

No. /WD I/WRD/Accts/2010-11/ 58/
Government of Goa,
Office of the Executive Engineer,
Works Division- I,
Water Resources Department,
Patto- Panaji Goa,
Date: - 31/03/2011.

To,
The Research Associate,
The Energy and Resources Institute (TERI),
Western Regional Centre,
House No. 233/GH-2,
Vasudha Housing Colony,
Alto St. Cruz, Bambolim- Goa,
Ph. 2459306/ 2459328/ Pin- 403202.

Sub: - Work order for "Study of effect of mines near water bodies-
Assessing the impact of mining activities on water bodies in the
state of Goa".

Ref: - Your letter No. Nil dated 10/01/2011.

Sir,

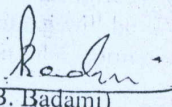
Your proposal for "Study of effect of mines near water bodies- Assessing the impact of mining activities on water bodies in the state of Goa" at your quoted amount of Rs.19,50,000/- (Rupees Nineteen lakh fifty thousand only) is accepted as per the terms and conditions.

You are requested to attend this office to complete the formal agreement with in 7 days of the receipt of the letter.

You are requested to start the work at once. Please note that the time allowed for carrying out the work shall be reckoned from the 15th day after the date of this order to comments the work.

The Time allowed for carrying out is 548 days from the date of the award letter. The stipulated date of commencement is 15/04/2011 and stipulated date of completion is 14/10/2012.

The Expenditure of this work is debitable to the Budget Head 4702/800/01/53 (Plan).


(P. B. Badami)
Executive Engineer

Copy to:

1. The Chief Engineer, Water Resources Department, Panaji- Goa.
2. The Superintending Engineer, Circle I, WRD, Panaji-Goa.
3. The Superintending Engineer, CPO, WRD, Panaji-Goa.
4. The Income Tax Officer, (TDS), Panaji-Goa.
5. The Sale Tax Officer, Panaji-Goa.
6. Work Order file.
7. Office file.
8. Guard file.

Study of effect of mines near water bodies- Assessing the impact of mining activities on water bodies in the state of Goa

Terms and Condition

I Data collection and preparation of the map

- List of the working mines/ map will be procured from the Department of Mines or Indian Bureau of Mines (IBM).
- Field data on the coordinates of these mines will be gathered using a Global Positioning System (GPS).
- Surface water flow base map or the river basin map will be collected from Water Resources Department or Department of Science Technology and Environment. In case of non-availability of the digital map, digitization of the toposheet will be done.
- Geo-referencing of the mine coordinates will be done on the surface water flow map to determine the spatial proximity between the mines and the water body using ArcGIS.
- Maps to be collected from the Survey of India/ National Bureau of Soil Survey and Land use Planning would include contour (100 m interval, 1:250,000), land use (1:2M), soil (1:5M) and drainage (1:250,000).
- Digital Elevation Model (DEM) for the study area shall be delineated using the spatial analyst tool of ArcGIS.
- Weather related parameters like temperature, precipitation, evaporation, humidity would be collected from the Indian Meteorological Department (IMD).
- Secondary river gauge data for river flow and groundwater level data would be obtained from the Water Resources Department. This data would be used for trend analysis and comparison with the primary data.

II Water quality and impact assessment

- *Site selection:* Based on the map few locations will be short-listed. Further interactions with the stakeholders will be held to solicit information on the status of water resources in the last 5 years. Following this exercise, a suitable site will be selected upstream and downstream of a mining area as a pilot study area.

A Surface water

- Daily rainfall data for the nearest gauging station will be collected from IMD.
- Flow levels will be recorded manually or with level recorder at identified locations with newly installed permanent staff gauges and gauging will be done three times in a day and at more frequent intervals during the storm events.
- Rating curves will be developed to convert stage to discharge using stream velocities taken with a current meter at equal distance on a cross-section at two depths (about 0.20 and 0.80 times the depth from water surface to stream bed).
- Stream discharge will be calculated by velocity-area method by using rating curves developed from stream velocity, stream water levels with corresponding cross-sectional areas.
- At high discharges, velocity will be estimated by recording the travel time of floating object through a known distance. At low dry-season flow levels, portable "Montana" flumes will be used for estimating discharge.
- To estimate a suspended sediment load, grab water samples will be collected thrice a day. More number of samples will be collected during

particular rain events and sediment concentration will be determined using 0.45 mm filter method.

- Sediment loads for particular storm events or longer time-periods will be estimated using sediment concentration and corresponding stream discharge or flow time-series data.
- Water samples will be collected for three seasons i.e. pre-monsoon, monsoon and post-monsoon to estimate the surface water quality.
- Samples will be analyzed in the laboratory for the physico-chemical parameters such as pH conductivity, total dissolved solids, total suspended solids, chloride, hardness, alkalinity, potassium, sodium, nitrate, iron, manganese, BOD, COD and DO using the standard methods (APHA 2005).

B Ground water

- Observation well network will be established for the study area.
- Water level data will be collected from the reference point and recharge capacity will be estimated.
- Measurement of the reduced level of the observation wells will be done and the information will be used to figure out the ground water flow direction and prepare a contour map.
- Assessment of ground water fluctuations in the study area and study the impact of mining vice-a-visa ground water levels will be done.
- The asses the ground water quality analysis, samples will be collected for three seasons i.e. pre-monsoon, monsoon and post-monsoon.
- Samples will be analyzed in the laboratory for the parameters such as pH conductivity, total dissolved solids, total suspended solids, chloride, hardness, alkalinity, potassium, sodium, nitrate, iron, manganese, BOD, COD and DO using the standard methods (APHA 2005).
- Secondary data related to rainfall pattern, historical data on ground water levels would be procured from the Water Resources Department and Central Ground Water Board. Data on the water levels in the mines pits will be gathered from the mining companies with the help of the Water Resources Department.

III Remedial measures

- Based on above studies and analysis the environmental management plan suggesting remedial measures will be recommended.

The time frame for the above work will be 18 months. (1) The Preliminary report—within one month from the date of the award letter. (2) Interim report- 9th month from the date of initiation. (3) Final report- 18th month from the date of initiation.

The agency will submit the **Final Report in six (6) sets.**

**Research Associate
(Teri)**

**Executive Engineer
(Works Division I), WRD**

Project timeframe

Total duration of the project: 1.5 years

Activities	Timeframe (Months)					
	1-3	4-6	7-9	10-12	13-15	16-18
Field visits and data collection						
Georeferencing and preparation of the map						
Stakeholder interactions for site selection						
Installation of staff gauge and monitoring						
Sampling and analysis for surface water quality						
Establishment of well network and monitoring of groundwater level						
Sampling and analysis for groundwater quality						
Data Analysis						
Preparation and submission of final report						

Deliverables

- Project initiation letter – at the time of proposal acceptance and zero date of project initiation
- Preliminary report – within one month from the date of the award letter
- Progress/Interim Report – 9th month from the date of initiation
- Final report – 18th month from the date of initiation

Research Associate
(Teri)

Executive Engineer
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Assessing the impact of mining activities on a water body: Case study of Salaulim Reservoir, Goa

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Water Resources Department
Government of Goa



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Table of Contents

TABLE OF CONTENTS.....	III
LIST OF TABLES	IV
LIST OF FIGURES	V
PROJECT TEAM.....	VIII
EXECUTIVE SUMMARY.....	1
1 INTRODUCTION	5
1.1 Background.....	5
1.2 Objectives of the project	9
1.3 Overall approach.....	9
1.4 Structure of the report	9
2 MINING STATUS AND SITE SELECTION	10
2.1 Location and extent of the mining leases	10
2.2 Selection of the study area	13
2.3 Location and extent of Salaulim reservoir	13
2.4 Characterization of Salaulim Catchment	14
3 BASELINE STATUS.....	43
3.1 Surface water	43
3.2 Groundwater	52
3.3 Water Quality	77
4 MANAGEMENT STRATEGIES FOR CONTROL AND PREVENTION OF IMPACTS	95
5 CONCLUSIONS AND RECOMMENDATIONS	104
Annexure I: Impacts on water bodies due to mining.....	107
Annexure II: List of working mines in 2010-11	111
Annexure III: Details of barge loading points	118
Annexure IV: List of seasonal streams in the catchment area.....	120
Annexure V: Existing mining leases in three watersheds	121
Annexure VI: Co-ordinates of all mines.....	128
Annexure VII: Rating Curves	129
Annexure VIII: Computation of sediment load	130
Annexure IX: Details of monitoring wells	133
Annexure X: Computation of groundwater balance and state of groundwater development in the study area.....	136
Annexure XI: Water Quality Standards	153
REFERENCES	155

List of Tables

Table	2.1: Salient features of Salaulim dam.....	14
Table	2.2:Monthly rainfall data from Ghatiapandu rain gauging station.....	27
Table	2.3: Monthly rainfall data from Neturlim rain gauging station.....	28
Table	3.1: Details of surface water sampling locations	44
Table	3.2: Rating curve equation for various sampling locations	47
Table	3.3: Details of the groundwater monitoring wells by CGWB in the study area	70
Table	3.4: Field data of pumping tests carried in the study area.....	72
Table	3.5:Summary of aquifer parameters in the study area	74
Table	3.6: Seasonal surface water quality	83
Table	3.7: Details of groundwater quality monitoring locations.....	87
Table	3.8:Groundwater quality during three seasons.....	91
Table	3.9: Characteristics of mine pit water.....	93
Table	3.10:Seasonal variation in iron concentration in groundwater samples.....	94

List of Figures

Figure 1.1: Map of Goa showing existing mining leases.....	6
Figure 1.2: Overall approach adopted for the project.....	9
Figure 2.1: Map of Goa showing existing and working mines.....	11
Figure 2.2: Data collection on mine co-ordinates	12
Figure 2.3: Location of working mines on the surface water flow map.....	13
Figure 2.4: Location of Salaulim reservoir.....	14
Figure 2.5: Location map of the Guleli River watershed.....	15
Figure 2.6: Location map of the Kumbhari River watershed	15
Figure 2.7: Location map of the Curpem watershed	16
Figure 2.8: Location map of all the three contributing watersheds	16
Figure 2.8 (a): Satellite image of the study area (Image date March 2011, Not to scale)	17
Figure 2.9: Elevation contour map of Salaulim Watershed area.....	18
Figure 2.10: Three dimensional view of the entire study area	18
Figure 2.11: Three dimensional view of the Guleli watershed.....	19
Figure 2.11(a): Satellite image showing the Guleli watershed	19
Figure 2.12: Three dimensional view of Kumbhari watershed	20
Figure 2.12(a): Satellite image showing Kumbhari watershed.....	20
Figure 2.13: Three dimensional view of Curpem watershed.....	21
Figure 2.13(a): Satellite image showing central part of the Curpem watershed.....	21
Figure 2.13(b): Satellite image showing northern part of the Curpem watershed.....	22
Figure 2.13(c): Satellite image showing southern part of the Curpem watershed	22
Figure 2.14: Drainage pattern of catchment of Salaulim reservoir	23
Figure 2.15: Study area shown on the soil map of Goa	24
Figure 2.16: Study area shown on the geological map of Goa	25
Figure 2.17: Land use distribution in the Salaulim catchment area.....	26
Figure 2.18: Monthly average rainfall (mm) for two rain gauging stations in the study area	27
Figure 2.19: Distribution and location of mining concessions (working and non-working) in the Salaulim watershed	29
Figure 2.20: Location of laterite quarries in the catchment.....	30
Figure 2.21: Location of working, abandoned and old mines in the catchment.....	31
Figure 2.22: Satellite image of active mines in the Salaulim watershed.....	32
Figure 2.23(a): Site 1: Oldmine	32
Figure 2.23(b): Site 2: Oldmine.....	33

Figure 2.23(c): Site 3: Oldmine	33
Figure 2.23(d): Site 4: Oldmine.....	34
Figure 2.23(e): Site 5: Oldmine	34
Figure 2.23(f): Site 6: Old mine	35
Figure 2.23(g): Site 7: Oldmine.....	35
Figure 2.23 (h): Site 8: Oldmine.....	36
Figure 2.23(i): Site 9: Old mine.....	36
Figure 2.23(j): Site 10: Old mine.....	37
Figure 2.23(k): Site 11: Old mine.....	37
Figure 2.23(l): Site 12: Old mine.....	38
Figure 2.23(m): Site 13: Old mine	38
Figure 2.23(n): Site 14: Old mine.....	39
Figure 2.23(o): Site 15: Old mine.....	39
Figure 2.23(p): Site 16: Old mine.....	40
Figure 2.23(q): Site 17: Old mine.....	40
Figure 2.24: Priority areas having high and very high erosion potential	42
Figure 3.1: Flow diagram showing the methodology for calculation of sediment load.....	43
Figure 3.2: Surface water sampling locations	45
Figure 3.3: Stream section for area-velocity method.....	48
Figure 3.4: Average total suspended solid concentration in surface water in three seasons..	50
Figure 3.5: Variation in the average total suspended solid concentration with respect to rainfall depth at Netravali.....	50
Figure 3.6: Seasonal variation in discharge at different sampling locations	51
Figure 3.7: Annual sediment load across various monitoring stations.....	51
Figure 3.8: Map showing the location of groundwater monitoring wells.....	54
Figure 3.9: Location map showing CGWB monitoring stations in the watershed	55
Figure 3.10: Groundwater levels in three seasons in Guleli watershed.....	56
Figure 3.11: Groundwater levels in three seasons in Kumbhari watershed.....	56
Figure 3.12: Groundwater levels in three seasons in Curpem watershed	57
Figure 3.13: Groundwater flow net during pre-monsoon season in Guleli watershed.....	58
Figure 3.14: Groundwater flow net for pre monsoon season in Kumbhari watershed	59
Figure 3.15: Groundwater flow net for pre monsoon season in Curpem watershed.....	60
Figure 3.16: Map showing pre monsoon depth to groundwater levels in wells in Guleli watershed	61
Figure 3.17: Map showing pre monsoon depth to groundwater levels in wells in Kumbhari watershed	62

