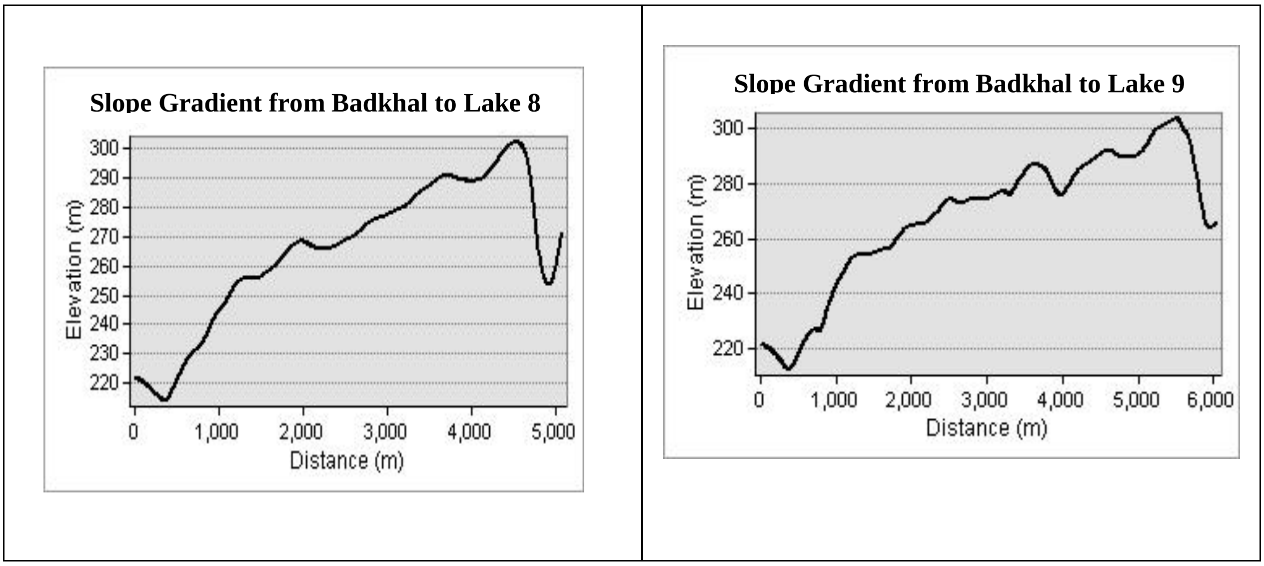


Figure 2. 9 B: Slope Gradient graphs from Badkhal to Lake 8 & 9

2.5 Management of Water bodies

The mining for the silica sand was mostly carried out below the water table by dewatering the ground water. There are about 40 mining pits, the deeper mine pits are 40-75m in depth and possibly exposing the ground water table. In the last, few years these mine pits have been filled up with rainwater runoff and water storage in the pits has been building up over the years. It is reported that evaporation losses from exposed water bodies is 0.89 Million cubic meters per year.

With the help of Google map and ground checking, it has been ascertained whether adequate quantity of water is available in these pits, which can be considered for transfer to lake area. This study is confined to the existing pits located within a distance of 5km from the catchment boundary. The quantum of water available in these pits are estimated along with its elevation variations and the lift required for transfer are shown in maps (**Figure 2.10, 2.11 and 2.12)** and given in the **Table 2.4** . The quality of water available in these pits is good and is suitable for all purposes.

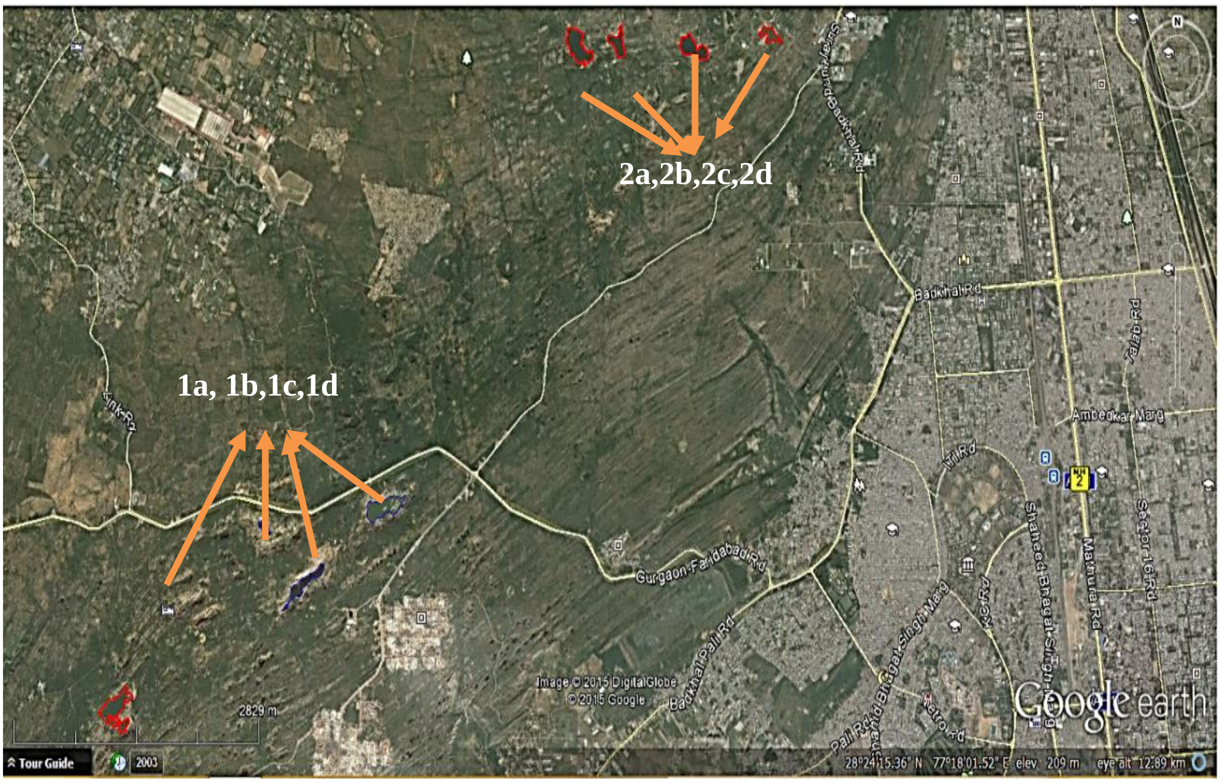


Figure 2.10: Map showing all identified pits around Badkhal catchment in red and blue in color.

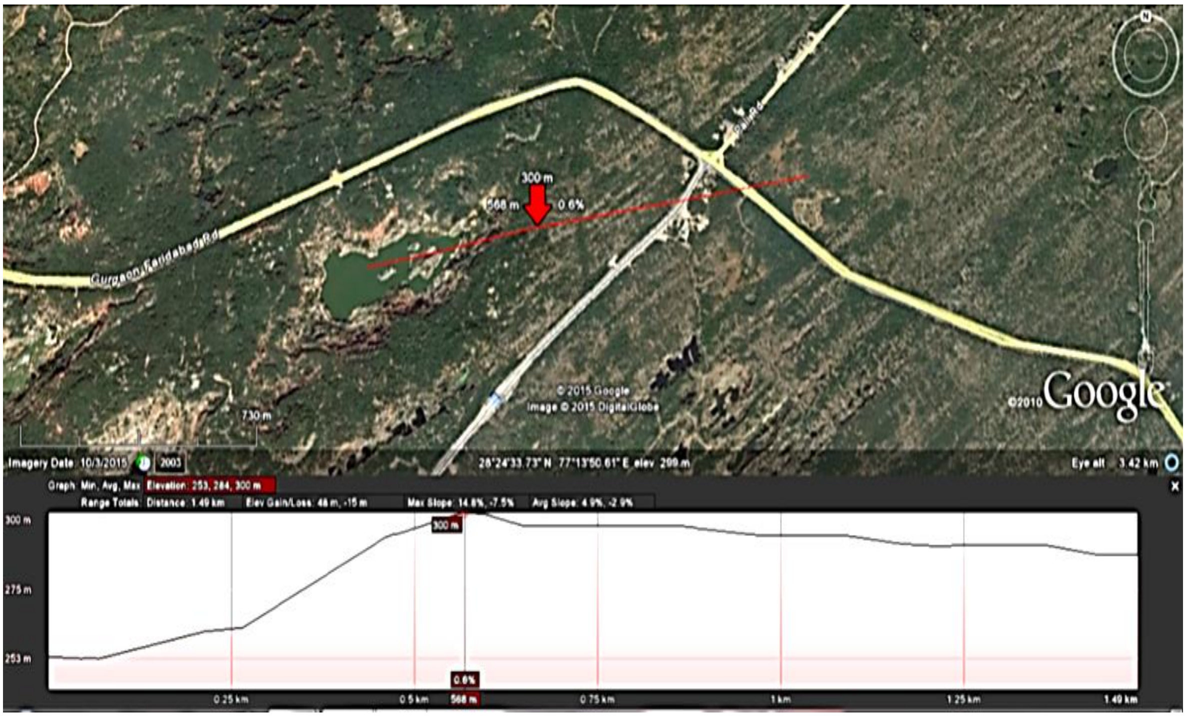


Figure 2.11 : Map showing nearest identified pits around Badkhal catchment within 1.49km and lift of water required for transfer is about 50m.

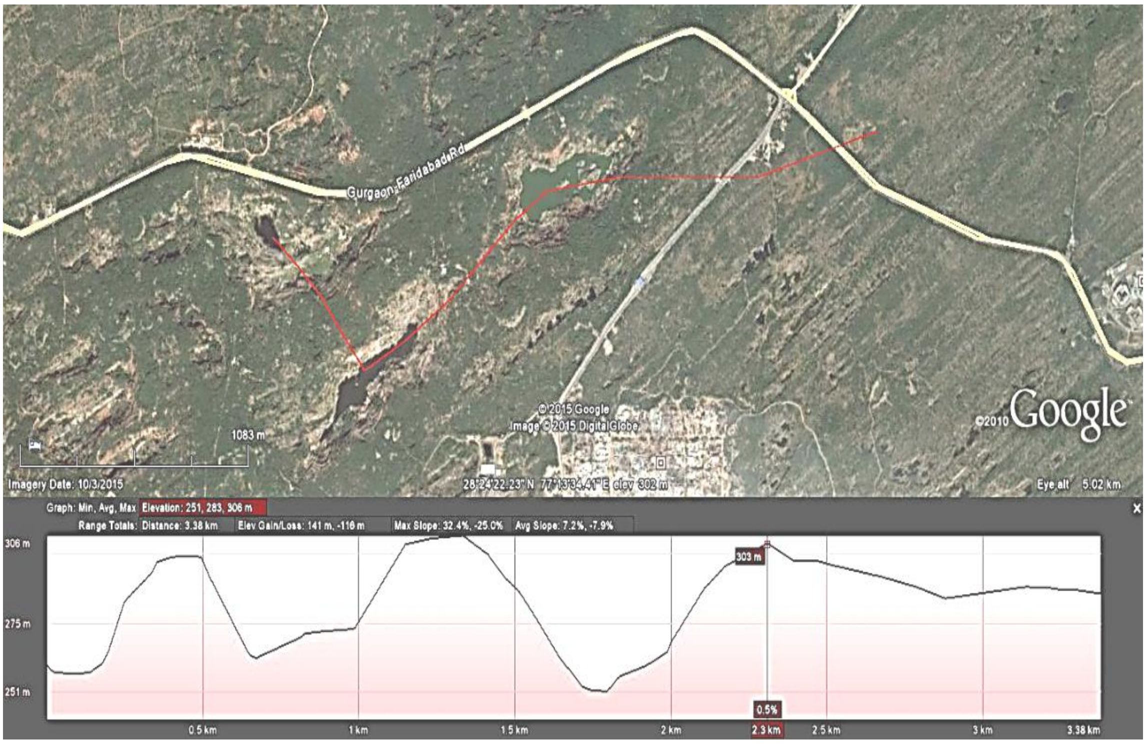


Figure 2.12: Map showing nearest three identified pits around Badkhal catchment within 3.4km and lift of water required for transfer is about 55m.

Table2.4: Details of the pits giving information on water storage and lift requirement

S. No	ID	Area in m2	Water Colum in m	Water volume In MCM	Elevation Need to Compensate In m
1	**2**	**3**	**4**	**5**	**6**
1	1a	75350	6.5	0.49	50
2	1b	47670	10	0.48	55
3	1c	12130	3	0.04	55
4	1d	68950	5	0.34	55
5	2a	67840	8	0.54	30
6	2b	33140	1.5	0.05	30
7	2c	50160	3	0.15	30
8	2d	22950	1	0.02	30

From the above table, which is based on the first approximation by the application of Google earth, it is apparent that the water column in the respective pits is not significant to be considered for transfer to the Badkhal Lake. However, the detailed hydrographic survey of the major water bodies will lead to the proper estimation. It is also made out from the Google earth study that the water in the pits will require lift from 30m to about 55m before considering its transfer. The storage capacity is also not so much to consider this options as the increased in the storage capacity each year is also not adequate for transfer and to make the lake sustainable.

CHAPTER 3

GEOPHYSICAL SURVEY

3.1 Introduction

In order to comprehend the desired information on disposition of sub surface lithological units, thickness of the overburden materials & alluvium sediments and configuration of the bed rock, 1680 line meter by tomography and 6 VES were carried out to cover the active area of the dried up Lake. The details of each of the technique and the parameter corrected are briefly described below. The field data has been interoperated using the advanced software.

3.2 Vertical Electrical Sounding (VES)

In vertical electrical sounding, the variation of resistivity with depth over a point is measured. In this, the centre of configuration is kept fixed and the measurements are made by successively increasing the electrode spacing. The apparent resistivity values obtained with increasing values of electrode separations are used to estimate the thickness and resistivity of the subsurface formations. In Schlumberger sounding arrangement, all the four electrodes are kept in a line symmetrically over a point `0; with inner (Potential) electrodes kept closer. For increasing the depth of investigation the current electrodes A and B are moved apart symmetrically about the centre point `0' keeping the potential electrodes fixed. The separation between the Potential Electrodes is changed only when the potential between them drops to allow value during the course of sounding. The apparent resistivity for each electrode separation is calculated by multiplying the resistance `R, Schlumberger configuration factor.

3.2.1 Data Acquisition

Field surveys were conducted during the month of November 2015. Six nos. of vertical electrical soundings (VES) with Schlumberger four electrode configurations were carried out in selected area to cover the entire Badkhal Lake area. The sounding measurements at each station were made at maximum half current electrode spacing (AB/2) ranging from 1.5m to 750m. At few places, AB/2 has been extended up to 1000m.

3.2.2 Data Interpretation

The sounding data has been analyzed with Interpex IX1D one dimensional resistivity data processing software. The processing involves manual/ automatic selection of model, equivalence analysis, and automatic iterative curve matching technique along with partial derivative technique with successive iterative process. In this iterative curve matching technique an initial model is given for which the computer arrives at the theoretical curve and compare with the field data, then it takes difference between the computed and field curves and assigns new model for reducing this difference (error). It again computes new theoretical curve and compares with the field curve, and sets another new model to reduce the differences (errors). This process of iterations goes on till the error is minimized and finally displays the match between the field and theoretical curves giving the final model parameters. The standardization of geo-electric parameters with lithology has been made on the basis of the available geological information at site with standard resistivity of different earth's material. Based on the results of resistivity soundings, the following lithology has been interpreted as shown in **Table-3.1**

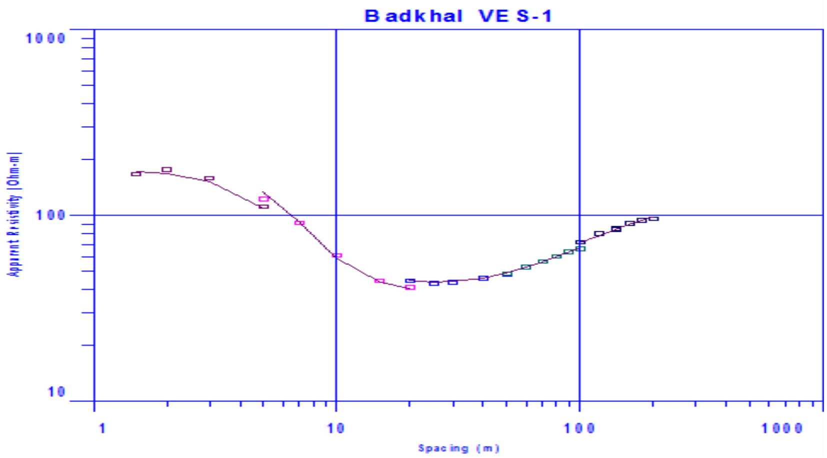
Table 3.1: Resistivity ranges versus interpreted lithology in Badkhal Lake

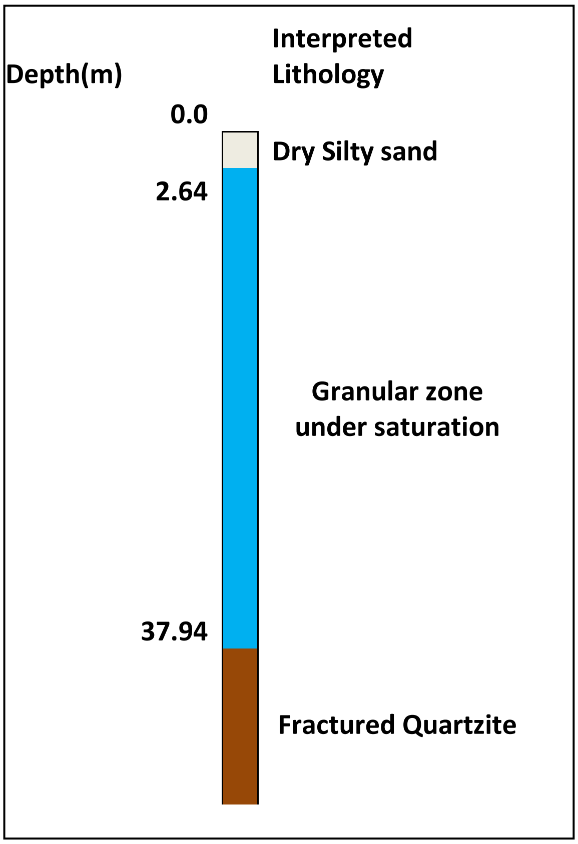
Resistivity Ranges in Ωm	Interpreted Lithology
7 – 15	Clay zone under saturation.
15 – 60	Alluvium soil comprises of silty sand/ fine to medium sand under fresh water saturation
60 to 180	Weathered / Fractured quartzite, lower resistivity up to 130Ωm shows quartzite under saturation
>180 to 300	Fractured quartzite, higher value indicates less fractured nature of rock mass
300 and above	Hard and compact nature of quartzite

3.3 DISCUSSION OF RESULTS

Total **s**ix no's of VES has been carried out at different six locations within the Badkhal lake to delineate the overburden thickness, depth to bedrock & potential aquifer zone with ground water table. The details of the all VES interpretation are as under

3.3.1 VES-1 (28°24'54" N 77°16'39" E) has been carried out about 30m west from the ridgeline and backside of tourist complex. Direction of the sounding is N 600 E and S 600 W. Resistivity depth probe reveals that the area is generally covered with 2.64m thick layer of silty sand, dry in nature having resistivity of the order of 234.08Ωm. This layer is followed by 35.33m thick layer of granular zone under saturation having resistivity of the order of 44.81Ωm. A layer of moderately high resistivity of the order of 132.86 Ωm further follows this layer. This high resistivity is possibly due to the presence of fractured quartzite at the depth is about 38m bgl. For detail, interpretation refers **Figure-3.1**

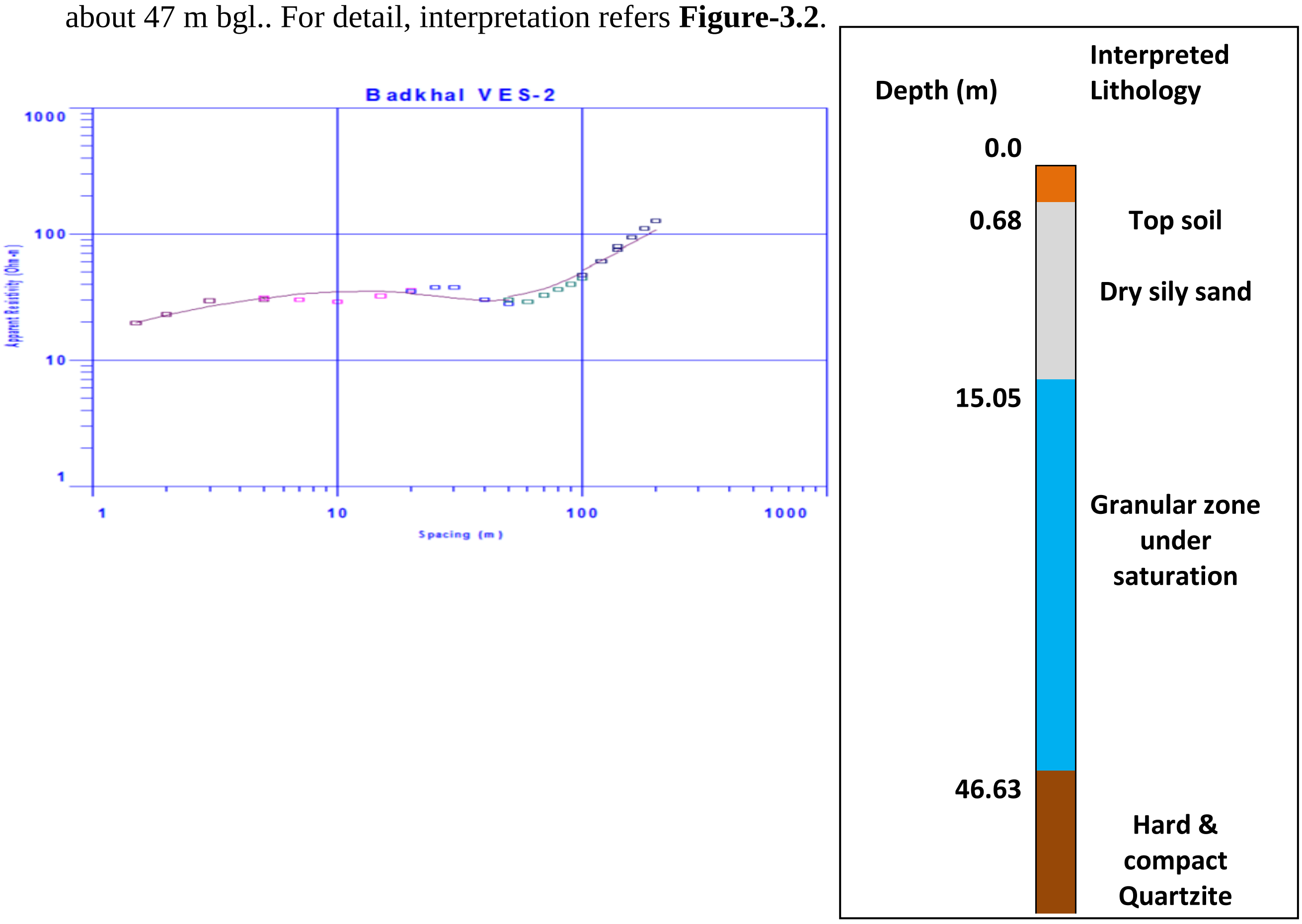




VES NO.	LOCATION	NORTHING	EASTING	LAYER				
				NO.	RESISTIVITY	THICKNESS (m)	DEPTH (m)	Interpretation
1	Back side of Tourist complex	28° 24' 54"	77 °16' 39"	1	234.08	2.64	2.64	Silty sand (Dry in Nature)
				2	44.81	35.33	37.97	Granular Zone (under Saturation)
				3	132.86	-	-	Fractured quartzite

Figure 3.1: Field Data curves & interpreted lithology of VES 1

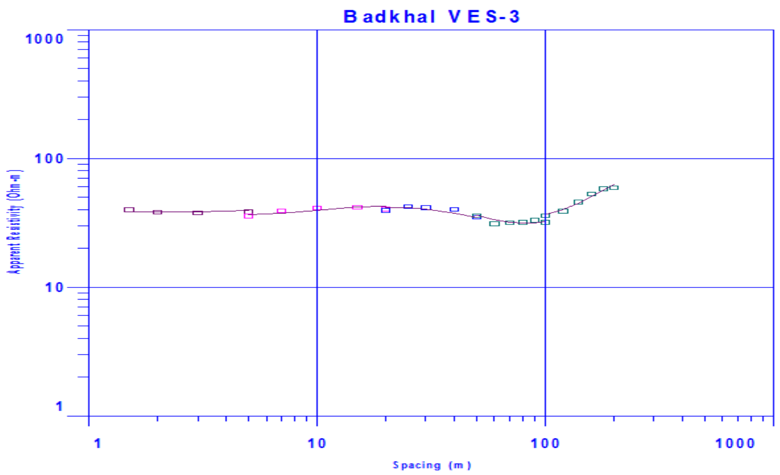
3.3.2 VES-2 (28°24'42.2" N 77°16'15.2" E) has been carried out in upstream side at the centre of the lake between two ridges. Direction of the sounding is N 66°E and S 66°W. Resistivity depth probe reveals that the area is generally covered with 0.68m thick layer of top loose soil, having resistivity of the order of 17.83Ωm. This layer is followed by a 14.37m thick layer of silty sand (dry in nature) having resistivity of the order of 44.25Ωm. This layer is further followed by a 31.58m thick layer having low resistivity of the order of 21.70 Ωm. This resistivity may possibly indicate the presence of granular zone under saturation. This layer is further followed by a layer, having high resistivity of the order of 6289.30 m. This resistivity may is possibly due to the presence of hard & compact quartzite at the depth is about 47 m bgl.. For detail, interpretation refers **Figure-3.2**.

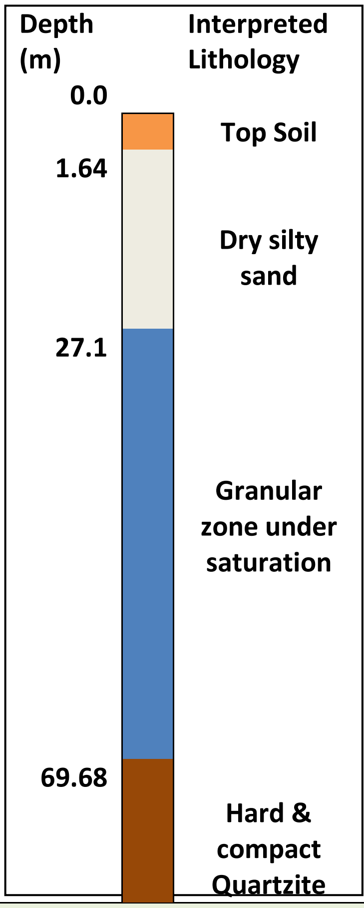


VES NO.	LOCATION	NORTHING	EASTING	LAYER				
				NO.	RESISTIVITY	THICKNESS (m)	DEPTH (m)	Interpretation
2	Between two ridges (In centre of the lake)	28° 24' 42.2"	77° 16' 15.2"	1	17.83	0.68	0.68	Top soil
				2	44.25	14.37	15.05	Silty sand (Dry in Nature)
				3	21.70	31.58	46.63	Granular Zone (under Saturation)
				4	6289.30	-	-	Hard & compact quartzite

Figure 3.2: Field Data curves & interpreted lithology of VES 2

3.3.3 VES-3 (28°24'48.3" N   77°16'15.2" E) has been carried out in west end of the ridge. Direction of the sounding is N 40°E and S 40°W. Resistivity depth probe reveals that the area is generally covered with 1.64m thick layer of top soil, having resistivity of the order of 45.12Ωm to 21.37Ωm. This layer is followed by a 20.46m thick layer of silty sand (dry in nature) having resistivity of the order of 40.96Ωm. This layer is further followed by 42.58m thick layer having low resistivity of the order of 18.45Ωm. This resistivity may possibly indicate the presence of granular zone under saturation. This layer is further followed by a layer of high resistivity of the order of 733.4Ωm. This resistivity is possibly due to the presence of hard & compact quartzite at the depth is about 70 m bgl. For detail interpretation refers **Figure-3.3.**