Figure 3.18: Map showing pre monsoon depth to groundwater levels in wells in Curpem watershed	63
Figure 3.19: Groundwater level fluctuation in Guleli watershed	64
Figure 3.20: Groundwater level fluctuation in Kumbhari watershed	64
Figure 3.21: Groundwater level fluctuation in Curpem watershed	65
Figure 3.22: Variation of summer season groundwater column thickness in the Guleli watershed	66
Figure 3.23: Variation of summer season groundwater column thickness in the Kumbhari watershed	67
Figure 3.24: Variation of summer season groundwater column thickness in the Curpem watershed	67
Figure 3.25: Variation in total well depths in Guleli watershed	68
Figure 3.26: Variation in total well depths in Kumbhari watershed	69
Figure 3.27: Variation in total well depths in Curpem watershed.....	69
Figure 3.28: Well hydrograph at Netrolim site.....	71
Figure 3.29: Well hydrograph at Deulwada site.....	71
Figure 3.30: Plot of time-drawdown and time-recovery data for well no.6T and estimated aquifer parameters	73
Figure 3.31: Plot of time-drawdown and time-recovery data for well no.14D and estimated aquifer parameters	74
Figure 3.32: Variation in iron concentration in raw water over the years	78
Figure 3.33: Variation in manganese concentration in raw water over the years	79
Figure 3.34: Seasonal variation in iron concentration in surface water	80
Figure 3.35: Seasonal variation in manganese concentration in surface water.....	81
Figure 3.36: Daily rainfall during early monsoon	81
Figure 3.37: Variation in iron concentration during early monsoon	82
Figure 3.38: Variation in manganese concentration during early monsoon	82
Figure 3.39: Total suspended solids in seasonal nallahs	85
Figure 3.40: Iron concentration in seasonal nallahs	85
Figure 3.41: Manganese concentration in seasonal nallahs	86
Figure 3.42: Locations for monitoring of groundwater quality.....	88
Figure 3.43: Seasonal variation in suspended solid concentration in groundwater	89
Figure 3.44: Seasonal variation in iron concentration in groundwater	89
Figure 3.45: Seasonal variation in manganese concentration in groundwater	90
Figure 4.1: Options for sediment management in reservoirs	97
Figure 4.2: Schematic diagram for pit water treatment.....	99

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The collation of data from various departments was only possible because of the assistance from many people. We take this opportunity to thank Shri. Prasanna Archarya, Director, Directorate of Mines & Geology, Shri. Paranjape (E.E), Public Works Department, Shri. Borkar (A.E), Salaulim Water Treatment Plant, Ms. Chandan, Laboratory Assistant at Salualim Water Treatment Plant, Shri. Joglekar, Sr. Environmental Engineer, Goa State Pollution Control Board, and Ms. Jennica, Scientist, Goa State Pollution Control Board. We are also grateful to Gangotri Consultants for providing valuable inputs to the section on groundwater. Thanks are also due to the mining companies who gave us access to their mines and relevant information. All the people involved with the field surveys, sample collection and analysis are duly acknowledged. This study was funded by the Water Resources Department, Government of Goa.

Executive Summary

Mining is one of the economic sectors in Goa. However, it has a large environmental footprint especially in terms of its adverse impact on water. To examine this issue, the overall objective of this study was to assess the impact of mining on water resources. The catchment of Salaulim reservoir in South Goa which is a prime source of water supply for 55% of Goa's population was identified as the study area. Field investigations were carried out to delineate the contributing watersheds, identify the number and location of active and non-active mines falling in these watersheds, assess the surface water quality including sediment load and groundwater development and quality. The study spanned over one and half years and three season monitoring was carried out. The major findings of this study are presented below. The recommendations for better management are given in the following section.

- There are three sub watersheds (Guleli, Kumbhari and Curpem) that contribute surface as well as groundwater to the Salaulim reservoir covering a total area of 180 km² and a reservoir area of 29 km².
- Nearly 87% of the total catchment/watershed is covered by forest, agriculture and plantations while around 13% is covered with human settlements, mining leases/dumps and water spread area.
- There were three active working mines in Curpem sub watershed and one in Guleli sub watershed. Therefore, total of four active mines were recorded from field survey and satellite image mapping during the period of study.
- There were five abandoned mines of which four were located in Curpem sub watershed and one in Guleli sub watershed. Further a detailed investigation using satellite image indicated the presence of 17 very old non-working mines of which 15 were located in Curpem and Guleli sub watersheds and two in Kumbhari sub watershed.
- There were five laterite quarries lying in the northern most part of the Curpem sub watershed.
- Seven perennial sampling locations in the watershed were identified using toposheets and the surface water was monitored for three seasons i.e. pre-monsoon, monsoon and post-monsoon. All these streams/rivers contribute to the main reservoir. Of these, two locations which had forest and no mining activity in the upstream direction were chosen as the control or reference points.
- Flow measurements, development of rating curves, computation of discharge and total suspended solid (TSS) estimation were done at all the locations and the sediment load was calculated. TSS concentration in non-monsoon periods was nearly same at all monitoring stations (control as well as others) and the variability in TSS amongst monitoring stations was mainly during monsoon period. This indicates surface run-off has major impact on water quality and areas that have mines were found to have higher impact. Total annual sediment load of 33993 tonnes was estimated. The highest sediment load was found in Kumbhari followed by Guleli River. The annual sediment load at Curpem was estimated to be 790 tonnes. The sediment load is a cumulative effect of erosion due to natural topography and silt runoff from the mining dumps and may vary.
- The groundwater availability in the three sub-watersheds worked out to be 192 hectare meter per annum and the present stage of groundwater development for the three sub-

watersheds is 38.84% which is classified as 'Safe' according to the Central Ground Water Board (CGWB) norms.

- The groundwater mainly gets recharge from the forested areas as compared to the low lying plain areas. It gets discharged in the low lying paddy fields, reservoir and rivers.
- Well hydrographs that were plotted using secondary data from CGWB indicate that there is no decrease in groundwater levels in the study area. However, a decreasing trend was observed in a well which lies close to the watershed but not within it. Taking this as an indication, judicious development/withdrawal of groundwater in future is warranted.
- The surface water quality was monitored for three seasons and compared with IS: 2296, Surface water quality standard for Class A. It was observed that the iron and manganese concentrations usually exceed the limit during monsoon and vary on daily basis. Around 54.3% of the total number of samples that were collected exceeded the prescribed limit for iron whereas 11.4% were beyond the permissible limit in case of manganese during early monsoon indicating the first flush effect. This water needs treatment before drinking. The other physico-chemical parameters were within the respective standard limit.
- There was an increase in suspended solid concentration during the monsoon season in the groundwater/wells located near the active mines. The TSS, iron and manganese concentrations were within the permissible limit. The groundwater flow net analysis was carried out to understand the potential pathway of contaminant. The preliminary observation was that the iron concentration was more at the wells closer to the mine and decreased with the increase in the distance. However, more data would be required to analyse the trend, expected rate and chemical alterations during transport before drawing any conclusion.
- The groundwater was also monitored for locations in vicinity of abandoned or old non-working mines. The iron concentration exceeded the standards at two locations during monsoon and the manganese was beyond limit in case of three locations at least in one season. The groundwater flow net analysis revealed that these locations were in the downstream direction of the old/abandoned mines which could be the reason for pollution.
- Past ten years secondary data on raw water quality (at reservoir) from the laboratory based at the water treatment plant and the rainfall during that period was used for trend analysis. It was found that both iron and manganese concentration rise beyond the permissible limit mostly during the monsoon season indicating the contribution due to surface runoff during this period. Further, there is an increasing trend in the highest value of iron concentration over the years. The highest recorded value did not surpass the prescribed limit in 2004; however it has been going beyond the limit in the later/current years. In case of manganese, the increase in concentration is also during monsoon season and has been exceeding the limit since the year 1993 as indicated by NEERI study. This may be attributed to the background level in the reservoir.
- It is anticipated that there could be a collective effect of active mines, approach roads, old and abandoned mines/dumps, and laterite quarries on water quality in the area.

Recommendations

A holistic approach is essential to control and prevent further adverse impact on the Salaulim reservoir owing to point and non-point sources of pollution. For attaining the desired objective of minimizing the negative impact on water quality and reservoir capacity due to sedimentation, four strategies are proposed which should be implemented concurrently. These include:

1. Preventive measures for control of soil erosion at sensitive areas in the watershed

The micro-watersheds in the catchment of Salaulim reservoir that are prone to severe erosion have been identified along with the streams that contribute high sediment load. These areas require implementation of soil conservation measures on urgent basis. The state-of-art control measures for sediment management were reviewed. The measures that are suitable for the area include non-structural and structural measures and have been discussed at length in the report.

2. Control measures at the mining sites/leases and dumps

The key sources within the mining lease area that add to the sediment load are (i) runoff within the mine lease area (ii) dewatering of mine pit water (iii) runoff from the dump. To address these localized issues robust measures entailing the best management plan (BMP) for handling mine site water are presented in the report. These measures should be strictly practiced by all the mine operators. Good practices in terms of dump management have been discussed and needs strict compliance.

3. Treatment measures to improve raw water quality at the reservoir

The thermal stratification of the reservoir and its effect on the behaviour of pollutants (i.e. iron and manganese) has been addressed in the report. Some of the key recommendations to manage the background pollutant levels to enhance raw water quality are: (i) pumping of raw water from the middle layer instead of lower most (hypolimnion) layer (ii) aeration to increase dissolved oxygen (iii) depth integrated sampling and analysis of the water samples at different parts of the reservoir should be done to study the behaviour of the pollutant

4. Institutional and governance measures

- Source water protection committee comprising members from different government departments such as WRD, PWD, DoMG, Forest department, Directorate of Agriculture and GSPCB should be constituted. The committee should be dedicated to taking action to prevent pollution in the watersheds which contribute to water supply reservoirs of the State including Salaulim
- Regular monitoring of surface and groundwater quality and levels should be carried out to keep a check. For observing the impact on deeper aquifers, shallow and deep piezometers should be constructed close to the mine area for monitoring the water levels in the shallow and deeper aquifers respectively.
- The current working mines should strictly implement all the control measures to prevent water pollution and should adhere to proper management plan at the time of closure. New mining activity should not be allowed in the immediate vicinity of

the reservoir and especially in the micro-watersheds that have been identified as areas of high erosion potential

- The rehabilitation of abandoned pits and dumps and de-silting of stream and nallahs due to past mining activities should be taken up on an urgent basis. This activity should be initiated by the government with the involvement of the mining companies
- Monitoring of water quality of mine water discharge, local river/nallah and domestic water (dug well/hand pumps) should be conducted as per approved calendar in order to evaluate the performance of the mitigation measures
- Dumps which are stabilized over the years and have established vegetation should not be disturbed. The slopes of these dumps should be checked and maintained below 10%
- Washing of trucks and runoff from haul roads should be curtailed
- Strict adherence with the national and local environmental standards/laws including environmental management plans (EMP) made for the mining leases to minimize water pollution

1 Introduction

1.1 Background

Geographically, the State of Goa is situated along the mid-west coast of India and lies between the co-ordinates 14° 53' 57" to 15° 47' 59" N and 73° 40' 54" to 74° 20' 11" E. On the west is the Arabian sea and the coastline stretches to a length of about 105 km in the state. Goa covers an area of 3702 sq km and has many physical features that are common to the neighbouring regions of Maharashtra and Karnataka. The state is divided into 12 talukas and is blessed with many rivers.

Profile of the water resources in the state of Goa

The State is drained by nine rivers namely Terekhol, Chapora, Baga, Mandovi, Zuari, Sal, Saleri, Talpona and Galgibag. Out of these, Mandovi, Zuari, Tiracol and Chapora flow westward in to the Arabian sea. Of these, Mandovi and Zuari are the major rivers flowing through the state. The following five dams, namely Salualim, Anjunem, Chapoli, Panchwadi and Amthane provide water to the State through the various schemes. Of these, Salualim dam in Sanguem is the largest with a height of 42.50m above the deepest bed and length of 1003.83m and a cultivable command area of 9686 Ha supplying 160 MLD of water in the State. It is fed by Sanguem or Guleli river a tributary of Zuari river and provides water to the four talukas of Mormugoa, Salcete, Quepem and Sanguem.

The Central Ground Water Board (CGWB), the apex body of the Govt. of India under the Ministry of Water Resources has prepared a "Master Plan for Development of Ground Water in Goa State" following the 1997 methodology. In this report, taking into account only the annual safe dynamic recharge, it has been stated that the ground water potential that can be exploited in the entire Goa state is about 134.74 MCM as on 2009. The groundwater in the state is mainly used for drinking and industrial purposes followed by agriculture to some extent. In the coastal belt, at most of the locations, there is a state of over development of groundwater. This is partly due to natural drainage of groundwater to the sea besides human consumption, which is highest along the coast due to very high population density and industrial withdrawals. At few locations in the mining belts, there is an over developed condition mainly due to dewatering from the mine pits as many of the mines have to operate below the local water table/piezometric levels.

Mining is one of the economic drivers for the state of Goa. The state is endowed with industrial minerals like manganese, iron, bauxite, limestone, dolomite, refractory clays, laminite sands, steatite, silica sand, feldspar, graphite, talc, quartz, and soap stone. However, the mineral sector is dominated by the extraction of iron and manganese ore. The mining belt of Goa is mostly concentrated in five talukas: Bicholim, Sattari, Sanguem, Quepem and Dharbandora. It is spread across an area of approximately 700 sq km a little less than 20% of Goa's total land area (TERI, 1997). In all there are 334 mining leases in existence out of which 89 mining leases were in operation during the period 2010-11. The spread of these lease areas across the State is shown in Figure 1.1.



Figure 1.1: Map of Goa showing existing mining leases

Source: Directorate of Mines & Geology, Government of Goa

Like most economic activities, mining also has detrimental impacts on the environment. Open cast mining that is practiced in Goa is often more than 200 m deep and can go down to 25-30 m below sea level¹. On an average the ore-to-overburden ratio is 1:3 which has resulted in a change in landscape such as deforestation and presence of mine pits and overburden dumps. There is a special concern about the wildlife sanctuaries that line the eastern border of the state, and co-exist with the mineral bearing areas. Transportation of ore by trucks results in health impacts owing to dust pollution (TERI, 2006). Further, ore transportation by barges also leads to surface water pollution. Dewatering of mine pits results in threats to water security because of the depletion of aquifers. Unscientific management of overburden dumps causes deterioration in land and water resources.