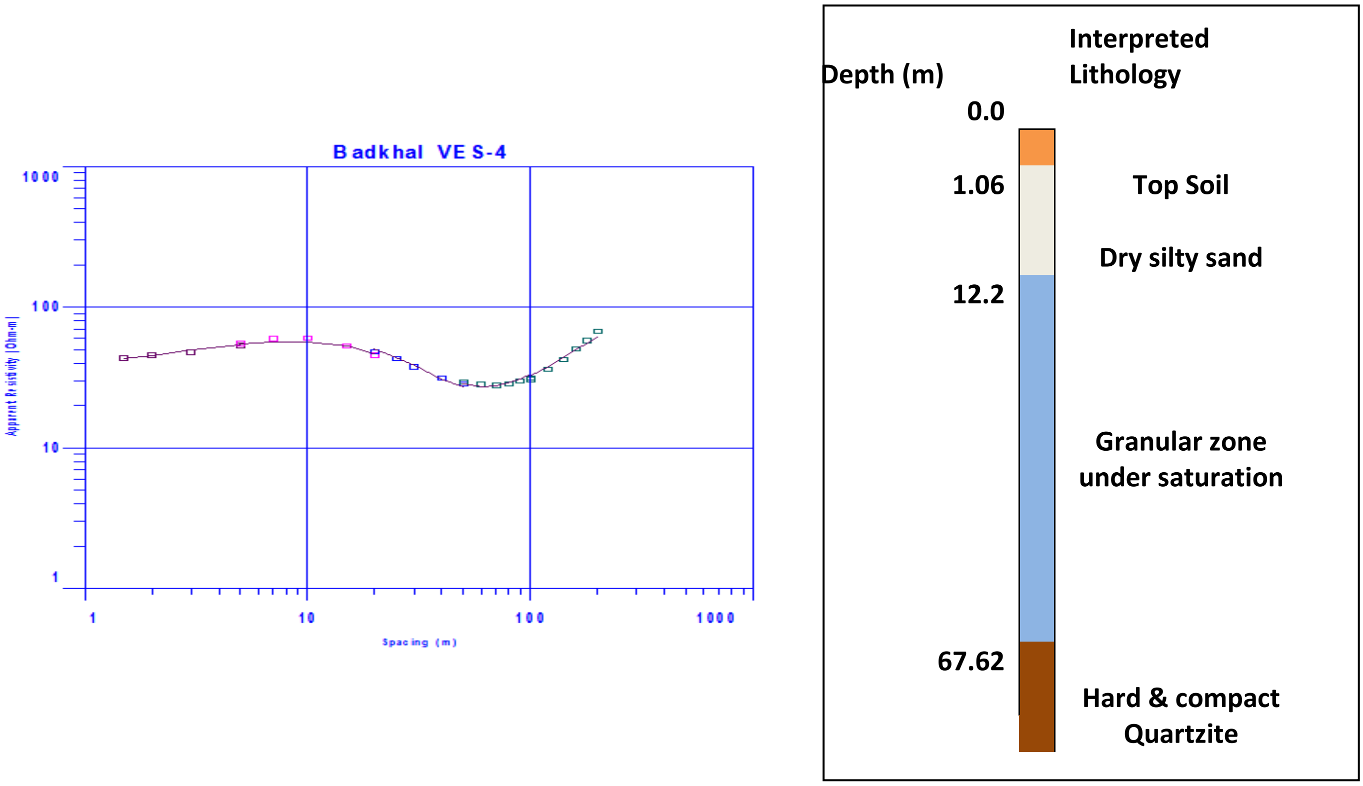




VES NO.	LOCATION	NORTHING	EASTING	LAYER NO.	RESISTIVITY	THICKNESS (m)	DEPTH (m)	Interpretation
3	Open space in the West end of the 1 st Ridge	28° 24' 48.3"	77° 16' 15.2"	1	45.012	0.74	0.74	Top soil
				2	21.37	0.89	1.64	
				3	40.96	20.46	27.1	Silty sand (Dry in Nature)
				4	18.45	42.58	69.68	Granular Zone (under Saturation)
				5	733.4	-	-	Hard & compact quartzite

Figure 3.3: Field Data curves & interpreted lithology of VES 3

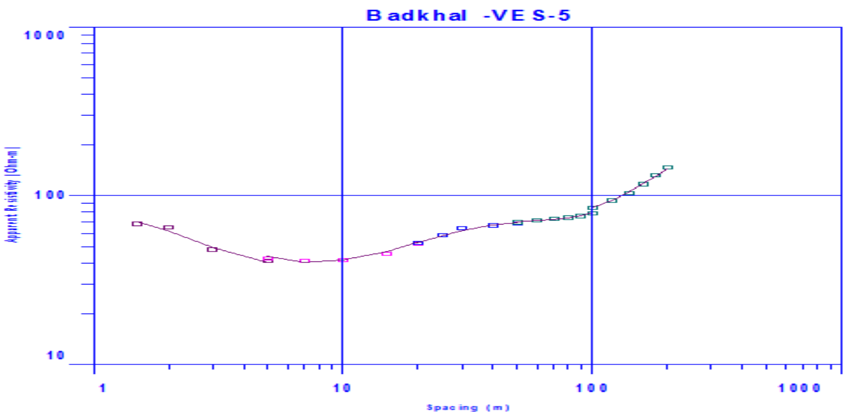
3.3.4 VES-4 (28°24'54" N 77°16'16.4" E) has been carried out in middle of the lake in play ground. Direction of the sounding is N 40°E and S 40°W. Resistivity depth probe reveals that the area is generally covered with 1.06m thick layer of top soil, having resistivity of the order of 44.25Ωm. This layer is followed by 11.14m thick layer of silty sand (dry in nature) having resistivity of the order of 66.30Ωm. This layer is further followed by 55.42m thick layer having low resistivity of the order of 18.56 Ωm. This resistivity may possibly indicate the presence of granular zone under saturation. This layer is further followed by a layer of high resistivity of the order of 2683Ωm. This resistivity is possibly due to the presence of hard & compact quartzite is about 68 m bgl. For detail interpretation refers **Figure-3.4.**

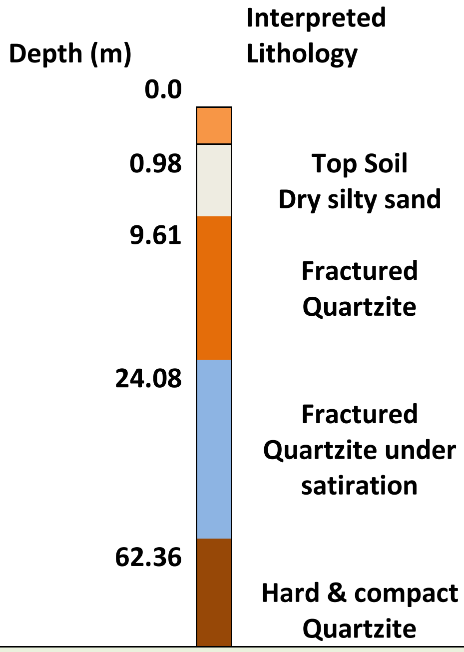


NO.	LOCATION	NORTHING	EASTING	LAYER				
				NO.	RESISTIVITY	THICKNESS (m)	DEPTH (m)	Interpretation
4	Middle of lake in open play ground	28° 24' 54"	77° 16' 16.4"	1	44.25	1.06	1.06	Top soil
				2	66.30	11.14	12.20	Silty sand (Dry in Nature)
				3	18.56	55.42	67.62	Granular Zone (under Saturation)
				4	2683.90	-	-	Hard & compact quartzite

Figure 3.4: Field Data curves & interpreted lithogy of VES 4

3.3.5 VES-5 (28°24'57" N 77°16'26" E) has been carried out in 30m east from west end of the ridge. Sounding location is at upland covered with filled soil & boulders followed by quartzite. Direction of the sounding is N 10°W and S 10°E. Resistivity depth probe reveals that the area is generally covered with 0.98m thick layer of dry nature top soil, having resistivity of the order of 92.38Ωm. This layer is followed by 8.62 m thick layer of silty sand (dry in nature) having resistivity of the order of 39.40Ωm. This layer is further followed by 14.47m thick layer having moderately high resistivity of the order of 141.12 Ωm. This resistivity may possibly indicate the presence of fractured quartzite. This layer is further followed by a layer of moderately low resistivity of the order of 37.14Ωm. This resistivity may possibly indicate the presence of fractured quartzite zone under saturation. This layer is further followed by a layer of high resistivity of the order of 7478.20 Ωm. This resistivity is possibly due to the presence of .hard & compact quartziteis about 63 m bgl. For detail interpretation refers **Figure-3.5.**

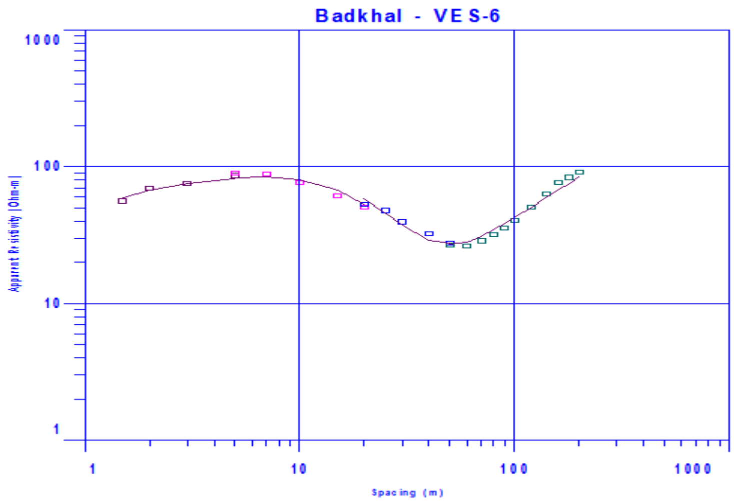


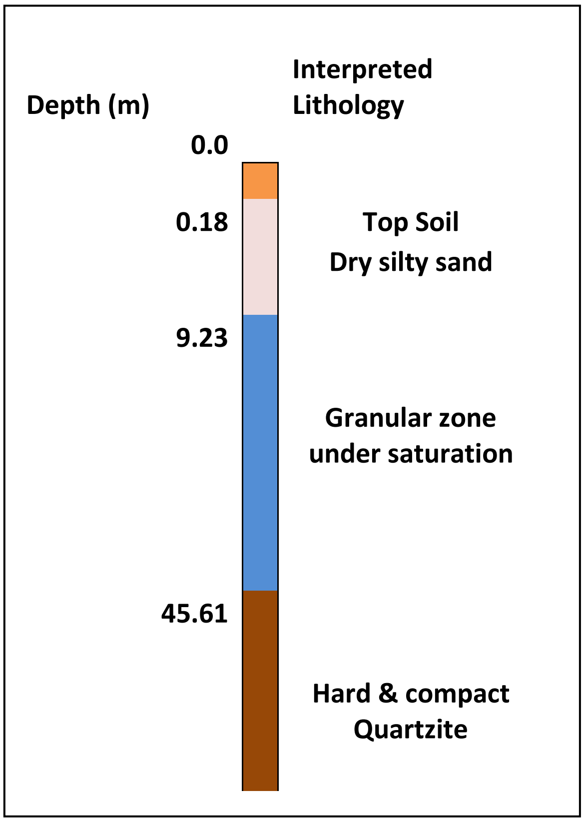


VES NO.	LOCATION	NORTHING	EASTING	LAYER				
				NO.	RESISTIVITY	THICKNESS (m)	DEPTH (m)	Interpretation
5	Near Eucalyptus trees (30m East from the Ridge	28° 24' 57"	77° 16' 26"	1	92.38	0.98	0.98	Top soil
				2	39.40	8.62	9.61	Silty sand (Dry in Nature)
				3	141.12	14.47	24.08	Fractured quartzite
				4	37.14	39.29	62.36	Fractured quartzite (under Saturation)
				5	7478.0	-	-	Hard & compact quartzite

Figure 3.5: Field Data curves & interpreted lithology of VES 5

3.3.6 VES-6 (28°24'52" N 77°16'45" E) has been carried out in east bank of lake at abutment toe of the lake. Direction of the sounding is N 26°E and S 26°W. Resistivity depth probe reveals that the area is generally covered with 0.18m thick layer of top soil, having resistivity of the order of 19.17Ωm. This layer is followed by 9.05m thick layer of silty sand (dry in nature) having resistivity of the order of 93.81Ωm. This layer is further followed by 36.38m thick layer having low resistivity of the order of 16.44 Ωm. This resistivity may possibly indicate the presence of granular zone under saturation. This layer is further followed by a layer of high resistivity of the order of 2966.20Ωm. This resistivity is possibly due to the presence of hard & compact quartzite is about 46m bgl. For detail interpretation refers **Figure-3.6.**





VES NO.	LOCATION	NORTHING	EASTING	LAYER				
				NO.	RESISTIVITY	THICKNESS (m)	DEPTH (m)	Interpretation
6	Badkhal lake abutment toe(150m downstream from Iron gate)	28° 24' 52"	77° 16' 45"	1	19.17	0.18	0.18	Top soil
				2	93.81	9.05	9.23	Silty sand (Dry in Nature)
				3	16.44	36.38	45.61	Granular Zone (under Saturation)
				4	2966.20	-	-	Hard & compact quartzite

Figure 3.6: Field Data curves & interpreted lithology of VES 6

All the results are tabulated in Table 3.2.

Table 3.2 : VES results with interpreted lithology and Ground water table

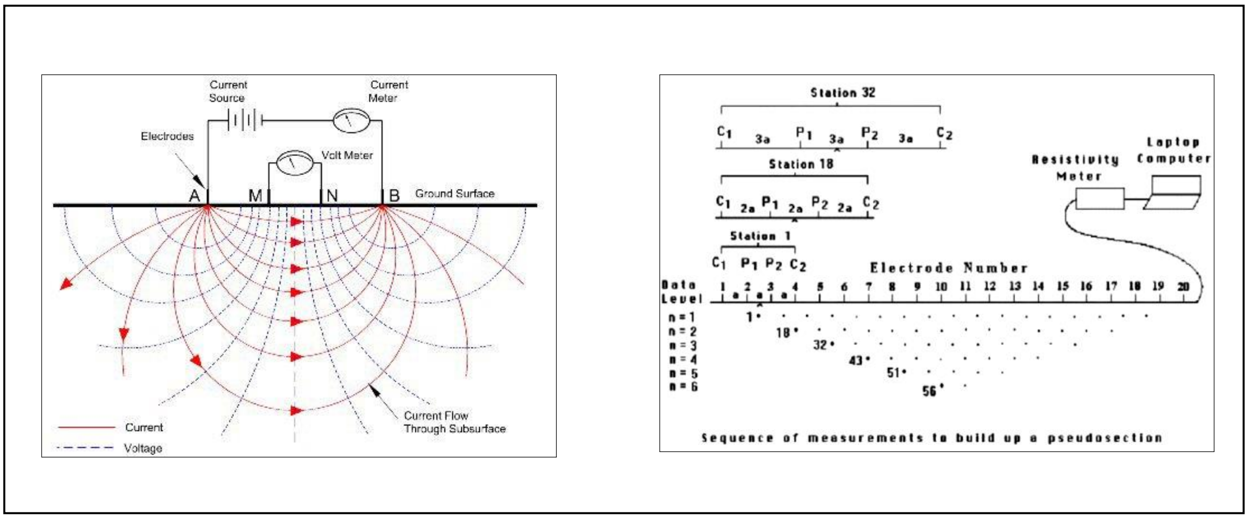
VES No	location	Latitude	Longitude	Layers			Interpreted Lithology	Interpreted Ground water table (m)
				Resistivity (Ωm)	Thickness (m)	Depth (m)		
VES-1	Back side of Tourist complex	28° 24' 54"	28° 24' 54"	234.08	2.64	2.64	Silty sand (Dry in Nature)	15.0
				44.81	35.33	37.97	Granular Zone (under Saturation)	
				132.86	-	-	Fractured quartzite	
VES-2	Between two ridges (In centre of the lake)	28° 24' 42.2"	77° 16' 15.2"	17.83	0.68	0.68	Top soil	15.0
				44.25	14.37	15.05	Silty sand (Dry in Nature)	
				21.70	31.58	46.63	Granular Zone (under Saturation)	
				6289.30	-	-	Hard & compact quartzite	
VES-3	Open space in the West end of the 1 st Ridge	28° 24' 48.3"	77° 16' 15.2"	45.12	0.74	0.74	Top soil	27.0
				21.37	0.89	1.64		
				40.96	20.46	27.10	Silty sand (Dry in Nature)	
				18.45	42.58	69.68	Granular Zone (under Saturation)	
				733.4	-	-	Hard & compact quartzite	
VES-4	Middle of lake in open play ground	28° 24' 54"	77° 16' 16.4"	44.25	1.06	1.06	Top soil	12.2
				66.30	11.14	12.20	Silty sand (Dry in Nature)	
				18.56	55.42	67.62	Granular Zone (under Saturation)	
				2683.90	-	-	Hard & compact quartzite	

VES No	location	Latitude	Longitude	Layers			Interpreted Lithology	Interpreted Ground water table (m)
				Resistivity (Ωm)	Thickness (m)	Depth (m)		
VES-5	Near Eucalyptus trees (30m East from the Ridge	28° 24' 57"	77° 16' 26"	92.38	0.98	0.98	Top soil	24.08
				39.40	8.62	9.61	Silty sand (Dry in Nature)	
				141.12	14.47	24.08	Fractured quartzite	
				37.14	38.29	62.36	Fractured quartzite (under Saturation)	
				7478.20	-	-	Hard & compact quartzite	
VES-6	Badkhal lake abutment toe(150m downstream from Iron gate)	28° 24' 52"	77° 16' 45"	19.17	0.18	0.18	Top soil	9.5
				93.81	9.05	9.23	Silty sand (Dry in Nature)	
				16.44	36.38	45.61	Granular Zone (under Saturation)	
				2966.20	-	-	Hard & compact quartzite	

3.4 Electrical Resistivity Tomography Survey (ERT)

Electrical resistivity tomography (ERT) or electrical resistivity imaging (ERI) is a geophysical technique for imaging sub-surfaces structures from electrical measurements made at the surface with multi-electrode system. The instrumentation and measurement procedure is briefly described below

For carrying out 2-D electrical imaging/tomography surveys large number of electrodes, connected to a multi-core cable. A microcomputer together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement. A Terrameter-LS system from ABEM Sweden was used for automatic data collection with 21 to 81 electrodes spaced at 3m to 10m intervals as per site condition. Gradient array and Dipole-Dipole array were used for data acquisition.



Figure–3.7 : Principle of Electrical Resistivity sounding and 2D Resistivity Imaging.

Data acquisition has been carried out through 12-Channel Multi-electrode Resistivity Meter/Terrameter-LS, which is a high speed resistivity imaging system. This equipment is capable of running self-checks for connectivity of electrodes and generates warnings on bad contacts. The details of the executed Resistivity Imaging Line coordinates in **Badkhal** Lake are placed in the **Table-3.3**.

Table-3.3: Co-ordinates of 2D Resistivity Profiles in Badkhal Lake, Faridabad, Haryana

S.N	Length (m)	Imaging Line/ Profile No.	Line start (UTM)		Line End(UTM)	
			Northing	Easting	Northing	Easting
1	480	1	3145319	723357	3144929	723093
2	800	2	3145065	723213	3145667	722698
3	40	3	3145785	722536	3145762	722550
4	60	4	3145361	723381	3145394	723344
5	200	5	3145407	723379	3145275	723235
6	100	6	3145307	723248	3145239	723319
Total covering length of Resistivity Imaging Lines: 1680m						

3.5 2D Electrical Profiling Interpretations

2D Resistivity Imaging has been carried out in Badkhal lake as per given location. Total six nos. of resistivity profiles have been carried out with a total coverage of 1680m. The details of the resistivity lines are shown in **Figure -3.7**

Resistivity Imaging data have been processed by RES2DINV software. After processing of the resistivity data, the subsurface stratification has been made based on the true resistivity value as well as keeping in mind the local geological setup in the surveyed area. The ranges of resistivity value with interpreted lithology are shown in **Table –3.4.**

Table –3.4 Resistivity Ranges with Interpreted Lithology in Badkhal Lake

Resistivity Ranges in Ωm	Interpreted Lithology
7 – 15	Clay zone under saturation.
15 – 60	Alluvium soil comprises of silty sand/ fine to medium sand under fresh water saturation
60 to 180	Weathered / Fractured quartzite, lower resistivity up to 130Ωm shows quartzite under saturation
>180Ωm to 300Ωm	Fractured quartzite, higher value indicates less fractured nature of rock mass
>300Ωm to 650Ωm and above	Hard and compact nature of quartzite

3.6 Discussion of Results

The result of the 2D ERT survey brought out the different subsoil litho units, fractures, basement rock with water saturation zones showing variation of resistivity both vertically as well as laterally. Resistivity Image sections along the proposed lines are placed in **Figure 3.8 to 3.13.**

3.6.1 ERT Profile-1

2D Resistivity Image survey has been carried out along the Lake embankment about 10 m from toe of the embankment. The line was planned with 6m uniform gradient array with N215^0 profile direction. Interpreted resistivity section indicates lateral variation of resistivity with depth.

The inverted resistivity section along this profile is interpreted in terms of three-layered model. A uniform top layer comprises of overburden soil having resistivity of the order of 25Ωm to 105Ωm extending down to 10m to 20m depth along the profile. This is followed by a uniform layer of low to medium resistivity of the order of 5.0Ωm to 25.0Ωm. Thickness of this layer varies from 60m to 100m been in interpreted along the profile. In this layer lower resistivity of the order of 5.0Ωm to 15.0Ωm indicates the clayey soil under saturation where as 15.0Ωm to 25Ωm indicates the presence of highly saturated sandy soil. Below this layer a zone of moderate resistivity between Chainage 140m to 210m along the profile line has been interpreted, with resistivity of the order of 105.0Ωm to 200.0Ωm with depth varying from 80m to 100m. This may possibly indicate the presence of weathered quartzite under fresh water saturation. Inverted resistivity model is presented in **Fig.3.8**.

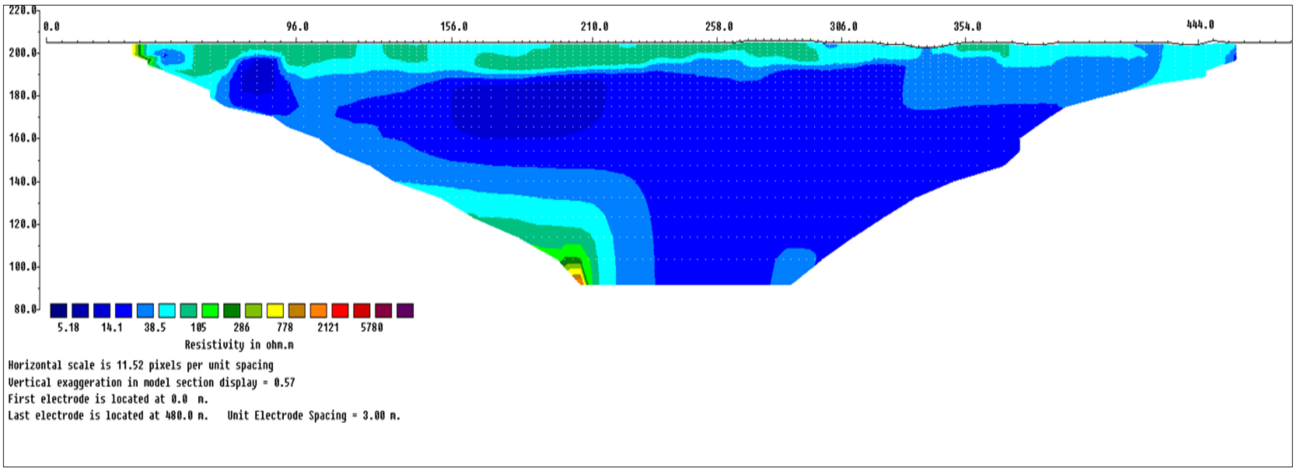


Figure-3.8: Resistivity section along ERT-1

3.6.2 ERT Profile-2

2D Resistivity Image survey profile of 800m has been carried out with 10m uniform gradient array a across the Badkhal Lake with profile direction N320^{0}. The line was planned almost perpendicular direction of ERT line-1. Interpreted resistivity section indicates variation of resistivity laterally with depth.

The inverted resistivity section along this profile is interpreted in terms of two layered model. The topmost layer comprises of overburden soil comprises of sandy soil under saturation having resistivity of the order of 15.60Ωm to 53.0Ωm having varying thickness from 20.0m to 80.0m depth along the profile. The depth of alluvium saturated zone is increasing towards east of the profile and has been interpreted between chainage 0.0m to 200m. Further the thickness of the zone varies from 30 to m to 80m between Chainage 200m to 340m along the profile. Beyond Chainage 340m to the end of the profile has been interpreted with uniform thickness of 20m.

This layer is followed by a thin uniform layer of higher resistivity of the order of 53.0Ωm to 180Ωm between 200m to end of the line interpreted as weathered/jointed nature of quartzite under saturation between 50m to 80m depth along the profile. In same layer followed by moderately high resistivity of the order of 183Ωm to 630Ωm has been interpreted as jointed quartzite. The lower resistivity within this zone indicates higher degree joints/ fractures, whereas higher resistivity range of this layer may indicates lower degree of joints. The resistivity value of the order of >630Ωm may indicates the presence of massive nature of quartzite. Inverted resistivity model is presented in **Fig 3.9.**

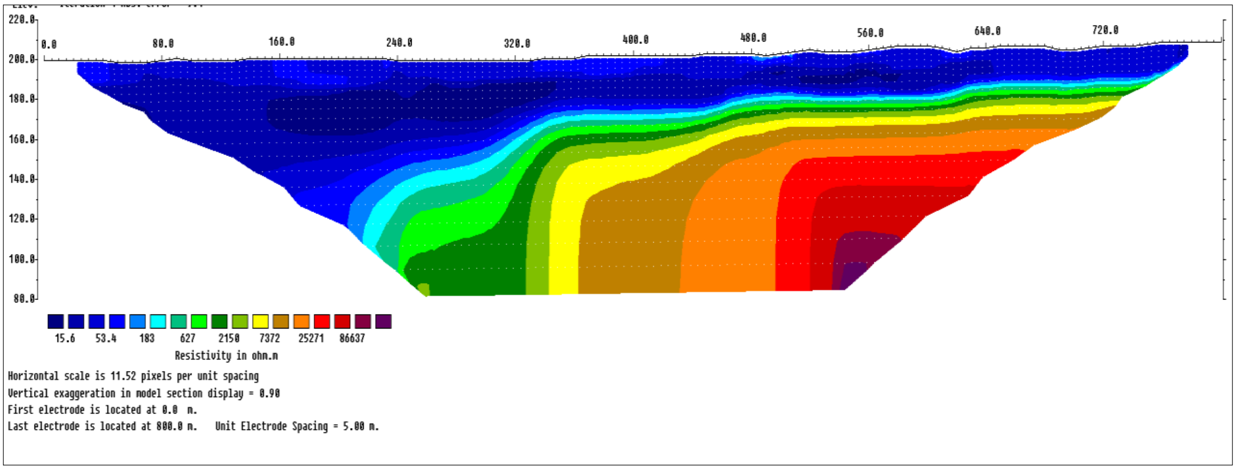


Figure-3.9: Resistivity section along ERT-2

3.6.3 ERT Profile-3

2D Resistivity Image survey profile of 40m has been carried out with 2m uniform dipole-dipole array a across the minor channel in the Badkhal Lake with profile direction E-W. The line was planned to decipher the saturated zone across the minor channel. Interpreted resistivity section indicates variation of resistivity laterally with depth.

The inverted resistivity section along this profile is interpreted in terms of two layered model. The topmost layer has been as weathered/highly jointed quartzite having resistivity of the order of 120.0Ωm to 638.0Ωm with varying thickness, from surface to 2.0m depth. In same layer between chainage 2.0m to 8.0m & 29.0m to 32.0m of the profile line, resistivity range from 638Ωm to 7966Ωm has been interpreted as compact quartzite up to 2.0m depth.
This is followed by a uniform layer of moderately low resistivity of the order of 22.0Ωm to 85Ωm extended with varying thickness from 5.0m to 10.0m, has been interpreted as highly fractured quartzite under saturation. The lower resistivity range of this layer may indicate higher degree of fractures, whereas higher resistivity range of this layer may indicates lower degree of fractures. Inverted resistivity model is presented in **Fig.3.10.**

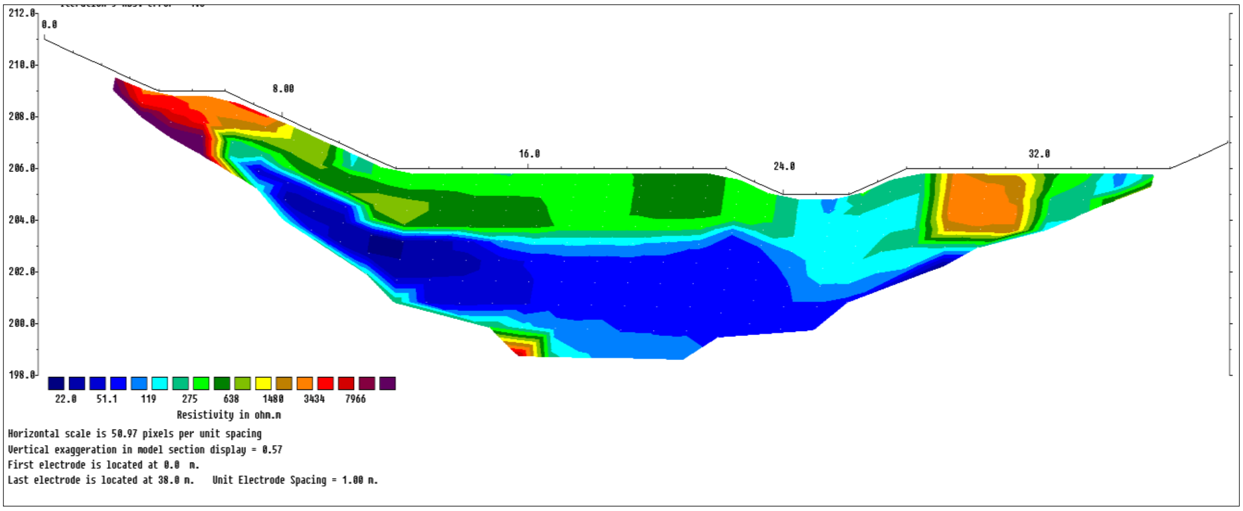


Figure-3.10: Resistivity section along ERT-3

3.6.4 ERT Profile-4

2D Resistivity Image survey profile of 60m has been carried out with 3m uniform dipole-dipole array a across the channel in the northern part in the Badkhal Lake with profile direction E-W. The line was planned to decipher the presence of bed rock and saturated zone across the minor channel. Interpreted resistivity section indicates variation of resistivity laterally with depth.   Inverted resistivity section along this profile is interpreted in terms of two layered models. Resistivity depth probe reveals that a high resistivity of the order of 193.0Ωm to 425.0Ωm with varying thickness from 0.0m to 9.0m depth has been reflected between chainage 0.0m to 16.0m along the profile line is interpreted as jointed hard quartzite. In continuation to the jointed quartzite a moderate resistivity of the order of 88.3Ωm has been mapped between 16m to 33m along the profile dipping towards east. This layer is interpreted as weathered quartzite at 8.0m to 10.0m depth between chainage 24 to 33m along the profile. Below this layer hard quartzite is expected.