Poor management of dumps and rainfall runoff over them has resulted in siltation of the adjoining land and water bodies. The surface runoff as well as that from the mining dumps leads to siltation of rivers and reservoirs, thereby increasing the concentration of iron and manganese. Precipitates of manganese impart colour to water from yellowish to black. Clonithrix and crenothrix which are commonly called iron bacteria use iron and manganese in their metabolism. If small amounts (0.1 mg/l) of iron and manganese are allowed to go into the distribution system, these forms will produce slime. Slime causes clogging of meters and valves. It also hampers the taste and odour of the water (NEERI, 1993). Progressive increase of Manganese concentration in drinking water has been reported to cause neurological problems (Xenophon et al., 1989; Gail et al., 2006).

Another problem that can be associated with mining operations such as beneficiation is the release of pollutants to surface waters. Many activities and sources associated with a dumpsite can contribute toxic and non-toxic materials to surface waters. The mobility of the pollutants from these sources is magnified by exposure to heavy rainfall. Impacts on surface waters include the build-up of sediments that may be contaminated with heavy metals, short and long-term reductions in pH and dissolved oxygen levels (particularly for lakes and reservoirs), destruction or degradation of aquatic habitat, and contamination of drinking water supplies and other human health issues. Further, washing of the mine trucks in the rivers leads to water pollution.

Past studies indicating the mining impact on water in Goa

This section describes the impacts of mining on groundwater, rivers and lakes that have been reported in different parts of Goa.

Groundwater: The groundwater recharges and availability in the mining watersheds of North Goa was studied by TERI, 2005. The study area was selected in Bicholim and Sattari talukas covering Sirigao in North-West to Surla-Velguem in South -East. The villages that lied in this area were Sirigao, Lamgao, Mulgao, Mayem, Piligao, Bicholim, Sanquelim, Cudnem, Honda, Pissurlem, Sonshi, Surla, and Velguem. The groundwater recharge and draft/extraction was studied and the micro-watersheds were classified into four categories depending on the stage of development. The four categories were (i) Non-critical (White; <50% groundwater developed), (ii) Sub-critical (grey; 50% to 75% groundwater developed), (iii) Critical (Black; 75-100% groundwater developed), (iv) Most-critical (Red; over-exploitation of groundwater). The problematic watersheds that were categorized as water stressed included Sirigao, Mulgao, Piligao, and Pissurlem.

¹ For details: <http://timesofindia.indiatimes.com/city/goa/60-ore-mined-below-water-table/articleshow/7198153.cms>, last accessed on January 2, 2011

Following the public interest litigation, an investigation was done by NEERI (2009) to assess the state of depletion of groundwater in Sirigao village in Bicholim taluka. It was found that almost all of the dug wells in Sirigao had dried up in December 2008 and the soil analysis indicated that silt deposition from the mining overburden had degraded the soil fertility in the agricultural fields. The water scarcity was attributed to the loss of recharge area due to deepening of the surrounding mines.

The impact of mining on the water resources in Nagargaon panchayat in North Goa was examined by Somasundaram 2009. The villages included in the study area were Carambolim Bramha, Dhava, Nagargaon, Ambede, and Bombede. The study concluded that opencast mining in Nagargaon panchayat may cause irreparable damage to water resource due to removal of potential recharge area.

Surface water: The physico-chemical characteristics of Mayem lake and other rivers in Bicholim taluka was studied by Nayak (1995). The silt runoff from the adjoining mining dumps was found to be the major reason for siltation of the Mayem lake. The riverine water quality at eight locations (Velgem, Harvale, Harvale canal, Sanquelim, Bicholim, Assonora, Kasarpal, Pilgaon) was also monitored. It was observed that the worst affected were Velgem and Harvale river (including Harvale canal) in terms of pH and suspended solids concentrations and it was due to mining activity in the vicinity.

A study conducted by TERI (1997) looked at the river and lake water quality. The study area included rivers such as Bicholim, Assnora, Madei, Arvalem, Velguem and Kalay. The important streams and nallahs were Kudnem, Dhonkal, Sonshi and Advoi. The lakes in the study area were Mayem, Mulgao and Moissal. The major effect of mining activity on water quality was presence of high turbidity due to discharge of silt particles. The worst affected rivers were found to be Bicholim, Madei, and Khandepar. Bicholim river was polluted mainly from the runoffs from dumps and beneficiation plants. Madei river was polluted due to mine dumps at Pale village. Khandepar river was polluted due to wash-offs from the dumps of Codli-Kirlapal, Bimbol-Sigao and Odamol-Tathodi group of mines. The details on the various water bodies and their impacted stretch in 1997 is given in Annexure I.

Surface sediment samples from Mandovi estuary was studied for foraminiferal characteristics by Nigam et al. (2005). The ever-increasing suspended load in Mandovi estuary, probably due to mining activities in the catchment area of the Mandovi estuary was suggested as the plausible reason for decline of fauna.

The Mandovi-Zuari estuarine system, the entire network formed by the Mandovi and Zuari rivers including the Kumbarjua Canal, is extensively used for the transport of iron and manganese ores. The intensive mining activities, runoff from the mineralized zones during the wet season, leaching from mines, extensive barge traffic plying along the rivers transporting the ores from the hinterland to Mormugao harbour contribute substantially to the input of these metals in the estuarine system. A study of the distribution and seasonal variation of trace metals, mainly estuarine (dissolved and particulate) environment and sediments in wet and dry seasons, was carried out by Mesquita and Kaisary (2007) to assess the probable influence of mining on the concentrations of these metals. The operation of several legal as well as illegal mining leases within the catchment of different rivers or streams or nallahs or lakes/ponds and/or dams² increases the probability of negative

² For more details: <http://www.zeenews.com/news645218.html>, last accessed on January 4, 2011

impacts of mining on the water resources multiple times. It is in this context, that the present study was conceptualized and the Water Resources Department requested TERI to examine the effect of mining on water resources. The objective of this study and the approach that was adopted is described in the following sections.

1.2 Objectives of the project

The main objectives of the project were:-

- To develop a map locating the proximity of the mines with the water bodies and identify a pilot study area to further
 - Assess the impact of mining activity on the surface and groundwater quality
 - Examine the effect of mines on the surface and ground water in the surrounding areas
 - Suggest remedial or preventive measures to tackle the negative impacts

1.3 Overall approach

The overall approach that was adopted in this study is depicted in Figure 1.2. The assessments involved collection of field data, samples and data analysis. The detailed methodology used to achieve each of the objectives is given in the subsequent chapters along with the results.

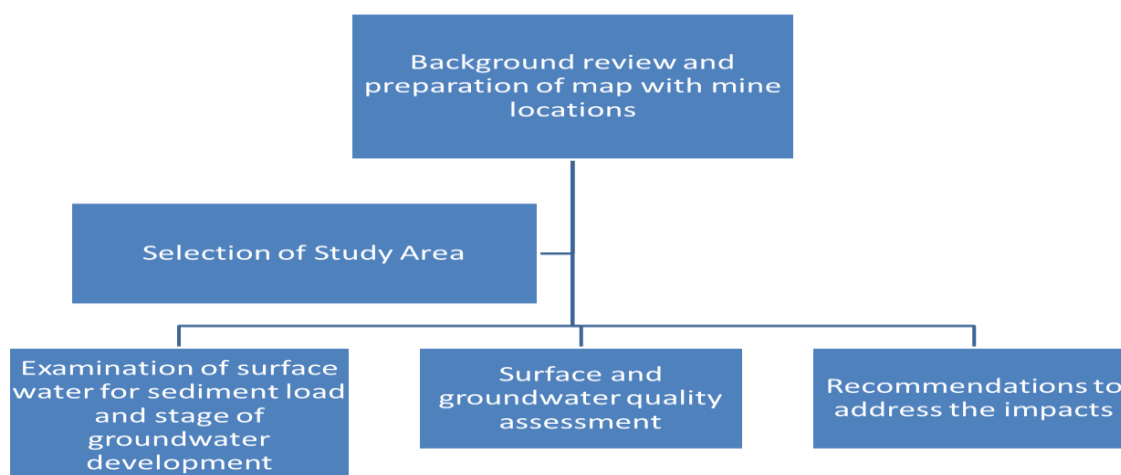


Figure 1.2: Overall approach adopted for the project

1.4 Structure of the report

This final report is the culmination of a 1.5 year long study which includes past trends, methodology followed to carry out the assessment and the results of the seasonal monitoring. Chapter 2 of the report describes the study area; Chapter 3 presents the sediment load estimation owing to mining in the surface water bodies, the stage of groundwater development in the study area and the water quality assessment. Chapter 4 illustrates the management strategies and preventive measures useful to combat water pollution due to mining followed by conclusions and recommendations in the next chapter.

2 Mining status and site selection

2.1 Location and extent of the mining leases

As mentioned in Chapter 1, opencast mining is the major economic activity in Goa and is predominant in Bicholim, Sattari, Sanguem, Dharbandora, and Quepem talukas. Around 89 mines were active in the year 2010-11 (DoMG). The map showing the existing leases and working mines is shown in the Figure 2.1. The first objective of the project was to develop a surface water flow map showing the location of the working mines. Following methodology was adopted for data collection and preparation of the map:

- List of the working mines was procured from the Directorate of Mines & Geology
- Field data on the coordinates of these mines was gathered using a Global Positioning System (GPS) as shown in Figure 2.2
- Digital surface water flow base map or the river basin map was collected from Goa State Pollution Control Board
- Geo-referencing of the mine coordinates was done on the surface water flow map to determine the spatial proximity between the mines and the water body using ArcGIS

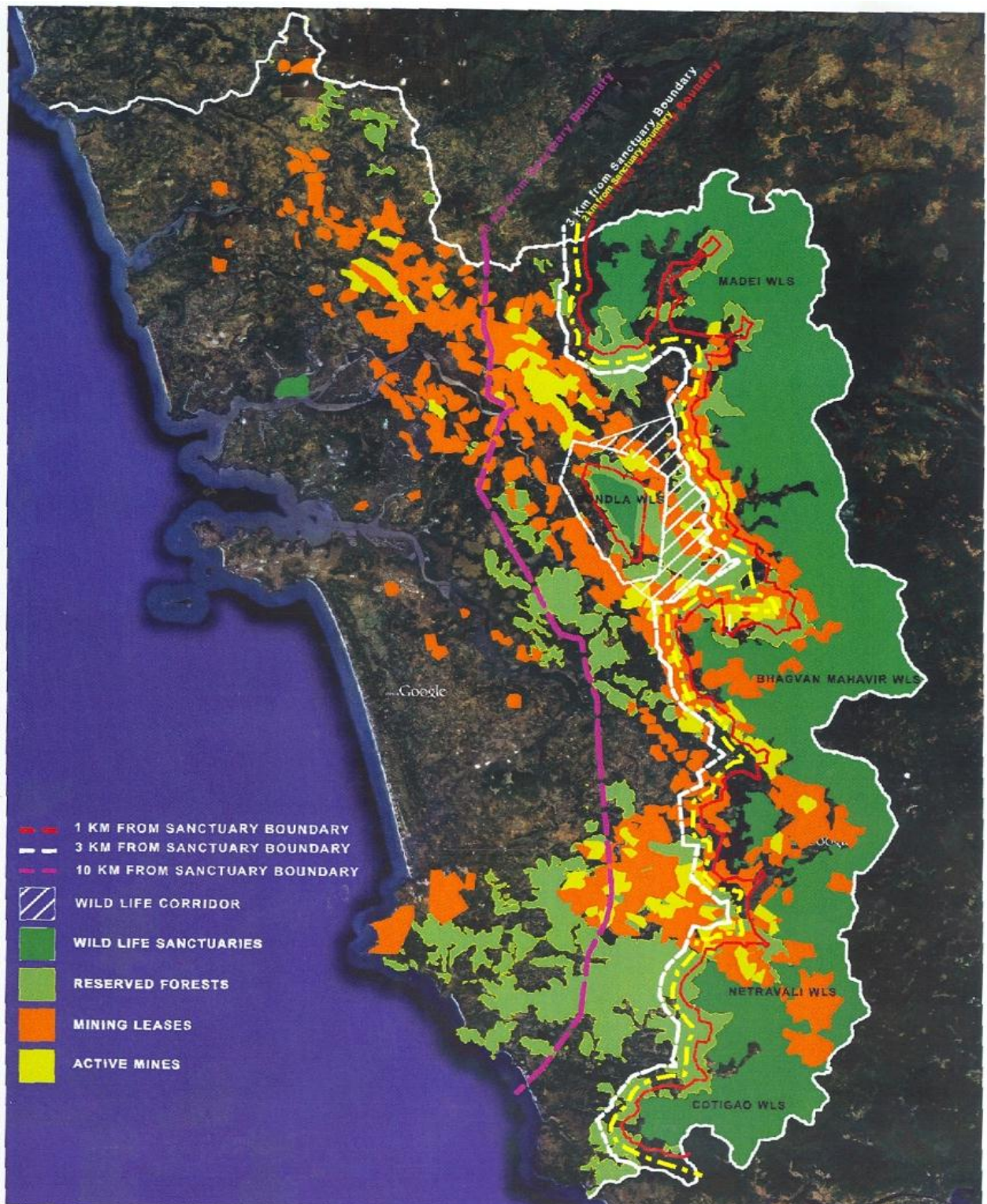


Figure 2.1: Map of Goa showing existing and working mines

Source: Goa Foundation, 2011



Figure 2.2: Data collection on mine co-ordinates

The co-ordinates of 89 mines that were active in 2010-11 (refer Annexure II) were overlaid on the surface water flow map. The final map is shown in Figure 2.3. The yellow and red colored areas in the map represent the low flow and medium flow areas respectively. The distance between the mines and surface water body was estimated using field data and Google Earth. The results of the same are shown in Annexure II. The distance between mines and major barge loading points is given in Annexure III. The proximity of the mine to a water body increases the risk of water pollution.

Surface water flow map and Mines of Goa

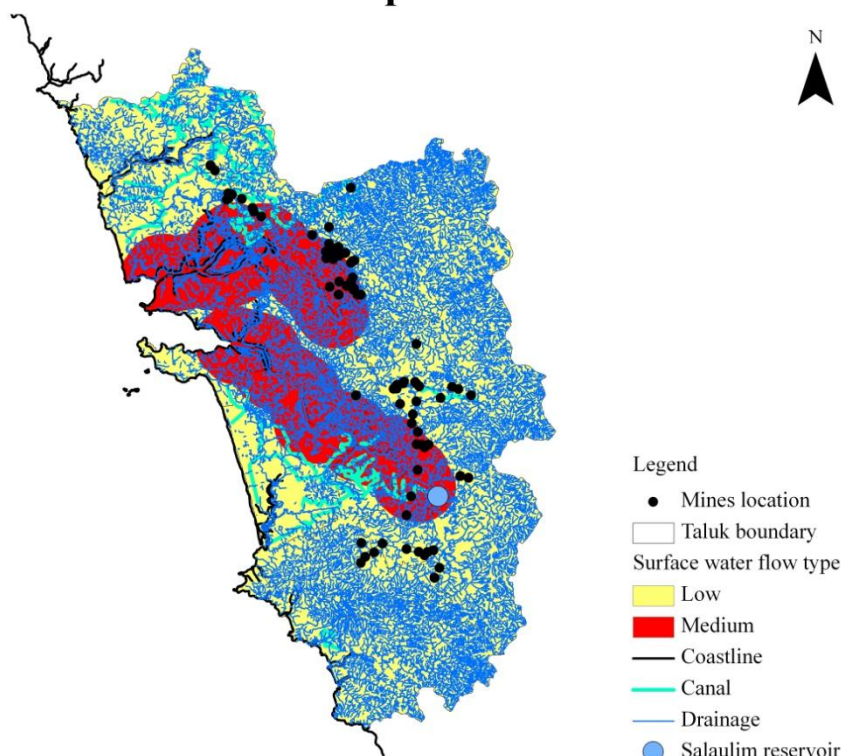


Figure 2.3: Location of working mines on the surface water flow map

2.2 Selection of the study area

Based on the stakeholder discussions, it was found that mines were in operation in the catchment area of Salaulim dam which is the prime source of water supply for 55% of the population in the State³. It was felt that this may have negative impacts on the reservoir and hence detailed investigations were warranted to assess the impacts and formulate necessary prevention or remedial action in time. Hence, the watersheds contributing to the reservoir and having mining activity were selected for the study.

2.3 Location and extent of Salaulim reservoir

The Salaulim dam is located on Guleli River (a tributary of Zuari River) in Sanguem, South Goa. The location of the reservoir is shown in Figure 2.4. The project currently caters to the irrigation and domestic water demand and plans to support industrial demand in future. The salient features of the dam are presented in Table 2.1. The reservoir water spread at Full Reservoir Level (41.15 m) is 29 sq.km. During the construction of the reservoir around 20 villages were submerged partially or fully along with some mining areas (NEERI, 1993).

³ Source: http://www.goanews.com/news_disp.php?pageno=2&catid=158&newsid=1158 , Accessed on April 30, 2011

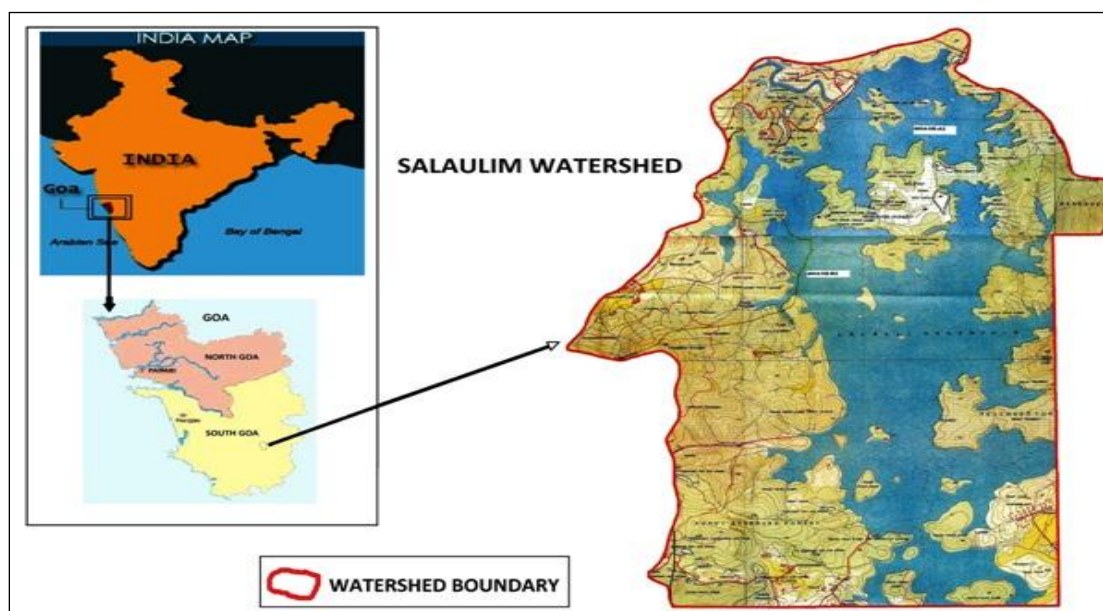


Figure 2.4: Location of Salaulim reservoir

Table 2.1: Salient features of Salaulim dam

LOCATION	State:Goa Taluka: Sanguem River:Sanguem (Guleli Nadi) Latitude:15 ⁰⁰ 4' to15 ⁰² 2'N Longitude:74 ⁰¹ 5' to 74 ⁰³ 1'E
HYDROLOGY	Catchment Area: 207 sq kms Min Annual Monsoon rainfall: 3665 mm
RESERVOIR	Maximum water level: RL 45.8 m Gross Storage Capacity: 234.36 Cu.m Dead Storage Capacity: 7.20 Cu.m Live Storage Capacity: 227.16 Cu.m
DAM	Type of Dam: Duckbill spillway, Earthen dam & Masonry Length of the dam: 1003.83m Height of the dam above the deepest bed level: 42.50m
IRRIGATION	Gross Command Area: 29373 Ha Cultivable Command Area: 9686 Ha

Source: Water Resources Department, http://www.goawrd.gov.in/documents/features_salauli.htm

2.4 Characterization of Salaulim Catchment

2.4.1 Location of the watersheds

The catchment of the Salaulim reservoir was demarcated using Survey of India toposheets (1:25,000) bearing nos. 48_{1/4} and 48_{1/8}. The drainage pattern & contour/ground elevation

was studied and the watershed boundaries and areas contributing to the reservoir were demarcated. The contributing watersheds have been sub divided as Guleli watershed (77 km²) located in the southeast of the reservoir (Figure 2.5), Kumbhari Nala watershed (73 km²) located in the east and south east of the reservoir (Figure 2.6) and Curpem watershed (32 km²) located in the west along the periphery of the reservoir (Figure 2.7). The water spread area covers around 29 km². Topographically the major part of the watershed area is represented by high peaks of the Western Ghats with elevation ranging between 150-500 meters above mean sea level (msl)(WGEEP, 2011). The highest topographical elevation is found in the eastern part of the watershed. The location of the entire study area is shown in Figure 2.8 and the corresponding satellite image in Figure 2.8 (a). The list of seasonal streams found in the catchment is shown in the Annexure IV.

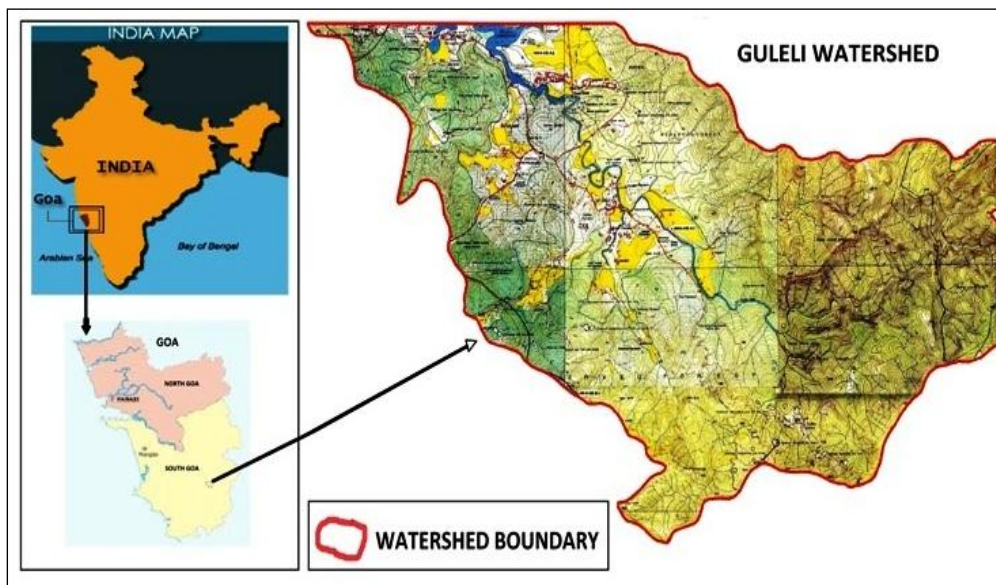


Figure 2.5: Location map of the Guleli River watershed

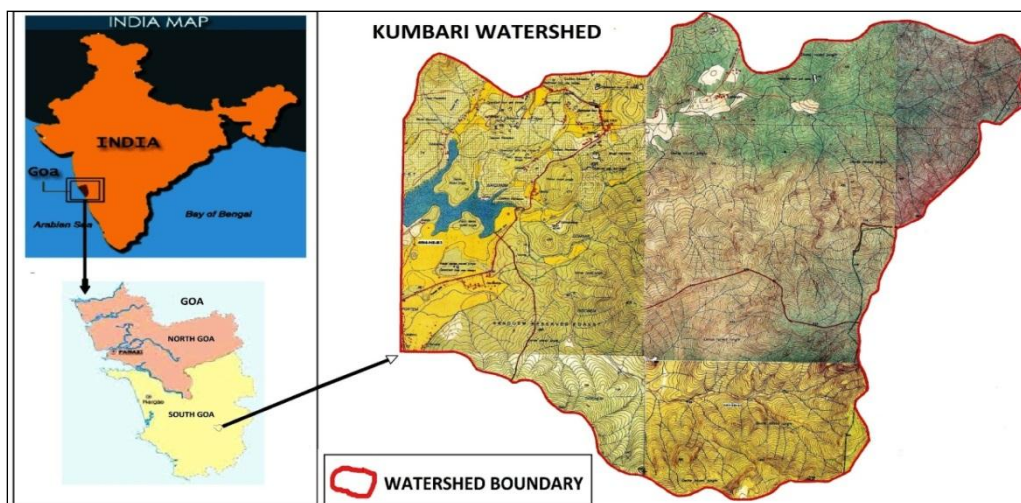


Figure 2.6: Location map of the Kumbhari River watershed

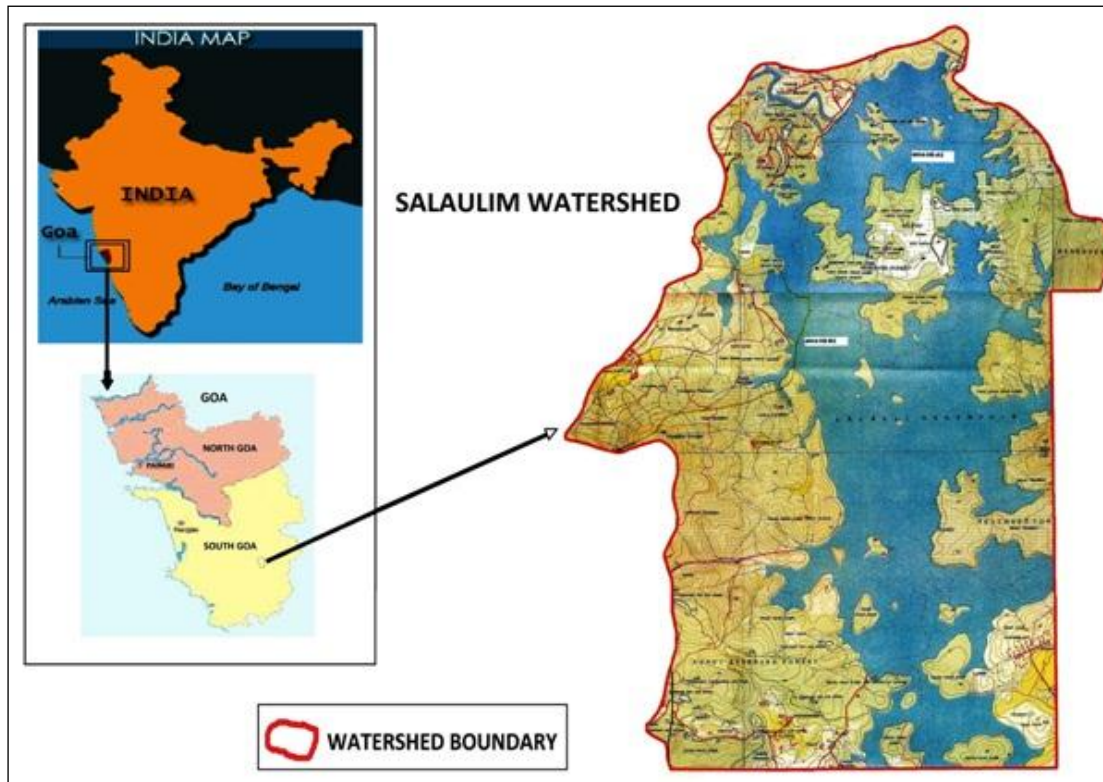


Figure 2.7: Location map of the Curpem watershed



Figure 2.8: Location map of all the three contributing watersheds

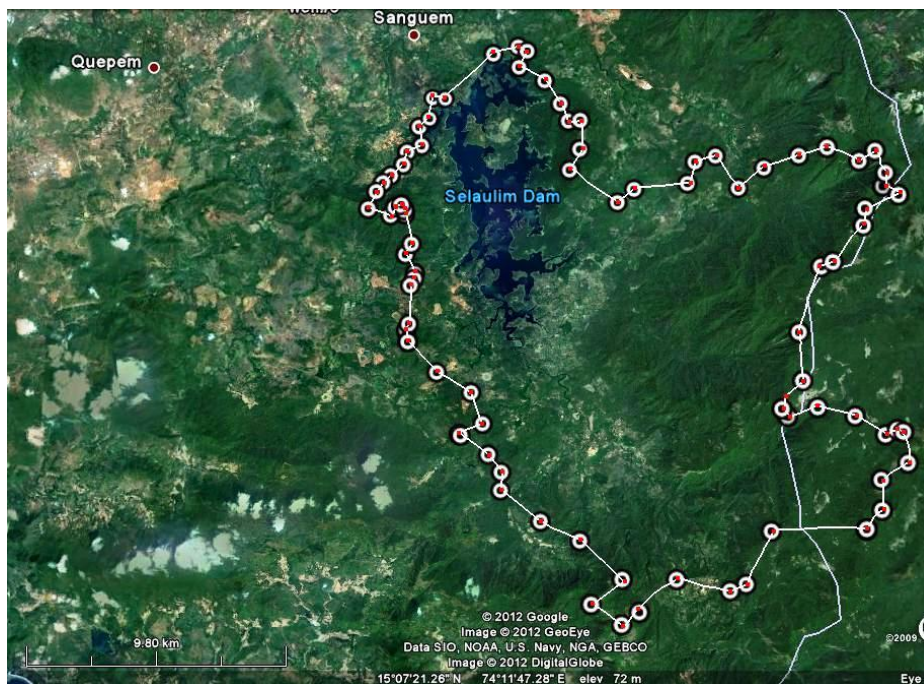


Figure 2.8 (a): Satellite image of the study area (Image date March 2011, Not to scale)

2.4.2 Topography and drainage network

The study area exhibits variable topography. The major part of the watershed area is represented by high peaks of the Western Ghats ranging in elevation of 200-927 meters above mean sea level (msl). The highest topographical elevation is found in the eastern part of the watershed. The plain region is seen close to the reservoir. The ground elevation contours above mean sea level (in meters) and the areas with more than 20% slope is shown in the Figure 2.9. For better visualization, a three dimensional (3D) map of the entire study area depicting the topography is presented in Figure 2.10. Further 3D maps for sub-watersheds - Guleli, Kumbhari and Curpem are shown in Figures 2.11, 2.12 and 2.13 respectively. The corresponding satellite images are given in Figures 2.11(a), 2.12(a), and 2.13 (a, b, c). It can be seen from the figures that the east and south-east areas of the watershed have high peaks. Few isolated peaks adjacent to reservoir area also seen on the west and east side.