From Chainage 16.0m to the end of the profile a uniform variation in resistivity of the order of 18.4Ωm to 65Ωm has been reflected all along the profile except two patches of slightly higher resistivity of 88Ωm has been mapped. Resistivity of the order of 18.4Ωm to 65Ωm may indicate the presence of granular soil where as higher resistivity indicates ruminant of weathered quartzite. Inverted resistivity model is presented in **Fig.3.11.**

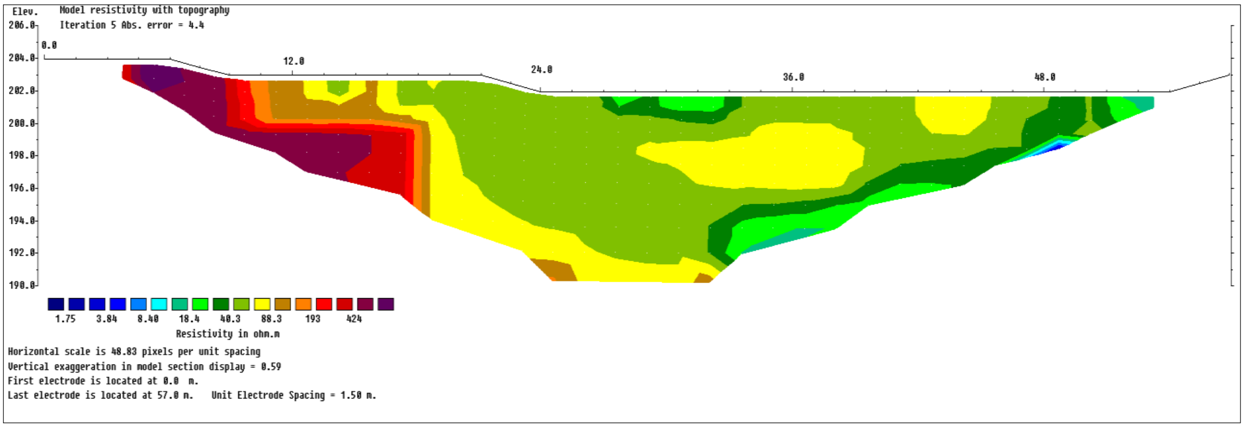


Figure-3.11: Resistivity section along ERT-4

3.6.5 ERT Profile-5

2D Resistivity Image survey profile of 200m has been carried out with 10.0m uniform dipole-dipole array in the lake along the western exposed hill. This profile is from North to South and crossing the ERT-4 line at the centre. The line was planned to decipher the presence of bed rock and saturated zone in the lake along the western exposed hill. Interpreted resistivity section indicates variation of resistivity laterally with depth.

The inverted resistivity section along this profile is interpreted in terms of three layered model. The topmost layer has been interpreted as fine to medium grained sandy soil under saturation having resistivity of the order of 25.0Ωm to 57.0Ωm with varying thickness from 5.0m to *22.0m depth. Thickness of granular zone at the crossing of ERT-4 and ERT-5 is well matched. Below the weathered zone, hard rock layer could be mapped at 10.0m depth through ERT-5 crossing ERT-4 line at Chainage 30.0m.

This is followed by a uniform layer of moderate resistivity of the order of 130.0Ωm to 294Ωm with varying thickness from 1.5m to 3.0m has been interpreted as fractured/weathered quartzite under saturation. This is followed by a uniform layer of high resistivity of the order of 294.0Ωm to 7760Ωm extended up to investigated depth has been interpreted as quartzite. The lower resistivity range of this layer 294.0Ωm to 650Ωm may indicate jointed nature of quartzite, whereas higher resistivity range >650Ωm of this layer may indicates hard & compact nature of quartzite. Inverted resistivity model is presented in **Fig.3.12.**

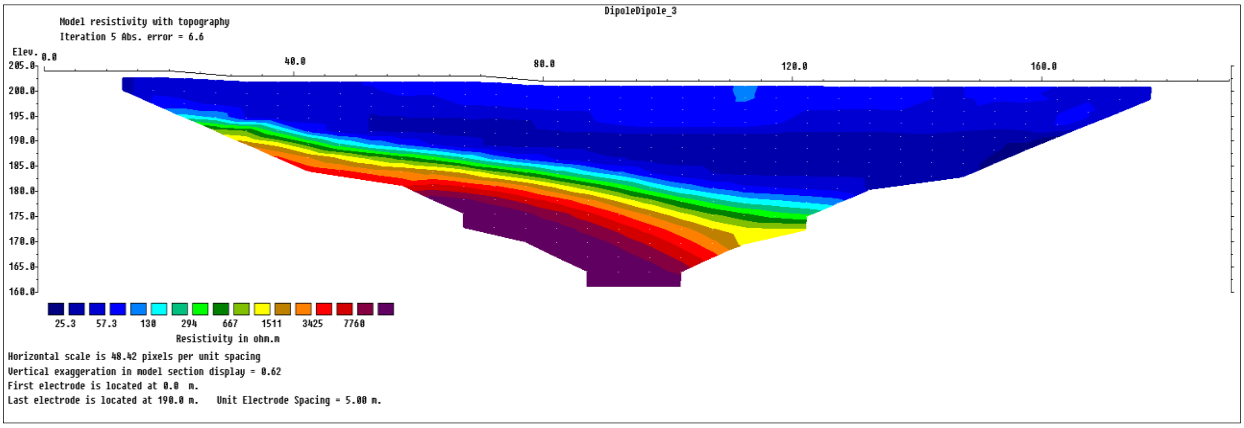


Figure-3.12: Resistivity section along ERT-5

3.6.6 ERT Profile-6

2D Resistivity Image survey has been carried out with a profile length of 100m with 5m uniform dipole-dipole array with West to East profile direction. This line crosses ERT-5 at 150m and ERT-1 at 85m. Interpreted resistivity section indicates lateral variation of resistivity with depth.

The inverted resistivity section along this profile is interpreted in terms of two layered model. The topmost layer comprises of fine to medium sand under saturation having resistivity of the order of 19.0Ωm to 43.0Ωm with varying thickness from 8.0m to 12.0m. This is followed by a uniform layer of lower resistivity of the order of 7.0Ωm to 15Ωm extended down up to investigated depth of 20m has been interpreted as clay zone under saturation. Depth of alluvium zone in ERT-6 has been correlated with the crossing point of ERT-1 and ERT-5 found to be well matched. Inverted resistivity model is presented in **Fig.3.13.**

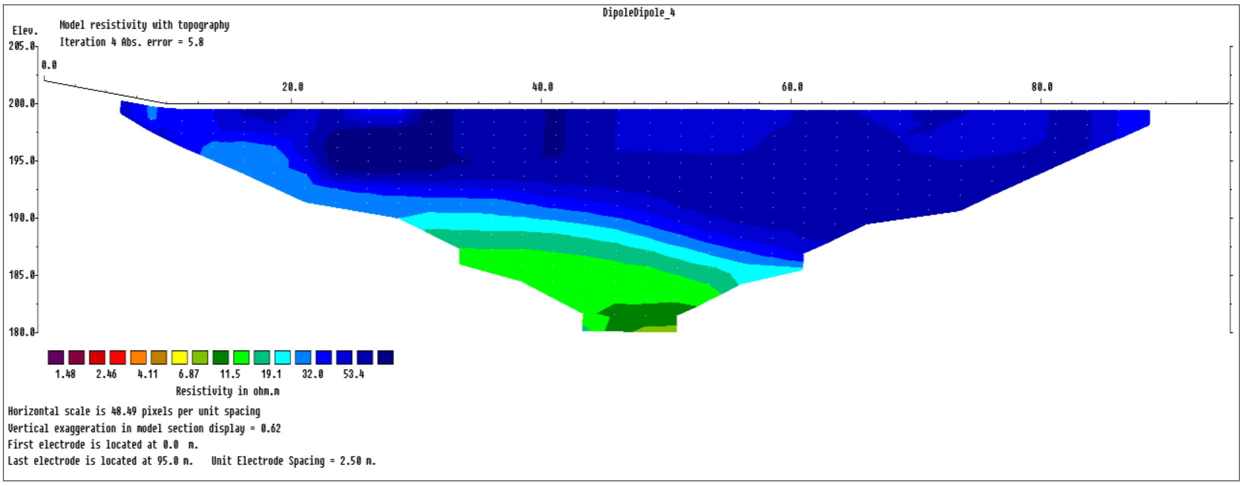


Figure-3.13: Resistivity section along ERT-6

3.7 Summary

The detailed Geophysical survey, using VES and Tomography, gives the continuous configuration of the subsurface lithology, its changes both vertically and horizontally, ground water quality and possible occurrence of water table at different parts of the Lakes. The thickness of the overburden is infrared to vary from 0.68m to 1.64m i.e. indicating the siltation, which has occurred in the lake with the transported water. The thickness of the alluvium sediments consisting of sand and silt with thin inter layer of clay varies from 36m to 65 m below the overburden material. The saturated aquifer zones are present mostly below the depth of 22m bgl upto the depth of the bedrock. The depth to water table in most of the part of the lake area is between 25 to 35m. The depth to Bedrock is undulating and is interpreted to be between depth ranges 38m to 68m below the lake area, however depth reduces towards the rock outcrops.

The data so obtained will be useful in planning the scaling of the overburden and to decide the location of the sub surface dyke.

CHAPTER 4

HYDROGEOLOGY

4.1 Introduction

In order to understand the behavior of the ground water table it is important to study the changes in sub surface lithology by analyzing the exploratory borehole data near to the study area. The sub surface lithological log of the exploratory borehole in sector 21 A, Faridabad is presented in **Figure 4.1**

The bedrock in the sector 21 borehole is encountered at 150m bgl. The aquifer zone is limited to the depth range from 55-72 m consisting of fine to very fine sand. The quality of ground water is found to be poor and saline. It is thus, clear that the deep aquifer are saline in nature overlain the bedrock.

Based on the exploratory drilling data, the generalized subsurface lithology is given below.

The study suggests that:

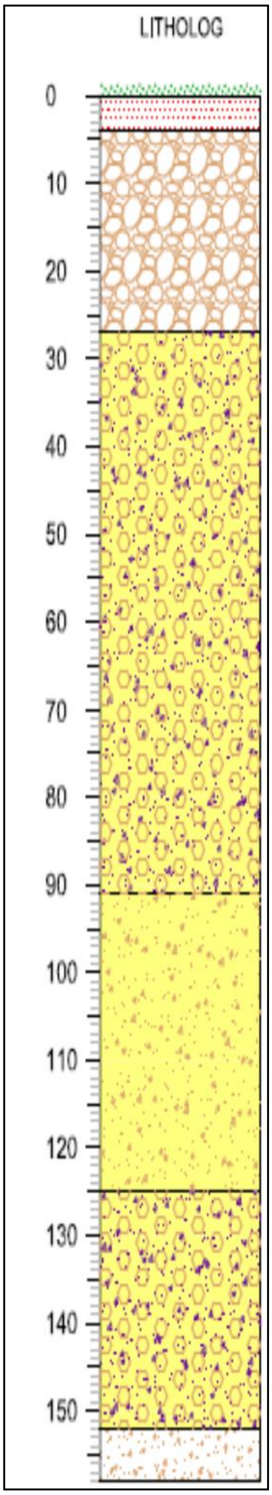
(i) The total thickness of unconfined aquifer is limited to about 50 m

(ii) The depth to bedrock in the west as deciphered from the drilling data is within 170 m bgl while in the east near the river Yamuna it is more than 350 m bgl.

(iii) The thickness of second aquifer is highly variable and increases from west to east.

(iv) The thickness of fresh aquifer is confined to 40m.

(v) Beyond 80m formations are mainly clayey and quality of water is marginal to saline.



Sr. No	Lithology	Depth Range (m bgl)		Thickness (m)
		From	To	
1.	Top soil, yellowish brown.	0.00	4.00	4
2.	Sand, yellowish grey, fine to medium.	4.00	7.80	3.8
3.	Sand, grey, fine to medium.	7.80	26.80	19
4.	Kankar (1-2 mm) with Sandy clay, yellowish, fine	26.80	30.60	3.8
5.	Kankar (1-3 mm) with Sandy clay, yellowish, fine and few gravel.	30.60	34.40	3.8
6.	Kankar with few gravels, grey colour, sub- angular to angular in shape and 2-4 mm in size.	34.40	38.20	3.8
7.	Sandy clay, yellowish with kankar (1-3 mm).	38.20	55.00	16.8
8.	Sandy clay, yellowish with kankar (0.5- 1 mm).	55.00	64.80	9.8
9.	Sandy clay, yellowish with kankar (0.5- 1 mm).	64.80	68.60	3.8
10.	Sandy clay (fine), yellowish with kankar (0.5- 1 mm).	68.60	72.40	3.8
11.	Kankar with Sandy clay, yellowish grey, Fine.	72.40	76.20	3.8
12.	Kankar with sandy clay, yellowish grey, Fine.	76.20	80.00	3.8
13.	Sandy clay, yellowish with kankar (1-2 mm).	80.00	91.40	11.4
14.	Kankar with a few gravel, grey, sub-angular to angular, 1-2 mm in size.	91.40	95.20	3.8
15.	Kankar with a few gravel, grey, sub-angular to angular, 1-2 mm in size.	95.20	99.00	3.8
16.	Clay, yellowish with kankar (1-2 mm).	99.00	110.40	11.4
17.	Clay, yellowish with kankar and few gravels.	110.40	114.20	3.8
18.	Clay, yellowish with kankar (1-2 mm).	114.20	125.60	11.4
19.	Sandy clay, yellowish with few kankar (1-3 mm).	125.60	152.20	26.6
20.	Quartzite, moderately weathered, reddish grey, sub-angular.	152.20	156.00	3.8
21.	Quartzite, slightly weathered, reddish grey colour, angular.	156.00	157.40	1.4

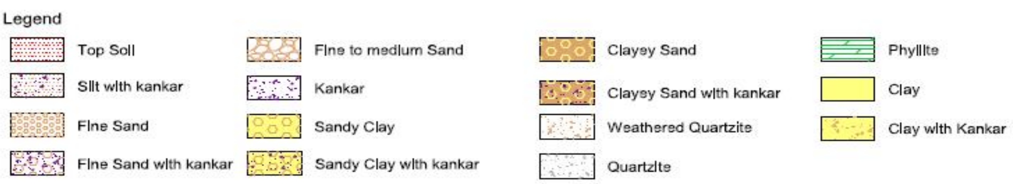


Figure 4.1 : Lithology of Exploratory Well at Friends Colony sector 21A, Faridabad District

4.2 Hydrogeology

The ground water is under unconfined/semi confined conditions in alluvium as well as in weathered and jointed quartzites. The water level was monitored from some of the tube wells and based on which depth to water levels and groundwater contour maps have been prepared using remote sensing and GIS techniques.