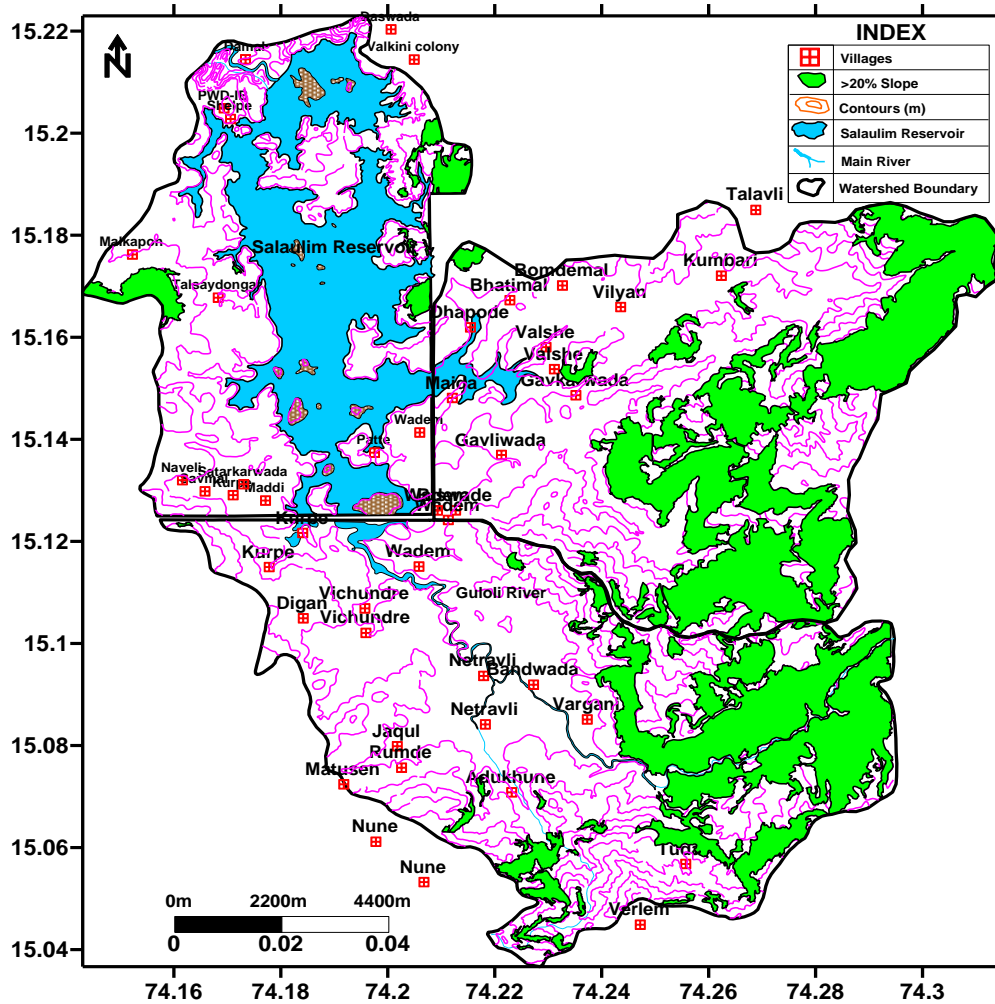


Figure 2.9: Elevation contour map of Salaulim Watershed area

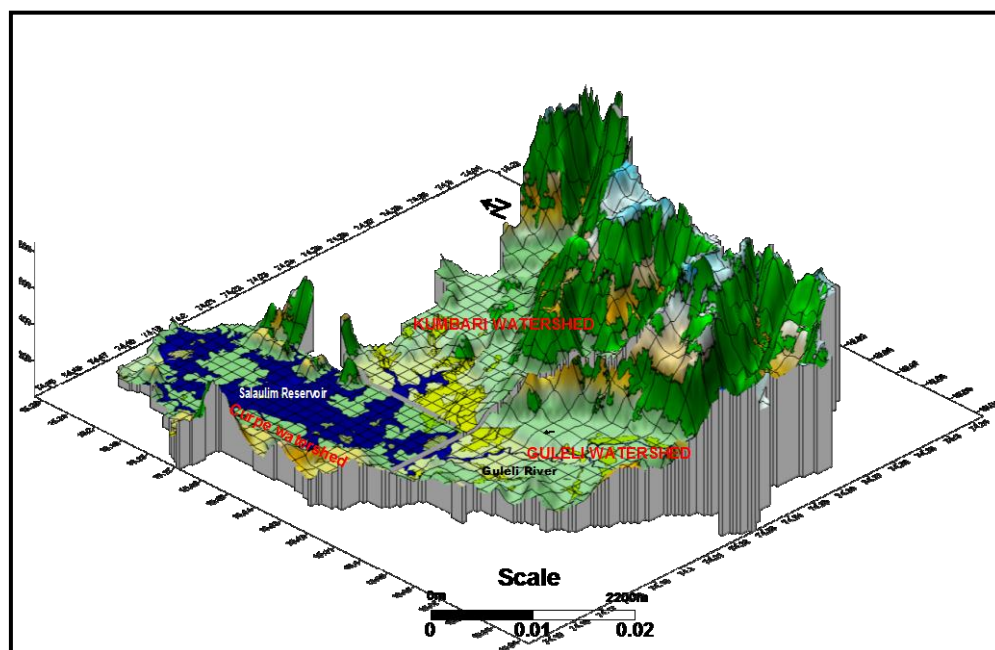


Figure 2.10: Three dimensional view of the entire study area

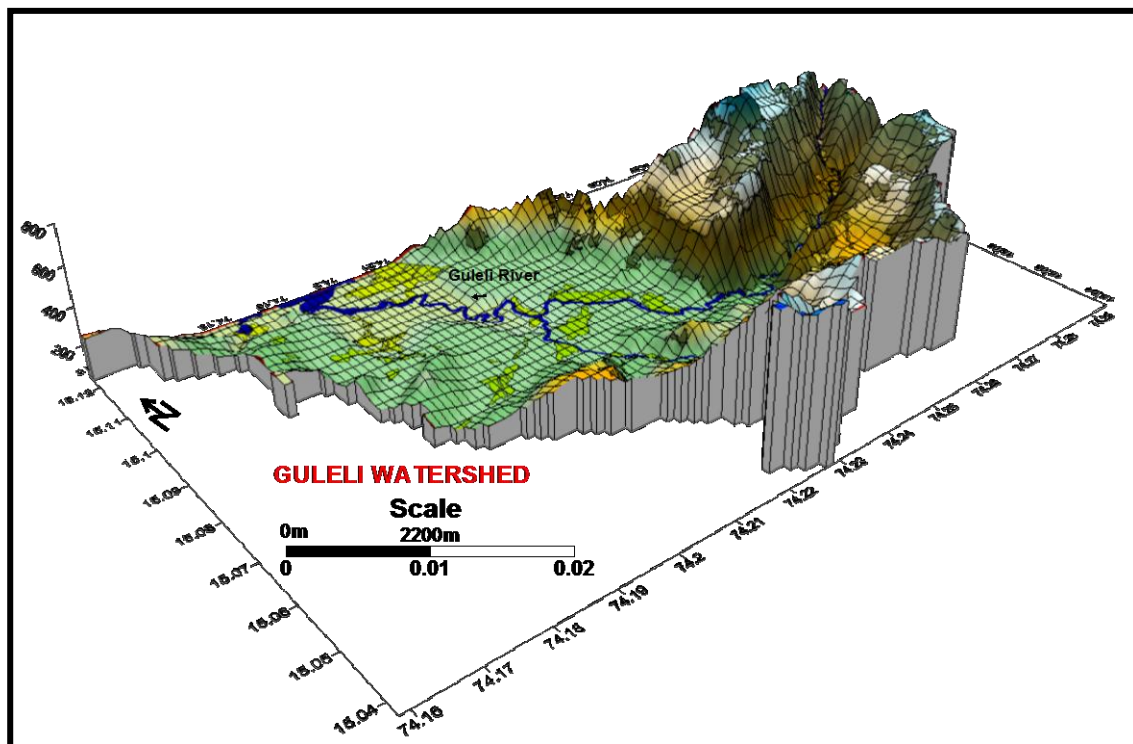


Figure 2.11: Three dimensional view of the Guleli watershed



Figure 2.11(a): Satellite image showing the Guleli watershed

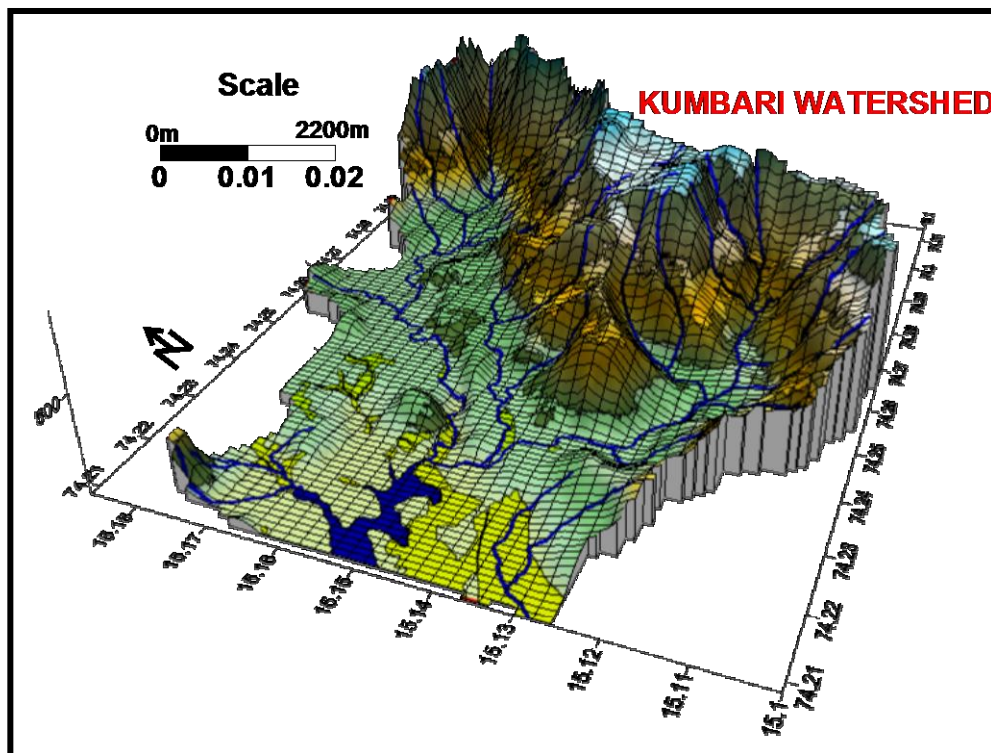


Figure 2.12: Three dimensional view of Kumbhari watershed

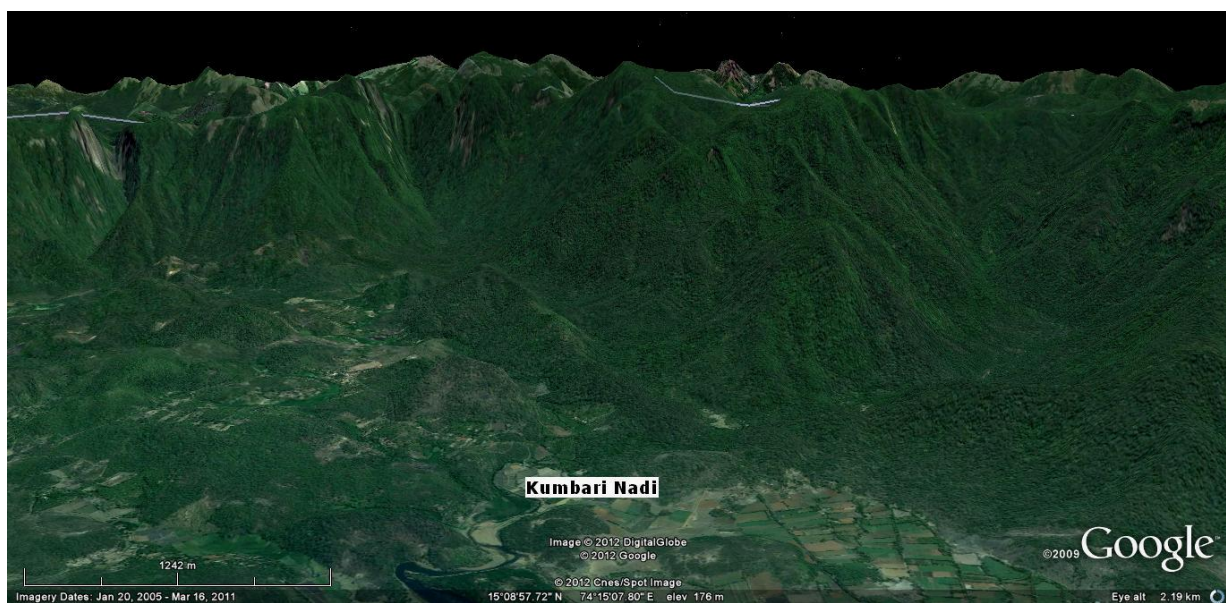


Figure 2.12(a): Satellite image showing Kumbhari watershed

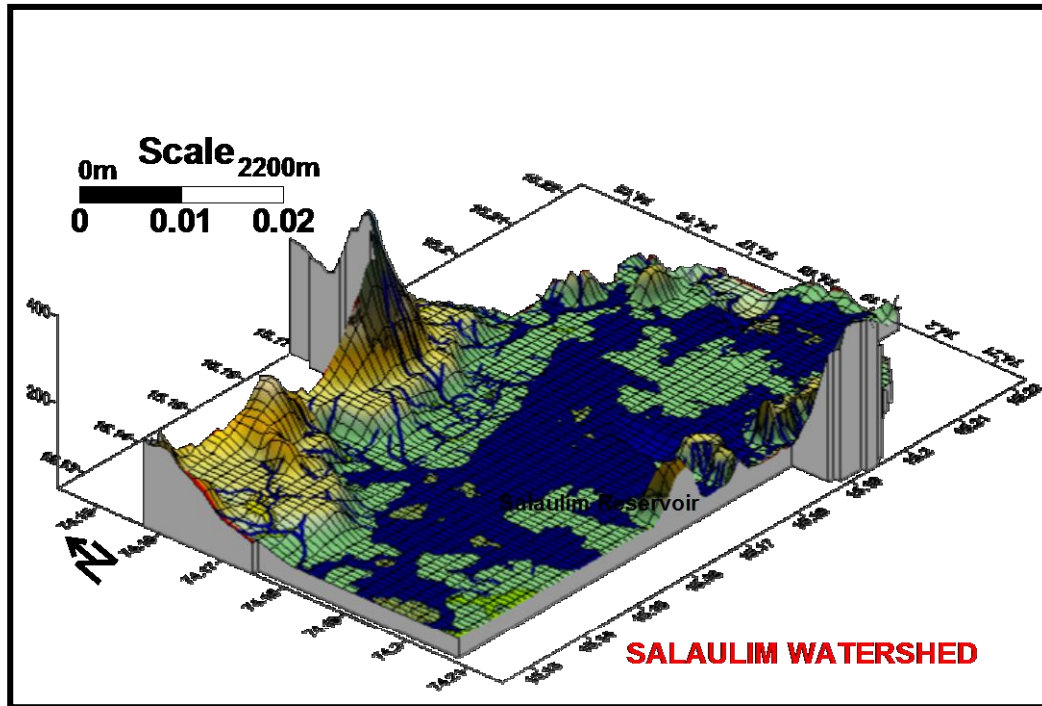


Figure 2.13: Three dimensional view of Curpem watershed



Figure 2.13(a): Satellite image showing central part of the Curpem watershed



Figure 2.13(b): Satellite image showing northern part of the Curpem watershed

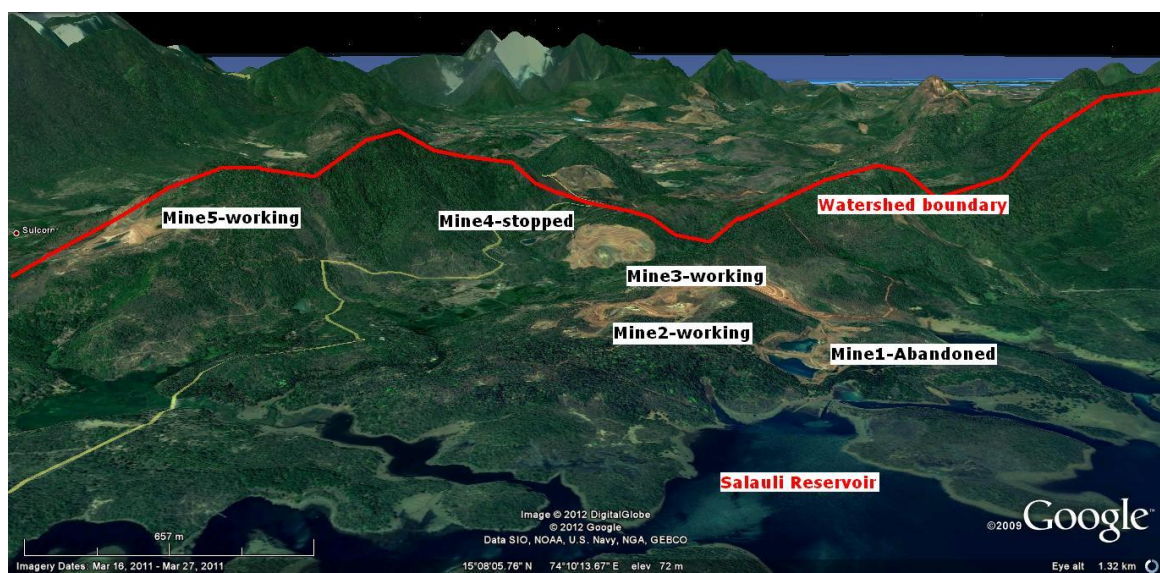


Figure 2.13(c): Satellite image showing southern part of the Curpem watershed

2.4.3 Soil, Geology and Land use

The top soil of varying thickness is observed almost throughout the study area except on steep slopes and hill-crests, where the land is rocky with exposed laterite. Loamy and sandy soils are generally found in the low lying agricultural fields. Soils of Torse/Netravali and Darbandora/Gavane type are mainly seen occurring in the southern and eastern parts of the study area. Whereas Metavade/Velguem and Bandoli/Arukot type of soils are exposed in the south central and western parts of the Salaulim study area. The soils falling within the study area can be seen on the soil map of Goa in Figure 2.15.

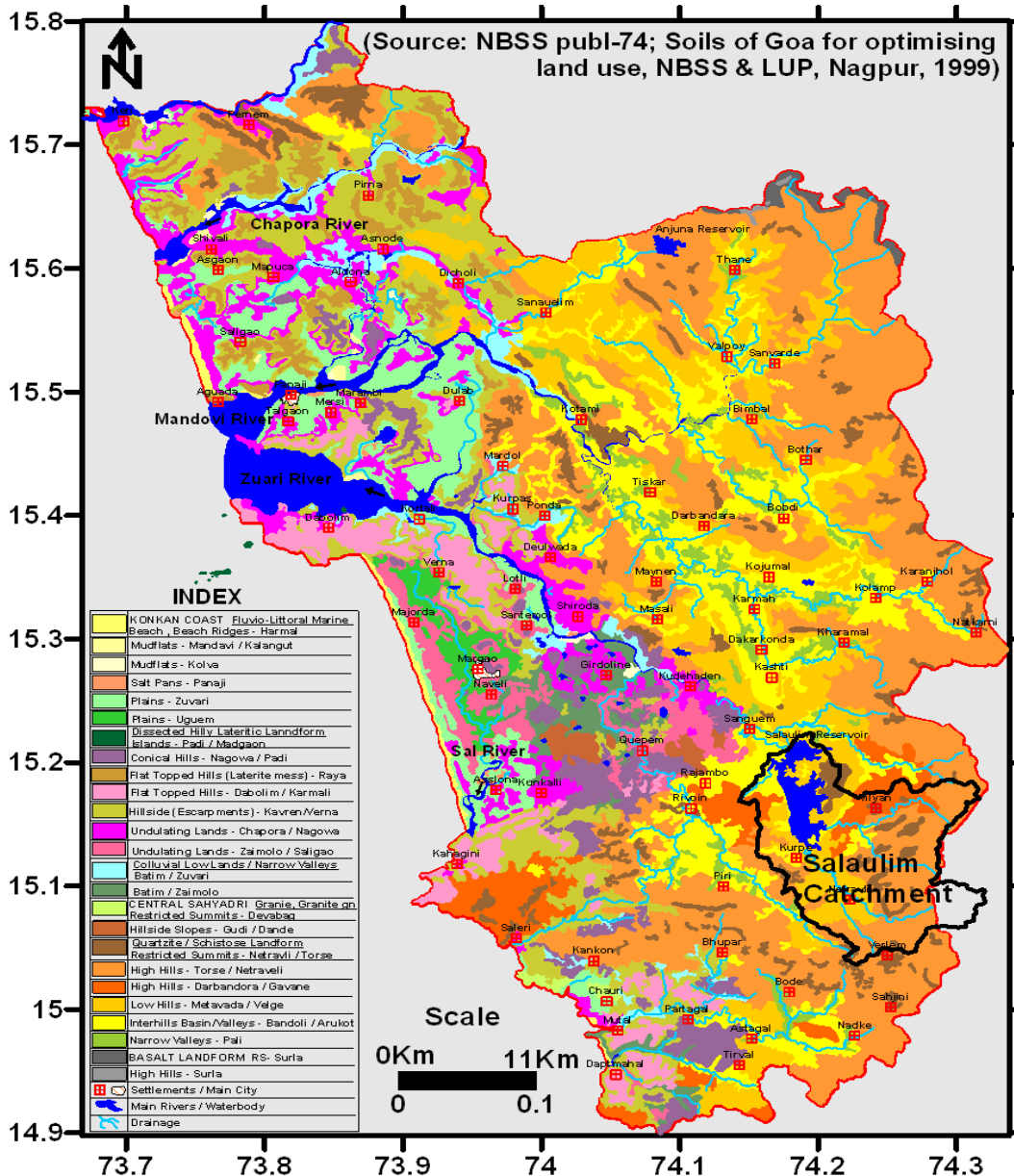
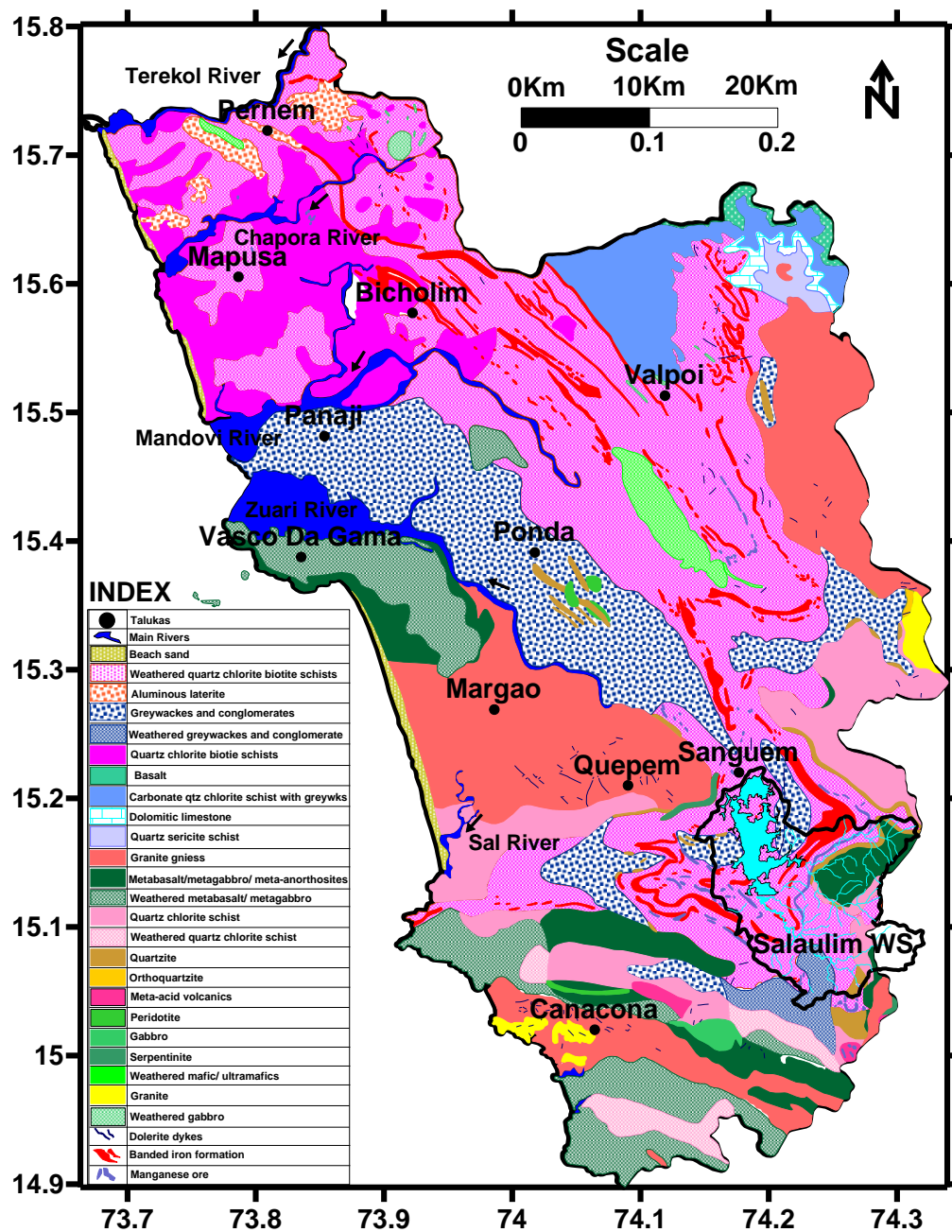


Figure 2.15: Study area shown on the soil map of Goa

The study area mainly consists of quartz-chlorite-biotite-schist with layers of chert, iron oxides, metabasalts, metagabbro. Laterites form the top layer in many parts of area followed by Greywacke with conglomerate, metagabbro, meta anorthositic gabbro, and banded iron formations. The major geological structures include plunging anticlines and synclines. The geological formations occurring in the study area are shown within the watershed boundary laid on the geological map of Goa (Figure 2.16).



(Source:GSI-1995;Geological and Mineral map of Goa)

Figure 2.16: Study area shown on the geological map of Goa

Based on the SOI topographic map and satellite images, the Salaulim catchment displays different land uses comprising forests, agriculture, plantations, and other land uses that include mining (laterite, iron, and manganese), mining dumps, and water spread areas. The percent distribution of these land uses is shown in Figure 2.17. It can be seen that around 13.2% of the catchment area is covered with mining activity, dumps and water spread area.