4.2.1 Depth to Water level Map (DTW Map)

In order to know the present status of depth to water level monitoring for depth to water was carried out, on select observation wells. From the data collected, the depth of water is observed to vary between 3.0 and 70 m.bgl, the showing extreme shallow and deep water levels. In most part of the area, the water table is between 20m to 35 m bgl. The shallow depth is observed in a dug well located in the valley near Aahada where the water level is 2.5m bgl. In the Sani temple campus in Parsaun village plateau, water level is found at 25m bgl. In the NIFM campus, downstream of Badkhal Lake depth to water level is very deep and is more than 63m bgl. At Anagpur and MRI University campus, it varies between 9m and 17 m bgl. the depth to water level map is given in **Figure 4.2**

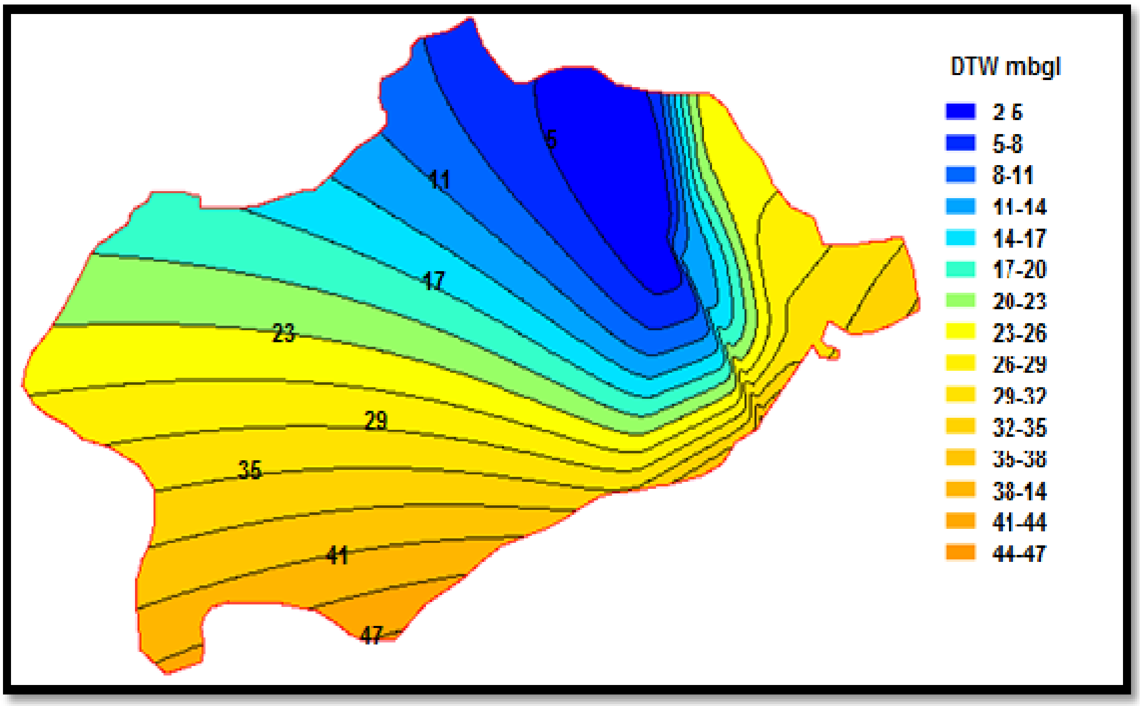


Figure 4.2: DTW Map of Badkhal catchment

4.2.2 Ground Water Contour Map

The plotting of the water levels with respect to topography contour, the altitude of water table ranges from 139 to 219 m.amsl (**Figure 4.3**). It is observed that the ground water flow direction is towards SE that indicates the intensive development of ground water in downstream of Badkhal Lake and towards Ankhir Village.

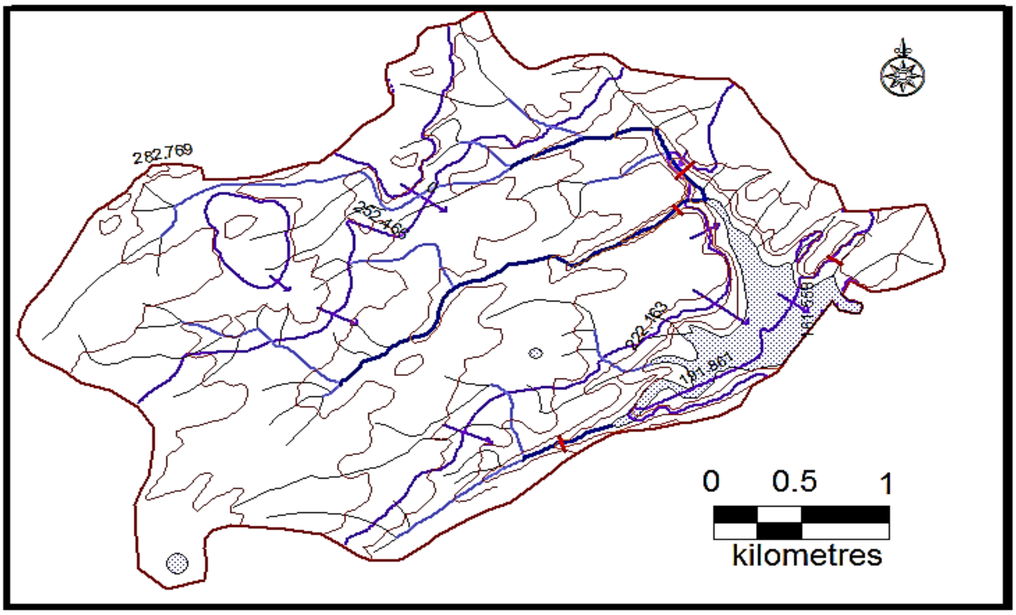


Figure 4.3: Ground Water Topography Map of Badkhal catchment

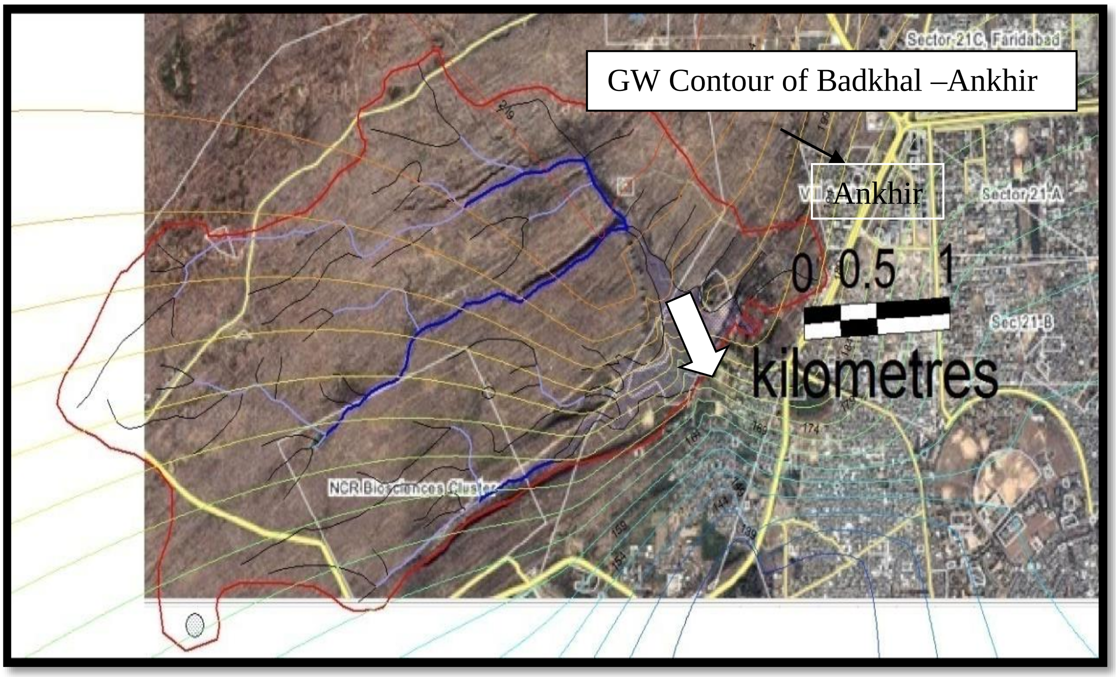


Figure4.4: Ground Water Contour map of Badkhal catchment

4.3 Analysis of watershed and drainage system

The watershed of Badkhal lake was analyzed using the Survey of India Toposheets no 53H/7 and 53H/3 on a scale of 1:50,000, the drainage pattern of the Badkhal catchment shown in **Figure 4.5**.

Map showing areas of micro watersheds of Badkhal catchment

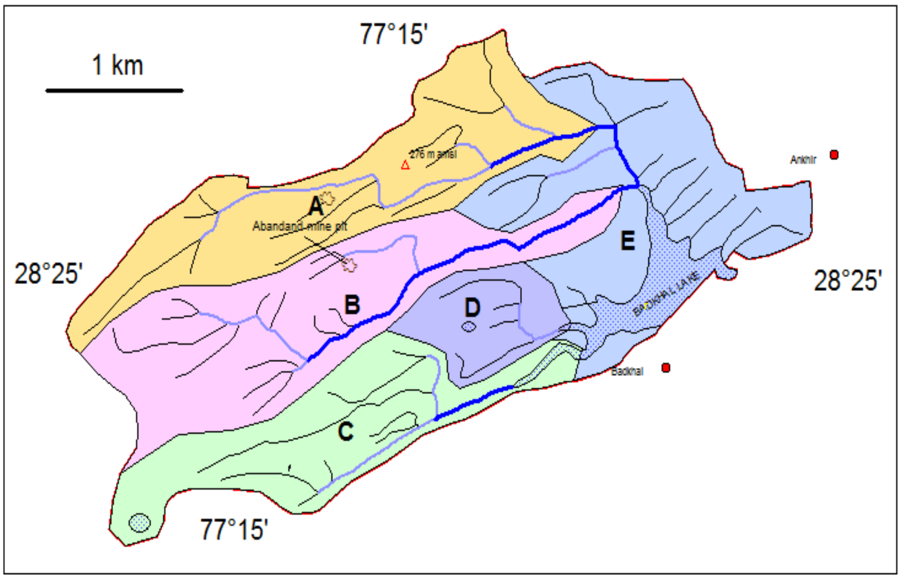


Figure 4.5: Micro watershed and drainage map of Badkhal catchment area

The perusal of the drainage map indicates the major drainage system comes from W-E direction in which it is found that the dendritic drainage in general follows the relief pattern. The catchment area of Badkhal Lake has been further divided into five micro watersheds (A to E), the Badkhal Lake area comes under micro watershed E. Based on the area of each of the micro watershed, runoff potential has been computed at 75 % dependable .the utilizable run off potential for the entire catchment is estimated as 322 Ham i.e. 3.22 Million cubic meters. The utilizable runoff potential of the Badkhal lake micro watershed (E) is estimated as 0.82 Million cubic meter.

The runoff for each of the micro watershed is given in **Table 4.1**

Table 4.1 : Calculation of runoff for micro watersheds of Badkhal catchment

Sr. No	Micro Watershed	Area (Ha)	Precipitation (@75%dependable level=523mm) (Ham)	Runoff @ 0.6 (Ham)
1	A	242.1	126.62	75.97
2	B	267.3	139.80	83.88
3	C	185.7	97.12	58.27
4	D	69.99	36.60	21.96
5	E	259.9	135.93	81.56
5		1025	536	322

1 Ham = 10,000 m^3

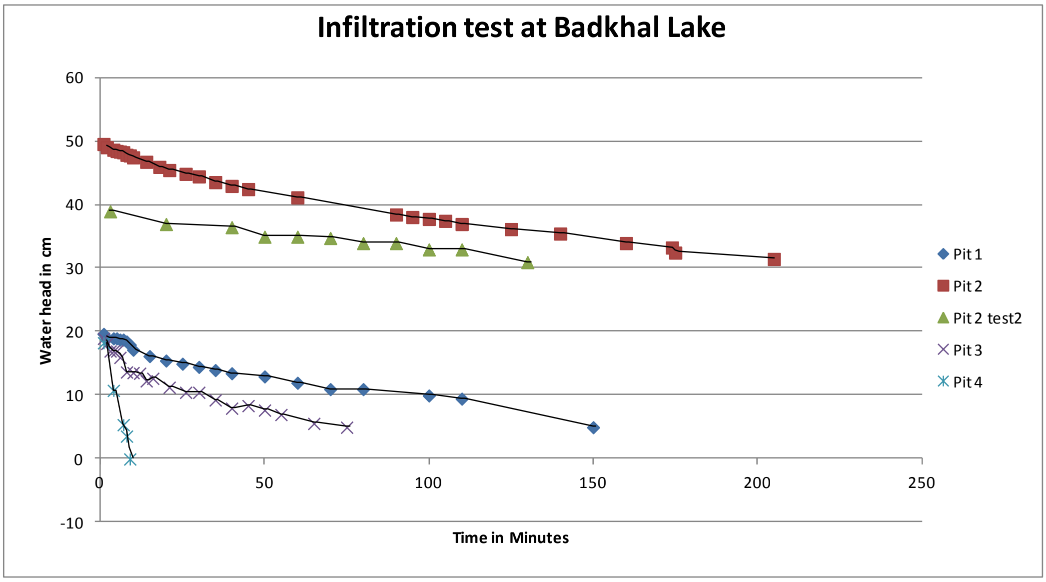
From the above table, that the runoff potential at 75% dependable level will be 536 Ham i.e.5.36 Million liter. This quantity can be utilized by proper treatment of the Badkhal catchment.

4.4 Calculation of seepage

The soil infiltration tests were conducted to know the nature of accumulated silts within the lakebed. The test results are given below.

	Time in mint	Water filtration in l	Water filtration l/mint	Water filtration Q in l/d	Coefficient of vertical permeability K	Specific yield=s
Pit1	60	35	0.583333	840	0.84	0.107232
Pit2 Test1	115	70	0.608696	876.5217	0.876522	0.109538
Pit2 Test2	130	85	0.653846	941.5385	0.941538	0.113529
Pit3	35	30	0.758143	1234.286	1.234286	0.156972

To improve the aquifer saturation level within the Badkhal catchment,it has been proposed to have four subsurface dykes within the narrow valleys



Calculation of Coefficient of vertical permeability=K of Badkhal lake is done as per the formula below and shown in the table and figure.

K=Q/w, Q= stabilized infiltration in m3/d and w=bottom area of pit in m2

s=0.117*(underroot K)—Boldyrev method

The soil infiltration tests at 0.5m and 1.0m depth on lake bed at various location established requirement of de-siltation of lake bed by 1.0m throughout the area of earlier submergence.