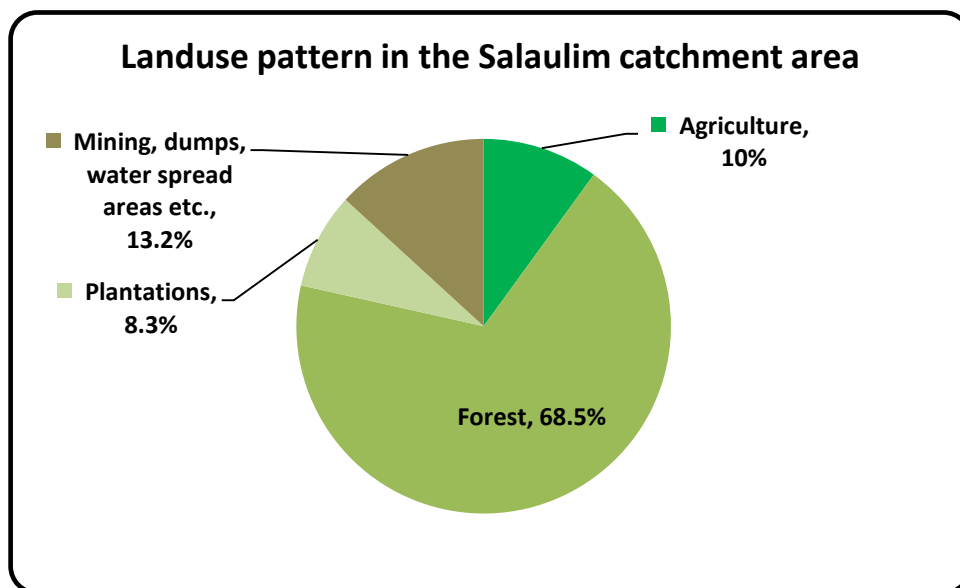


Figure 2.17: Land use distribution in the Salaulim catchment area

2.4.4 Climatic condition in the region

The minimum and maximum temperature is in the range of 20°C to 36°C. The relative humidity varies from a minimum of 80 to 85% in April/May to a maximum of 90 to 95% in the month of July/August. The overall climate in the region falls in the category of humid tropical. The catchment area receives heavy precipitation during monsoon period between June to September. Monthly rainfall data for the past 10 years from 2002 to 2011 has been collected from two gauging stations located in the study area. The data is given in Tables 2.2 & 2.3. The plot of monthly rainfall for both the stations is shown in Figure 2.18. As seen from the above graph monthly rainfall measured at Neturlim shows higher values compared to Ghatiapandu rain gauging station especially during the month of June. It is almost equal during the month of July. The annual average rainfall for Neturlim station is higher by 10.53% compared to Ghatiapandu station. The monsoon rainfall for both the measuring stations is little higher than 10% of the non-monsoon rainfall.

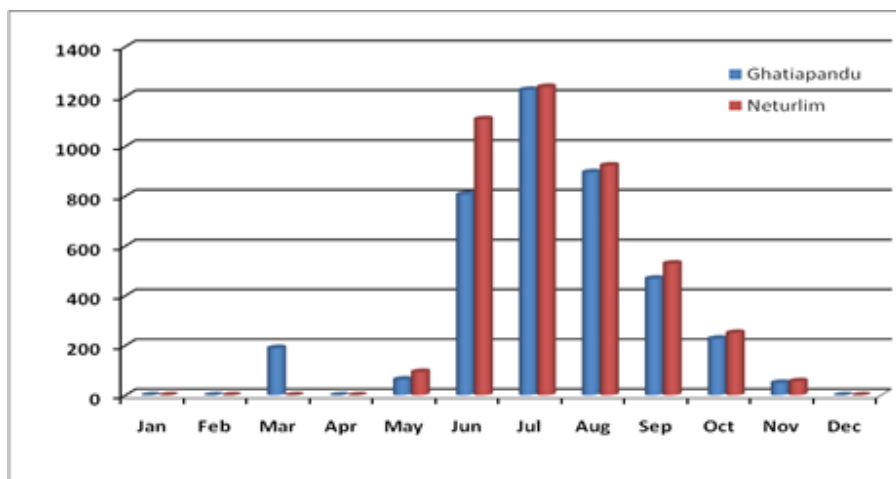


Figure 2.18: Monthly average rainfall (mm) for two rain gauging stations in the study area

Table 2.2: Monthly rainfall data from Ghatiapandu rain gauging station

Year/Month	Rainfall in mm at Ghatiapandu													
	June	July	Aug	Sep	Total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
	Monsoon					Non-Monsoon								
2002	1047	780	616	134	2577	280	-	-	-	-	-	-	127	407
2003	978	1121	773	343	3215	203	-	-	-	-	-	-	-	203
2004	801	957	804	211	2773	119	38	-	-	-	-	-	9	166
2005	932	1291	608	586	3416	258	1	-	-	-	-	-	50	309
2006	630	1008	989	576	3203	349	73	-	-	-	-	-	396	817
2007	865	913	1381	685	3844	229	47	-	-	-	-	-	51	326
2008	78	1654	1196	572	3499	39	-	-	-	-	190	-	-	229
2009	823	1526	508	640	3498	297	106	-	-	-	-	-	-	404
2010	708	1636	942	555	3842	325	186	-	-	-	-	-	-	511
2011	1210	1386	1142	386	4124	177	51	-	-	-	-	-	-	227
Average	807	1227	896	469	3399	228	50	0	0	0	190	0	63	360
Total annual average rainfall at Ghatiapandu = 3759 mm														

Table 2.3: Monthly rainfall data from Neturlim rain gauging station

Year/Month	Rainfall in mm at Neturlim														
	June	July	Aug	Sep	Total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total	
Monsoon					Non-Monsoon										
2002	1141	889	794	194	3018	167	-	-	-	-	-	-	-	-	167
2003	1274	1012	812	207	3304	362	-	-	-	-	-	-	-	-	362
2004	1108	1187	943	173	3412	134	22	-	-	-	-	-	260	415	
2005	1226	1514	550	716	4006	111	1	-	-	-	-	-	-	112	
2006	856	1287	915	820	3879	253	68	-	-	-	-	-	503	825	
2007	1161	995	1553	640	4345	241	19	-	-	-	-	-	95	355	
2008	1225	740	1108	642	3715	68		-	-	-	-	-	82	150	
2009	752	1872	522	662	3808	579	166	-	-	-	-	-	-	744	
2010	901	1493	924	677	3995	262	279	-	-	-	-	-	-	541	
2011	1449	1401	1110	561	4521	332	9	-	-	-	-	-	-	341	
Average	1109	1239	923	529	3800	251	56	0	0	0	0	0	94	401	
Total annual average rainfall at Neturlim =4202 mm															

2.4.5 Mining activities in the area

The Salaulim catchment falls in a geologically potential iron and manganese ore zone. Mining activities in the catchment area primarily includes extraction of iron and/or manganese ore and laterite quarrying. During the present study a detailed analysis of the number and distribution of all the lease concessions were carried out using the data from Directorate of Mines & Geology. Extensive search and mapping of mining activities using satellite images was done. Field inspections were undertaken to ground check the active, abandoned and very old mine pits in the watershed area. The location of all the sanctioned mine concessions by erstwhile Portuguese are shown in Fig. 2.19. The list of each concession and their details for Curpem, Guleli and Kumbharisub-watersheds is given in Annexure V.

The location of the laterite quarries, active mines and abandoned mines is shown in the Figures 2.20 and 2.21 respectively. A list of existing mining leases that fall in different watersheds is presented in Annexure V. There were seven laterite quarries (Figure 2.20) that were identified during field visits which could also be source of pollution due to surface runoff during monsoon. Out of seven, five fall within the watershed and all are located in the north-west direction.

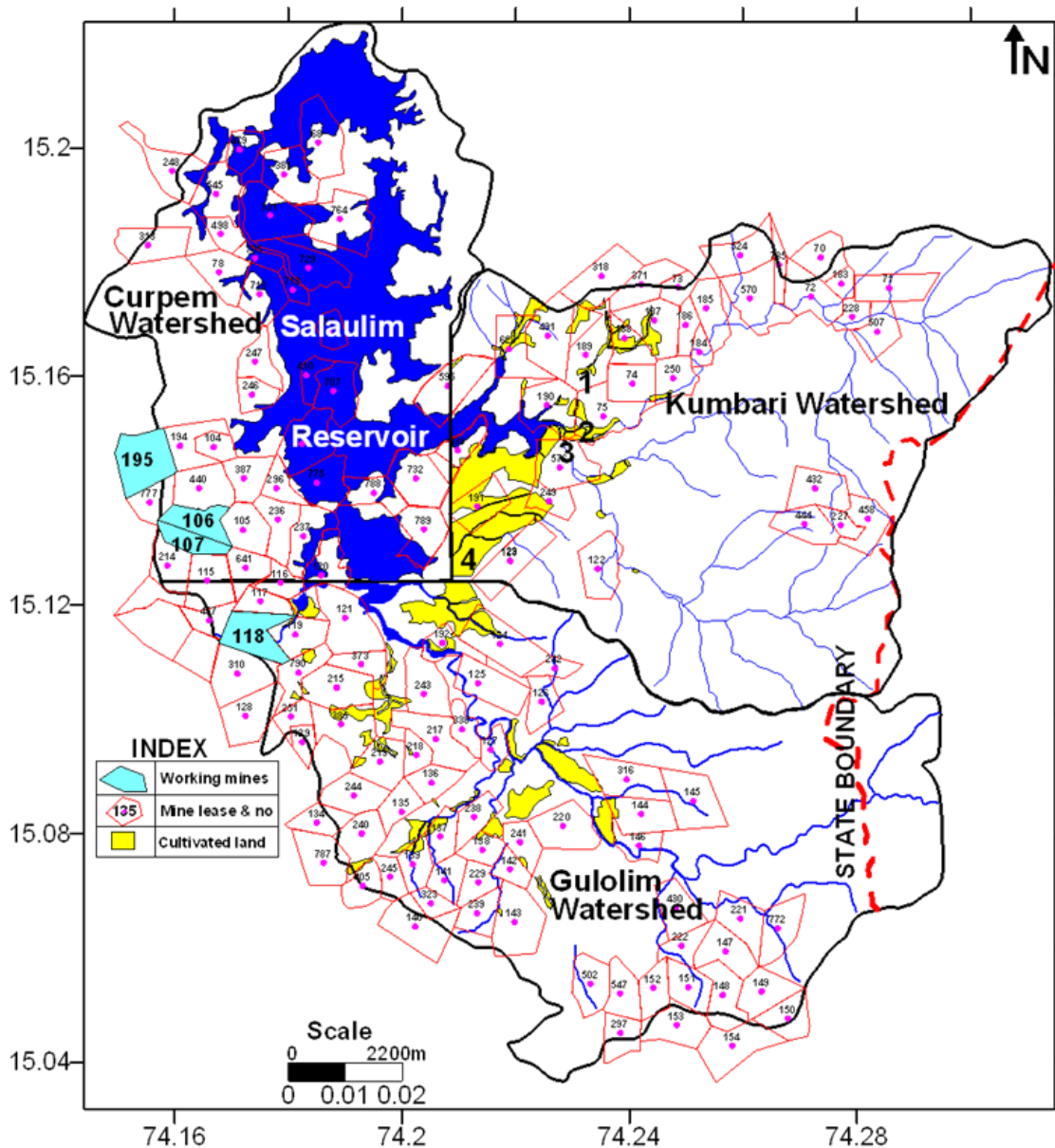


Figure 2.19: Distribution and location of mining concessions (working and non-working) in the Salaulim watershed