4.5 Sources of water

There can be different sources of water which can be considered for revival of the lake. Five possible sources of water have been considered along with their merits and demerits (**Table 4.2).**

Table 4.2: Sources of water

Revival of Badkhal Lake- Sources of water		
Sr No	**Technology/ Methodology**	**Remarks**
1	Transfer of Yamuna Flood water and Bhuria nala	Yamuna is a riparian river so the use of flood water may required discussion; The availability of flood water is for a limited period 4 to 10 days, The elevation differences is 30 m and the aerial distance about 14 km; The Yamuna is a polluted river; The management of flood water in NCT is not known, **Therefore not considered for transfer of water**
2	Ground water development of deep aquifers	Groundwater is already over exploited and area is categorized as critical, The discharge from tube well is around 0.3 million liter/day, The aquifer not sustainable; aquifer zones are limited in thickness; **Therefore not considered for impoundment**
3	Transfer water from nearby water bodies	The water bodies are located in different catchment areas; water lift; 30-55m and from the distance varying from 0.9km to 4.9 km, Water storage inadequate; Transfer through undulating topography and safety; **Therefore not considered for impoundment**
4	Treatment of Badkhal Catchment	Mining activity is impact to Badkhal catchment, flow to the Badkhal lake reduced to almost negligible; construction of subsurface dykes and check dam can provide some resources for lake sustainability. Detail study for optimization of structures to use the runoff is essential - Data not available. **Recommended for adaptation**.
5	Impoundment of treated wastewater	Available in large quantity near to the Badkhal Lake, Treatment technologies are available to treat the wastewater to the required quality standard; will provide sustainability even under climatic change. Recommended for implementation.

4.6 Treatment of Badkhal catchment

To revive the lake it is important to improve the saturation level within the aquifer below Badkhal catchment. The present groundwater scenario within Badkhal catchment area has been established and bedrock configuration is known through hydrogeological and geophysical investigations.

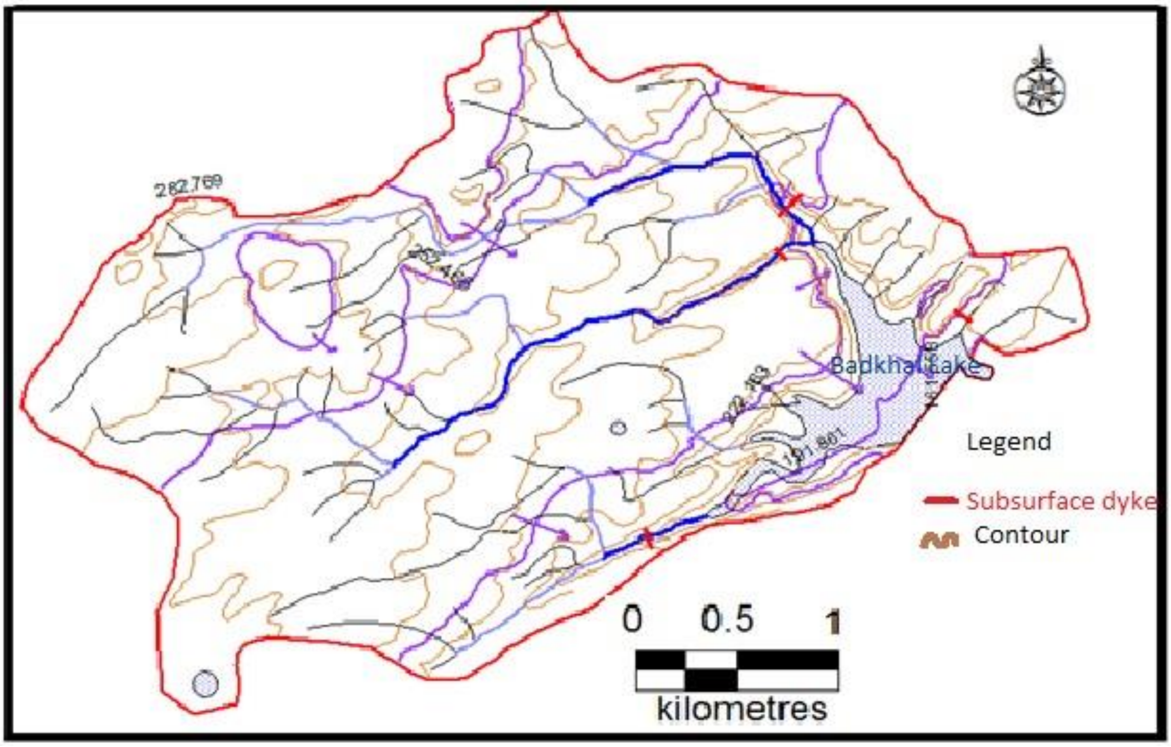
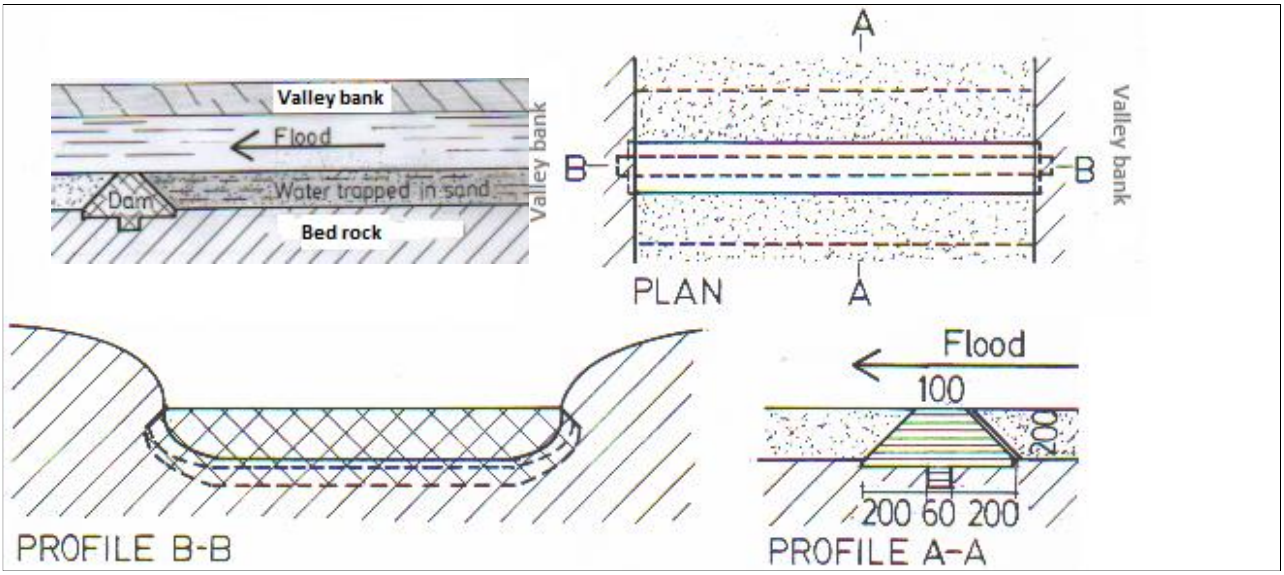


Figure 4.6: Badkhal Watershed showing sub surface dykes

Subsurface dyke is a structure that is built in an aquifer with the intention of obstructing the natural flow of ground water, thereby raising the ground water level and increasing the amount of water stored in the aquifer**. (Figure 4.6)**

To improve the aquifer saturation level within the Badkhal catchment, it has been proposed to have four subsurface dykes within the narrow valleys

The sites and depth of dykes has been finalized based on the groundwater flow pattern, VES and Electric Resistivity Tomography (ERT) data analysis. The locations of proposed subsurface dykes are shown on map. The design of construction is given below:



The rate of depletion of drainable water in the catchment area due to the typical gentle topography could be efficiently arrested by the dyke. The dyke can maintain higher water table in parts of catchment area for a longer period. The ideal location for the dyke is a well defined, wide, greatly sloping valley with a narrow outlet having limited thickness of porous rock on the top with massive or impervious bedrock below. Subsurface dyke has many advantages. There is minimum evaporation loss since the storage is subsurface. There is no siltation and loss of reservoir capacity. The cost of maintenance is negligible. It is environment-friendly.

The primary objective of a subsurface dyke is the creation of a subsurface storage reservoir and low seepage losses. Valley shapes and gradients are used for site identification. Optimally, a valley should be well defined and wide with a very narrow outlet (bottle necked). This reduces the cost of the structure and makes it possible to have a comparatively large storage volume. This indicates that the gradient of the valley floor should not be high since that would reduce the storage volumes behind a dam of given height.

The limitations on depth of underground construction deem that the unconfined aquifer should be within a shallow to moderate depth (down to 10-18 m bgl) and has a well-defined impermeable base layer. Such situations occur at the valley part of Badkhal lake catchment.

The dyke is ideally constructed across narrow ground water valleys. On the basis of a thorough study of a water table contour map of the area, a narrow ground water valley section where the flow lines tend to converge from up gradient direction, usually coinciding with a surface drainage line, as the case here. The requirement of narrow flow section is fulfilled in watershed in Badkhal lake catchment having rolling topography where relatively narrow depressions separate hard rock spurs.

The drainage valley across which the subsurface dyke is constructed should carry a seasonal stream, which goes dry in winter and summer and the water table should be located well below the streambed, preferably throughout the year (The stream should be preferably influent or may be effluent for a very limited period during rainy season). The valley section should preferably have a moderate gradient (less than 1%) so that the benefit spreads sufficiently in the up-gradient direction.

The thickness of aquifer underlying the site should be adequate (more than 5 m) so that the quantity of ground water stored is commensurate with the effort and investment. Here, the drainage courses have a limited thickness of alluvial deposits underlain by a weathered and fractured quartzite aquifer, which in turn passes into consolidated unaltered aquitard. This forms an ideal situation.

The subsurface dyke directly benefits the up-gradient area and hence should be located at a sufficient distance below the storage zone and areas benefiting from such recharge. This implies construction of ground water conservation structures in lower parts of the catchments but sufficiently upstream of watershed outlet.

The construction of four dykes will reduce the out flow and will help in raising the water table.

CHAPTER 5

TECHNOLOGY OPTIONS - FOR WASTEWATER TREATMENT

5.1 Introduction

In the restoration of water bodies/lakes where enough storm water is not available for the purpose, treated wastewater with quality checks is also considered an option. There are examples across the world where treated wastewaters (Following the EP guidelines) have been used for impoundment in the lakes/water bodies. Thus, in the use of wastewater for impoundment, the quality remains the uppermost consideration and this aspect cannot be compromised.

5.2 Option of using water recovered from wastewater

The option of using water recovered from wastewater need to consider the following aspects

1. Source of wastewater
2. Available quality of wastewater
3. Quality parameters required of treated wastewater
4. Technology options
5. Capacity of plant
6. Location of treatment plan

1. **Source of Wastewater**

Discussions were held with MCF officials on the availability of wastewater. Several options were considered and ultimately it will be the decision of the administration as to where the plant should be located. The different options are given below

- To divert the wastewater coming from Sanik Colony for treatment to an area near the Lake. However, it was determined that the quantity was not sufficient to meet the requirement of water.
- To source the wastewater from the Sector 21 pumphouse which is located near the Badkhal flyover and from where the water is being discharged into the nullah which carries the wastewater to the Yamuna canal.
- To divert sewage from a selected point in sector 21 where the quantity of sewage available is in excess of 10MLD, back to Badkhal Lake or adjoining hills where the Treatment Plant can be set up.

2. Wastewater Quality

Preliminary investigations reveal that nearly 118MLD of untreated sewage is being discharged into the nullah which carries the sewage to the Yamuna Lake. This is a huge quantity polluting the Yamuna River and even if a small percentage of this could be treated it will serve the purpose of filling the Lake and also reduce the discharge of polluted water to the Yamuna River. The sewage was analyzed for its quality at different time points of the day to determine the maximum and minimum BOD loads in the wastewater. **(Table 5.1& 5.2)**

Table 5.1 : Nature of sample: Waste water (Individual Sample)

Sr. No	Date &Time of Collection	Parameter	Results
1	12/10/2015 6:00 AM	Temperature	21^0C
		Biochemical oxygen Demand (BOD) at 27^0 C – 3days	74.2 mg/l
		Total Kjeldahl Nitrogen (as N)	6.6 mg/l
2	12/10/2015 9:00 AM	Temperature	22^0C
		Biochemical oxygen Demand (BOD) at 27^0 C – 3days	122 mg/l
		Total Kjeldahl Nitrogen (as N)	11.8 mg/l
3	12/10/2015 12:00 PM	Temperature	22^0C
		Biochemical oxygen Demand (BOD) at 27^0 C – 3days	168.4 mg/l
		Total Kjeldahl Nitrogen (as N)	13.5 mg/l
4	12/10/2015 3:00 PM	Temperature	22^0C
		Biochemical oxygen Demand (BOD) at 27^0 C – 3days	117 mg/l
		Total Kjeldahl Nitrogen (as N)	4.6 mg/l
5	12/10/2015 6:00 PM	Temperature	22^0C
		Biochemical oxygen Demand (BOD) at 27^0 C – 3days	91.5 mg/l
		Total Kjeldahl Nitrogen (as N)	3.7 mg/l
6	12/10/2015 9:00 PM	Temperature	22^0C
		Biochemical oxygen Demand (BOD) at 27^0 C – 3days	81.8 mg/l
		Total Kjeldahl Nitrogen (as N)	3.0 mg/l

Table 5.2: Nature of sample: Waste water (Composite Sample)

Sr. No	Parameter	Results
1	Total Suspended Solids	308.0 mg/l
2	Biochemical oxygen Demand (BOD) at 27^0 C – 3days	129.6 mg/l
3	Chemical Oxygen Demand (COD)	478.2 mg/l
4	Phosphorous	2.1 mg/l
5	Total Kjeldahl Nitrogen (as N)	9.2 mg/l

The analysis shows a depressed value of 11-16 mg/L for TKN which is normally in the range of 30-50mg/L. This could mean that the domestic effluent is getting mixed with industrial effluent. This needs further investigation and confirmation. Small quantities of industrial effluent if mixed with domestic effluent can be handled with normal treatment processes. However if the quantity of industrial effluent is large then more detailed analysis of wastewater is essential to design the treatment plant.

3. Treated Water Quality

To use this water for filling the lake and ensuring a perpetual supply it is important to achieve strict limits of quality of the effluent being discharged. US Environment Protection Agency, published “2012 guidelines for water reuse” in September 2012, the guidelines pertaining to impoundments and environmental reuse are given in **Table 5.3**

It has also been brought out that for impoundments where human contact is possible the guidelines are strict with respect to pathogens fecal coliform and total suspended solids (TSS). The guidelines also call for strict limits of Nitrogen and phosphorus discharge to prevent algae formation. Lastly, Dissolved oxygen levels are to be maintained to support marine life in the lake.

Table 5.3: The guidelines pertaining to impoundments and environmental reuse

Reuse Category and Description	Treatment	Reclaimed Water Quality Parameters	Reclaimed Water Monitoring	Setback Distances	Comments
Impoundments					
The use of reclaimed water in an impoundment in which no limitations are imposed on body-contact. (Lakes)	Secondary treatment Filtration or tertiary treatment Disinfection	pH = 6.0-9.0 ≤ 10 mg/l BOD ≤ 10 mg/l TN ≤ 1 mg/l Ph ≤ 2 NTU TSS No detectable fecal coliform/100 ml 1 mg/l Cl2 residual (min.) no detectable odour	pH – weekly BOD – continuous Turbidity – continuous TN-continuous Fecal coliform - daily Cl2 residual – continuous	500 ft (150 m) to potable water supply wells (min.) if bottom not sealed	Dechlorination may be necessary to protect aquatic species of flora and fauna. Reclaimed water should be non-irritating to skin and eyes. Reclaimed water should be clear and odourless. Nutrient removal may be necessary to avoid algae growth in impoundments. Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. Reclaimed water should not contain measurable levels of pathogens. Higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. Fish caught in impoundments can be consumed.
Environmental Reuse					
Environmental Reuse The use of reclaimed water to create wetlands, enhance natural wetlands, or sustain stream flows.	Variable Secondary (4) and disinfection (6) (min.)	Variable, but not to exceed: ≤30 mg/l BOD (7) ≤ 30 mg/l TSS ≤ 200 fecal coliform/100 ml (9,13, 14) 1 mg/l Cl2 residual (min.) (11)	BOD – weekly SS – daily Fecal coliform - daily Cl2 residual – continuous		Dechlorination may be necessary to protect aquatic species of flora and fauna. Possible effects on groundwater should be evaluated. Receiving water quality requirements may necessitate additional treatment. Temperature of the reclaimed water should not adversely affect ecosystem. See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements.

Hence, the treatment Plant will have to be constructed using any of the latest technology for sewage treatment. In order to insure continuous monitoring it is therefore important that the Plant should be fully automated with PLC/SCADA and real time monitoring of all the important parameters. Since the plant will have to be constructed, adjoining a residential colony there should be no odor from the plant. The plant has also to be eco friendly.

Based on the DATA collected and international standards for use of recycled water for use in Lakes and impoundments the following design criteria should be considered. No relaxation should be given in these Parameters while considering impoundment in water bodies/lakes**.** **(Table 5.4)**

Table 5.4: Design parameters for municipal wastewater treatment plant

Dry weather influent characteristics			
Denomination	**Maximum**	**Average**	**Unit**
BOD		150	Mg/l
COD		400	Mg/l
TSS		300	Mg/l
TKN		30	Mg/l
TP		3	Mg/l
Total Coliform			MPN/100ml
Flow		10000	m^3/day
Wet weather influent characteristics			
Denomination	**Maximum**	**Average**	**Unit**
Flow		10000	m^3/day
Minimum influent wastewater temperature: 18° C **Maximum influent wastewater temperature:25° C**			
Treated Water Parameters			
Denomination	**Maximum**		**Unit**
BOD	<5		Mg/l
COD	<50		Mg/l
TSS*	<5		Mg/L

TN	<10	Mg/l
TP	<1	Mg/l
Total Coliform**	<23	MPN/100 ml

It is all to be insursed that the following parameters are strictly maintained.

*The turbidity of reclaimed water at a point in the wastewater treatment process after filteration and immediately before disinfection complies with the following-

1. The 24 hr average turbidity of filtetred effluent is 2NTU's or less and
2. The turbidity of filtered effluent does not exceed 5 NTU's at any time

**The reclaimed water meets the following criteria after disinfection treatment and before discharge to a reclaimed water system-

1. There is no detectable fecal coliform organism in 4 of the last 7 daily reclaimed water samples taken and
2. The single sample maximum concentration of fecal coliform organisms in reclaimed water sample is less than 23/100ML

4. Technology Options

The end water quality is a critical requirement if the reclaimed water is to be used for impoundment in the Lake and remain a perpetual source of supply to the Lake. Several technology options have been examined. Only those technologies that can meet the treated water quality requirements and have CPHEEO approval have been evaluated in **Table 5.5.**

Table 5.5: Biological Wastewater Treatment Processes

TECHNICAL CORRELATION OF DIFFERENT TECHNOLOGIES FOR BADKHAL LAKE

S No.	Design Parameters	Activated Sludge Process	Moving Bed Bioreactor (MBBR)	Sequencing Batch Reactor (SBR)	Membrane Bio-reactor (MBR)	Fixed Bed Biofilm Activated Sludge (FBAS)
1	Principle of Operation	Suspended Growth Process - Involves production of activated mass of micro-organisms capable of stabilizing waste under aerobic condition. Liquid-Solid Separation takes place by gravity settling in a clarifier	Activated Sludge with suspended media packing in the form of plastic rings which are kept in suspension with air pressure. The plastic rings provide surface area for growth of biofilm. Liquid-Solid Separation takes place in a secondary clarifier	Activated sludge - operated in batch mode. The process of filling, aeration, settling and separation is carried out in one reactor. Hence multiple reactors are required for taking the wastewater. No separate liquid solid separation equipment required.	Suspended Growth Process - The wastewater is circulated continuously through membranes which allow separation of treated water. The biomass remains in suspension and is continuously aerated.	Activated Sludge with Fixed Film in the form of plant roots and bio textile, which provides the surface area for growth of biofilm. The biomass remains in suspended and fixed form. Liquid -solid separation is done thru secondary clarifier or disc filter.
2	Hydraulic Retention Time (HRT, hrs) which impacts size of reactors	10-15 hrs	8-12 hrs	20-30 hrs	10-12 hrs	6-10 hrs
3	MLSS (mg/l) which impacts efficiency of treatment	3000-4000	8000-10000	4000-5000	12000-16000	10000-16000

S No.	Design Parameters	Activated Sludge Process	Moving Bed Bioreactor (MBBR)	Sequencing Batch Reactor (SBR)	Membrane Bio-reactor (MBR)	Fixed Bed Biofilm Activated Sludge (FBAS)
4	Achievable Parameter - BOD (mg/L) for the treated effluent (<10mg/L)	< 10 mg/l	< 10 mg/l	< 10 mg/l	< 2 mg/l	< 10 mg/l
5	Achievable Parameter - TSS (mg/L) for the treated effluent (<5mg/L)	< 20 mg/l	< 20 mg/l	< 15 mg/l	< 2 mg/l	< 5 mg/l
6	Extra provision for achieving TSS<5	Filtration required	Filtration required	Filtration required	No additional requirement	No additional requirement
7	Odor	Since reactors and clarifiers are open to atmosphere strong chanced of foul smell/ odor	Since reactors and clarifiers are open to atmosphere strong chanced of foul smell/ odor	Since reactors and clarifiers are open to atmosphere strong chanced of foul smell/ odor	System totally enclosed. No odor or foul smell expected.	Reactors are covered with green plants. No odor or foul smell expected.
8	Operation and Maintenance	Difficult to control operations if there is wide fluctuation in wastewater quantity and quality. Maintenance requirement normal	Difficult to control as suspended media can escape from the reactor and washout of the system. Some media anyway escapes, and has to be replaced periodically.	Requirement for more than one tank to accommodatecleaning schedules. Maintenance costs slightly higher due to decanter system.	Operation cost is high due to very high power requirement. Membranes need to be replaced in 5-8 years.	PLC control essential for highest efficiency and lowest power consumption. Maintenance costs normal.

S No.	Design Parameters	Activated Sludge Process	Moving Bed Bioreactor (MBBR)	Sequencing Batch Reactor (SBR)	Membrane Bio-reactor (MBR)	Fixed Bed Biofilm Activated Sludge (FBAS)
9	Process performance	Adaptable to many types of wastewater and it has large dilution capacity for shock and toxic loads	Process control more complicated and high peak flows/ shock loadings can disrupt operation.	PLC control essential to obtain best results. Can destabilise in case of large variation in quantity and quality of wastewater	Adaptable to many types of wastewater and it has large dilution capacity for shock and toxic loads	Process highly adaptable and can easily handle shock loads due to higher level of quantity and diversity of biomass in reactors
10	Power consumption	HIgh	Higher than Activated Sludge	Higher than activated sludge	Highest compared to any technology	Lowest compared to any technology
11	Land Area Requirement sq. m	10000	8000	7500	3500	4000

Based on the comparison of the technologies given above, MBR and the FBAS process are the most suitable for the present application.

In the technology options, consideration should be given to the technology, which can entirely take care of the problem of smell and odour. This is an important aspect at the increasing urbanization, so that the technology finally selected to the requirements of urbanized areas.

The other challenges which the technology for the construction of STP should adequately address the following constituents

- Can an STP be built in minimum space?
- Can an STP be built in the heart of a densely populated area?
- Can an STP be designed to consume less energy?
- Can an STP be made odorless?
- Can an STP be made to look like a garden which will blend into an urban environment?

5. Capacity of Plant

The availability of wastewater in the nearby areas helps in proposing the capacity to obtain required amount of water for initial filling of 6m and subsequently obtaining higher capacity, to further raise the level of the lake. In computing the capacity, it is also important to take into consideration losses as a result of evaporation from the exposed surface and also the seepage losses of the unlined bottom of the lake. It is estimated that to fill the lake upto 6m covering an area of 30.4ha the total quantity works out to be 10 MLD. Considering the evaporation and seepage losses to be 2.63 MLD, the balance available would only be 7.37 MLD. It will take about 300 days for the lake to be filled up to level of 6m and to become an operational tourist spot. The computations of monthly evaporation rate, requirement of makeup water and the estimated requirement of water in three years is given in **Table 5.6.** In view of the fact that the quantity of wastewater available is about 118 MLD, the amount required for treating will be only 10% of the total availability. In case it is proposed to fill up the lake beyond 6m, additional quantities of wastewater is possible by enlarging the capacity of the treatment plant or to have second STP.

Table 5.6 : Projected Evaporation Of Water From Badkhal Lake **Monthly Evaporation Rate**

Month	mm/d	Quantity of water evaporated every day (cu.m)	Quantity of water evaporated in the month (cu.m)
January	2.2	669	20753
Feburary	4.2	1278	39620
March	7.2	2191	67920
April	9.9	3013	93390
May	10.9	3317	102823
June	10.1	3073	95276
July	4.7	1430	44337
August	5	1522	47167
September	6.1	1856	57543
October	5.1	1552	48110
November	4	1217	37733
December	3.5	1065	33017
TOTAL QUANTITY EVAPORATED (annually)			687688
TOTAL QUANTITY EVAPORATED (annually) in ML			688
AVERAGE DAILY MAKE UP OF WATER IN ML			**1.88**
Based on the projections given above the average daily requirement of makeup water in Badkhal is 1.88MLD. The peak requirement is 3.3MLD and the minimum requirement is 0.67MLD.			

PROJECTED REQUIREMENT OF RECYCLED MAKE UP WATER

Expected surface area of water (sq. m) if lake is filled to 6M.	304300
Total volume of water in Lake (cu.m)	1825800
Expected loss due to percolation into the ground (annually)	15%
Quantity of water lost annually due to percolation (cu.m)	273870
Quantity of water lost annuallydue to percolation (ML)	273.87
Average Quantity of water lost daily due to percolation (ML)	0.75
Average Quantity of water lost daily due to evaporation (ML)	1.88
TOTAL DAILY REQUIREMENT OF WATER	2.63

Estimated requirement of water in 3 years					
	Make up water required (ML)	**Water required to fill Lake to 6M)**	**Total annual requirement**	**Annual production from a 10MLD Recycling Plant(ML)**	**Surplus available for other applications (ML)**
Year 1	960	1825.8	2786	3500	714
Year 2	960	0	960	3500	2540
Year 3	960	0	960	3500	2540

6. Location of Plant

Although the location of STP plant is a prerogative of the consult department but considering the present disposal of wastewater from different areas near to the Badkhal Lake, the most suitable site seems to be in Sector 21, adjoining to pump house.

This technology has been selected as they will occupy minimum, will not emit any odor and consistently meet the treated water quality norms. It is also important that the technologies are evaluated on a Lifecycle Principle, which should consider cost of Land, Capital cost of plant, and O&M cost including energy for a period of 15 years.

CHAPTER 6

CONCLUDING REMARKS

The revival of Badkhal Lake is an important step to restore the ecology and to promote the tourism as it was earlier a decade ago. For this purpose, different scientific studies have been carried out to comprehend the aquifer system below the lake area and also the possible sources of water for its restoration. The earlier studies revealed that the major reason for the lake getting dried up can be attributed to the unplanned and haphazard mining activies, for the construction material and for the silica sand which required large scale pumping of ground water being under the water table. The blasting as integral part of the mining activity over the years disrupted and denuded the catchment area besides opening of the joints, soil erosion, and creating environmental hazards. This resulted in reduced flow to the lake and ultimately getting it dried up. The remote sensing and GIS study provided the information on the drainage pattern of the Badkhal catchment and its geomorphologic analysis will help in deciding the location of the different type of water conservation and recharge structures by utilization of monsoon runoff while planning for the treatment of Badkhal catchment. The hydrogeological and geophysical survey has provided the information on the extensiveness of the different aquifer zones and the thickness of the overburden, overlying the alluvial sediments. The depth to water, water table contour maps with the groundwater flow direction have indicated the movement of the groundwater pointing that the heavy groundwater exact action in the surrounding areas is causing out flow from the lake area. In order to check the outflow, using the geophysical and hydrogeological data, it is recommended to construct four sub surface dykes, which will help in recovering the ground water levels over the years.

While working on the status of the water stored in some of the water pits near to the Badkhal Lake, the application of Google earth, pending hydrographic survey of the water pits, have given an idea of the thickness of the stored water, distance and the lift required for its utilization. This study indicates that if water in the pits is to be considered for transfer to the Badkhal Lake for its revival, it would require lifting the water from the respective pit to a height varying from 30m -55m.

After fully comprehending, the geological and hydrogeological set up and study of the various sources of water, a comparative study has been made to identify the possible sources of water which can be considered for transfer to the lake for its revival. **(Refer Table 4.2)**

From the above study, the feasible options are

1. Treatment of the Badkhal catchment
   a) Construction of four sub surface dyke to check the out flow from the aquifers under the lake area
   b) Restoration of drainage channels leading to the lake area.
2. To use the treated wastewater with desired quality checks using state of art technology.

Total water requirement to fill the lake up to 6m depth in an area of 30.43 ha (active lake area) is estimated to be 1825.8 million liter.

At present, the untreated wastewater from the city is being discharge into the river Yamuna causing environmental problems. It is gathered that the wastewater generated in the nearby Sector 21 and 46 is about 118 MLD, out of which if 10% is treated to the required quality standard it can be used safely for impoundment to revive the lake. The technology to be used should take care of the pathogen and other quality norms. The comparative study of all the possible treatment technologies shows that the use of MBR and FBAS, are more suitable for the present application. It has also been considered whether the base of the lake should be lined to check the seepage losses or it remains unlined to allow the seepage to recharge groundwater. It is opined that considering the hydrogeological aspect and climate change scenario, the base of the lake should preferably be kept as unlined to allow the seepage other than scaling of the overburden of 1m thickness. The rise in the water table will reduce the power input for pumping, indirectly amount to reducing the emission of green house gases, as the power plant in Faridabad is coal based. The above options for water resources to revive the lake also meets the requirements of the smart city, which provides the recycling of the wastewater and water conservation practices.

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