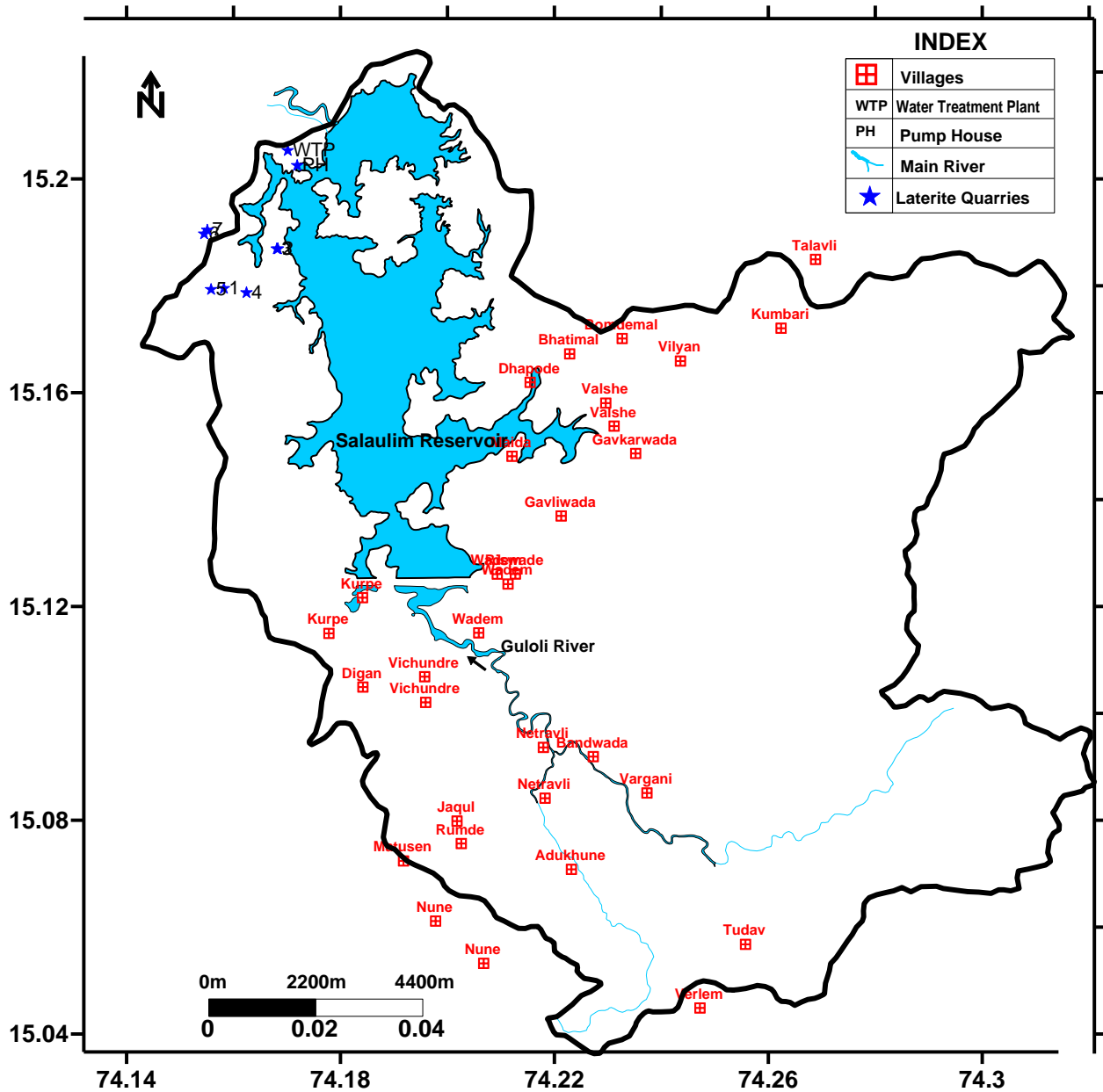


Figure 2.20: Location of laterite quarries in the catchment

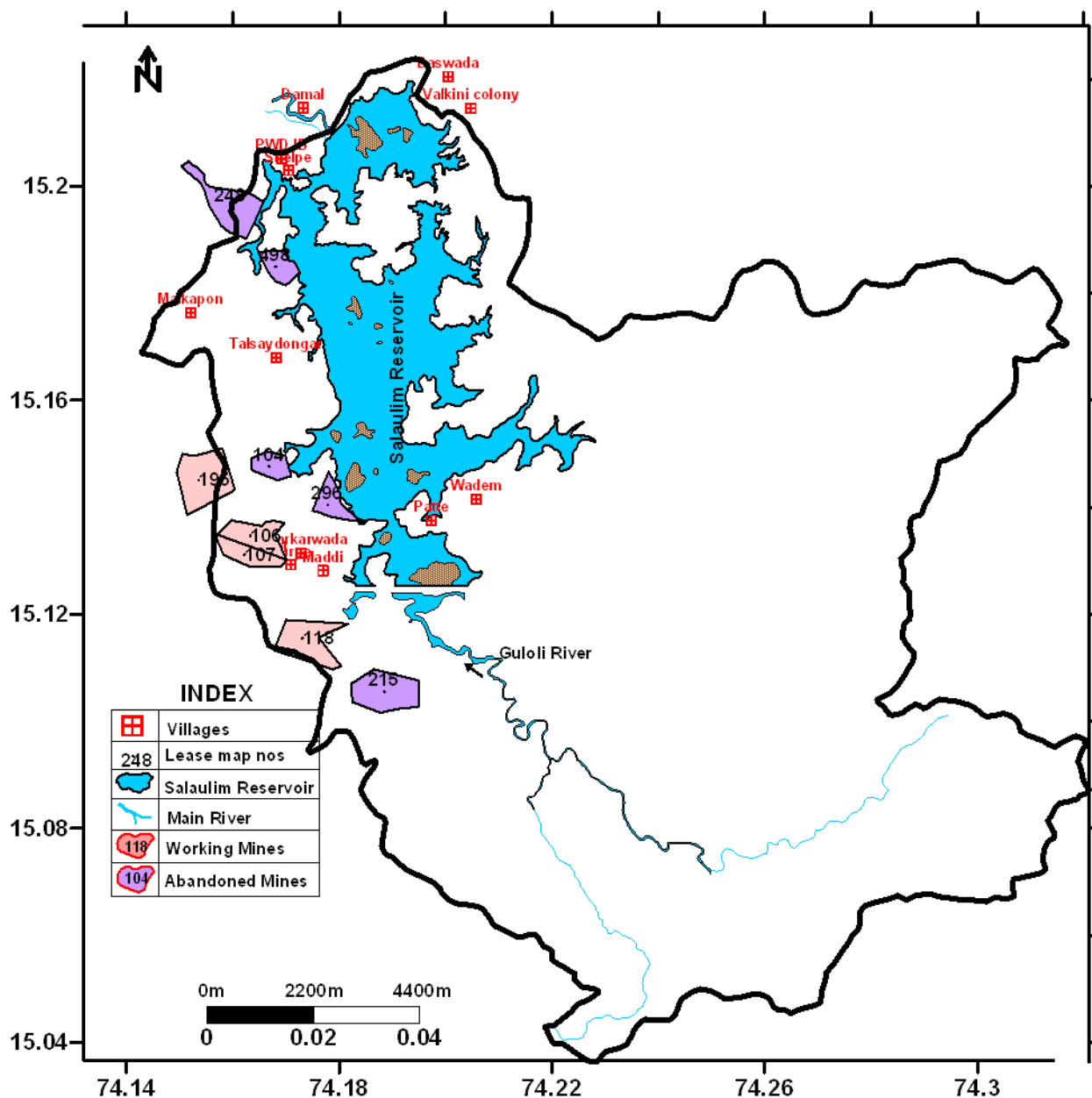


Figure 2.21: Location of working, abandoned and old mines in the catchment

Of all the above concessions very few mines were in operation during the study period. There were four active mines and seven abandoned mines. There were seventeen very old non-working mines that have been identified from the satellite image. The geographical coordinates of all these mines are given in Annexure VI. As shown in the figures above, all the working and abandoned mines are in the Curpem watershed in western part of the Salaulim reservoir. Similarly majority of old non-working mines are located in Guleli and Curpem watersheds and two are in Kumbhari watershed. Two old and abandoned mines are seen located within the reservoir in the northern part now an island after the dam was built.

The satellite image (dated March 2011 and accessed in July 2012) showing active mines are presented in Figure 2.22. All the old non-working mines which have been identified using

the satellite image are shown in Figure 2.23 (a to q). Around 17 very old non-working mines were found in the study area. The old mine at site 3 (Figure 2.23c) was identified as illegal mine by the Shah Committee Report (2012).



Figure 2.22: Satellite image of active mines in the Salaulim watershed

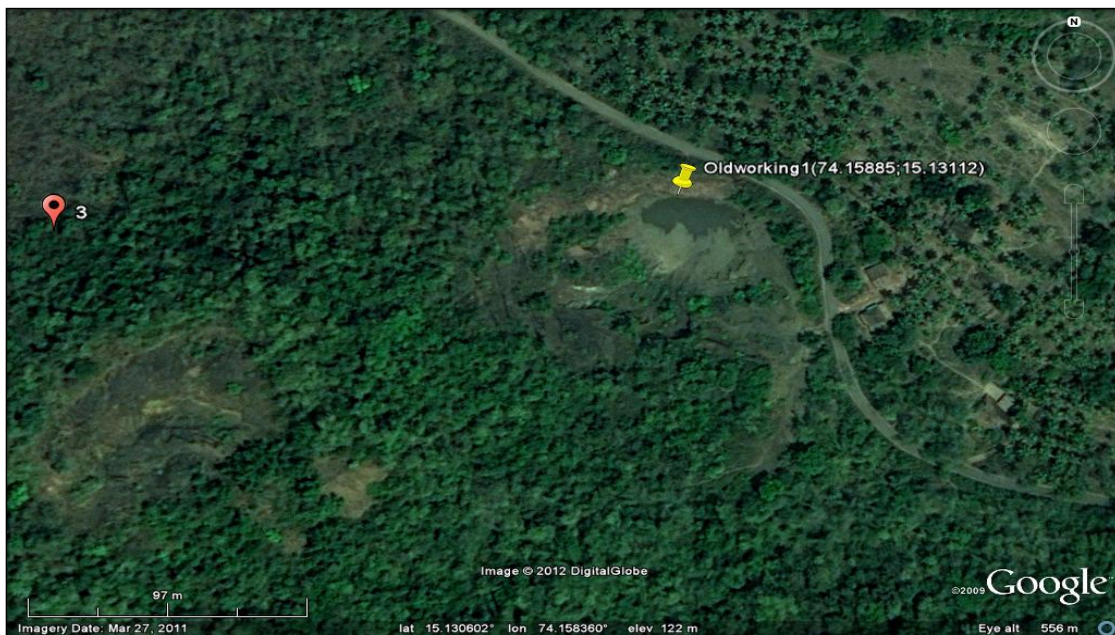


Figure 2.23(a): Site 1: Oldmine



Figure 2.23(b): Site 2: Oldmine



Figure 2.23(c): Site 3: Oldmine



Figure 2.23(d): Site 4: Oldmine

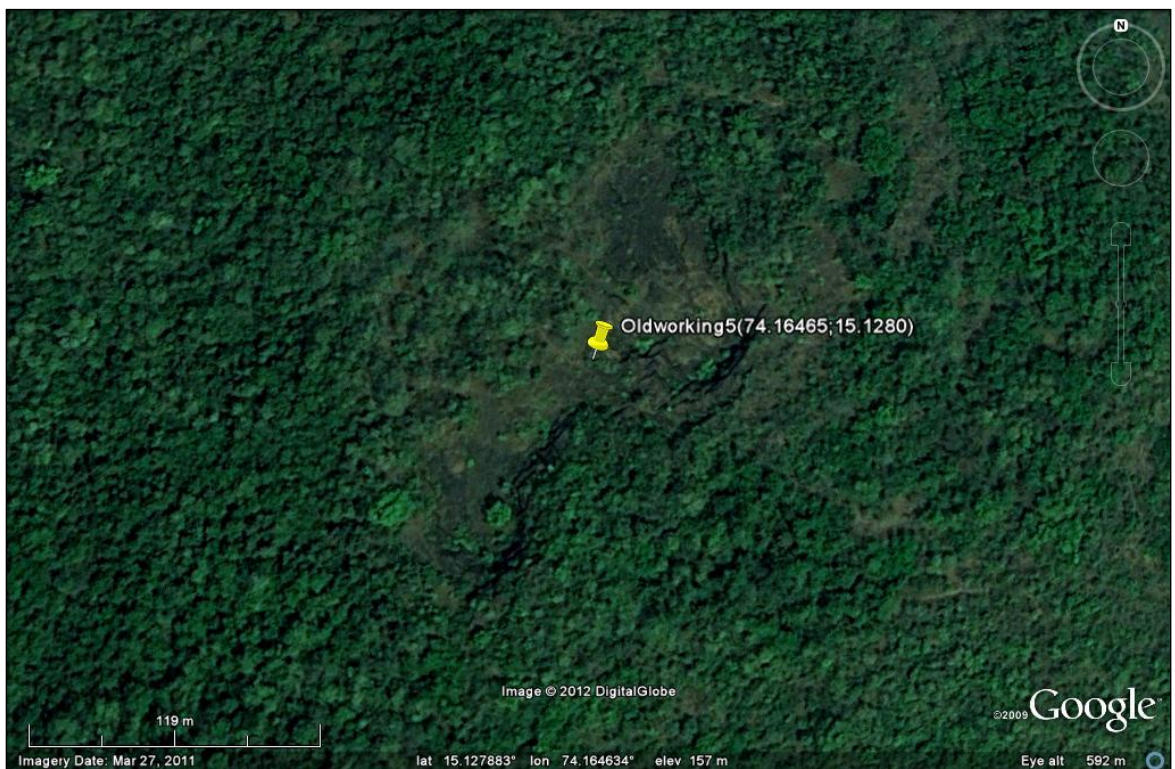


Figure 2.23(e): Site 5: Oldmine

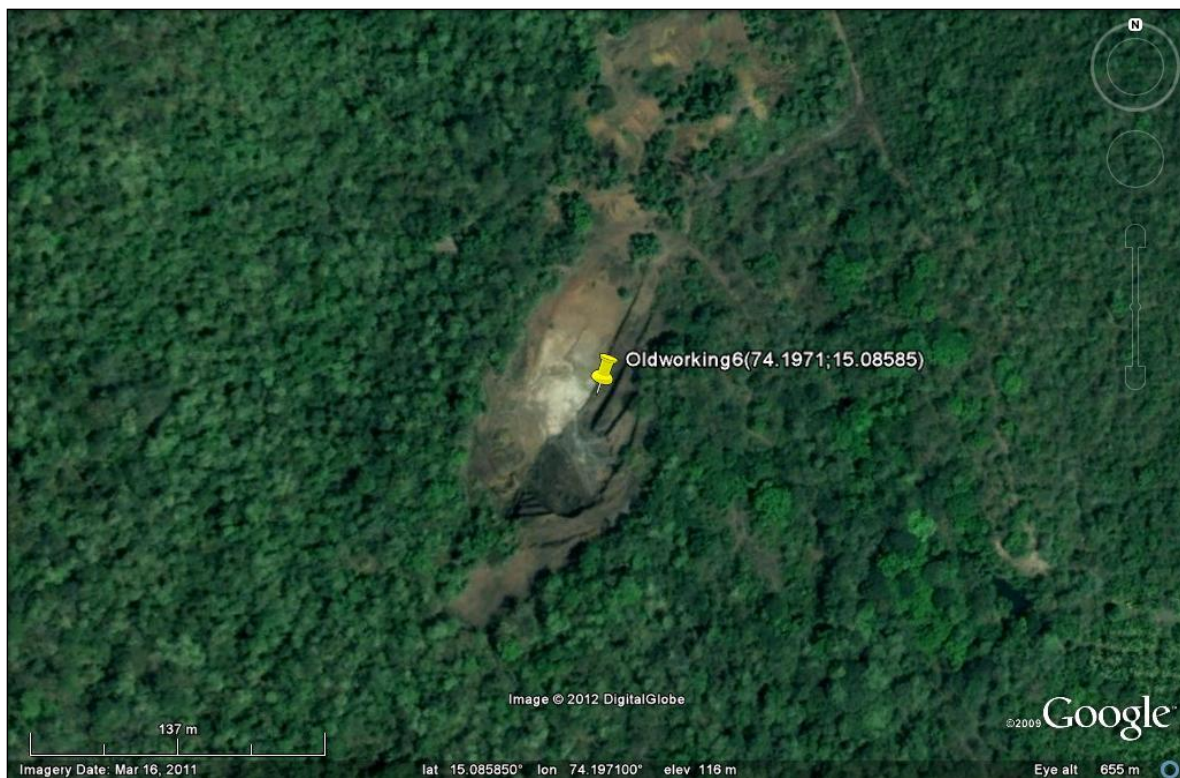


Figure 2.23(f): Site 6: Old mine



Figure 2.23(g): Site 7: Oldmine

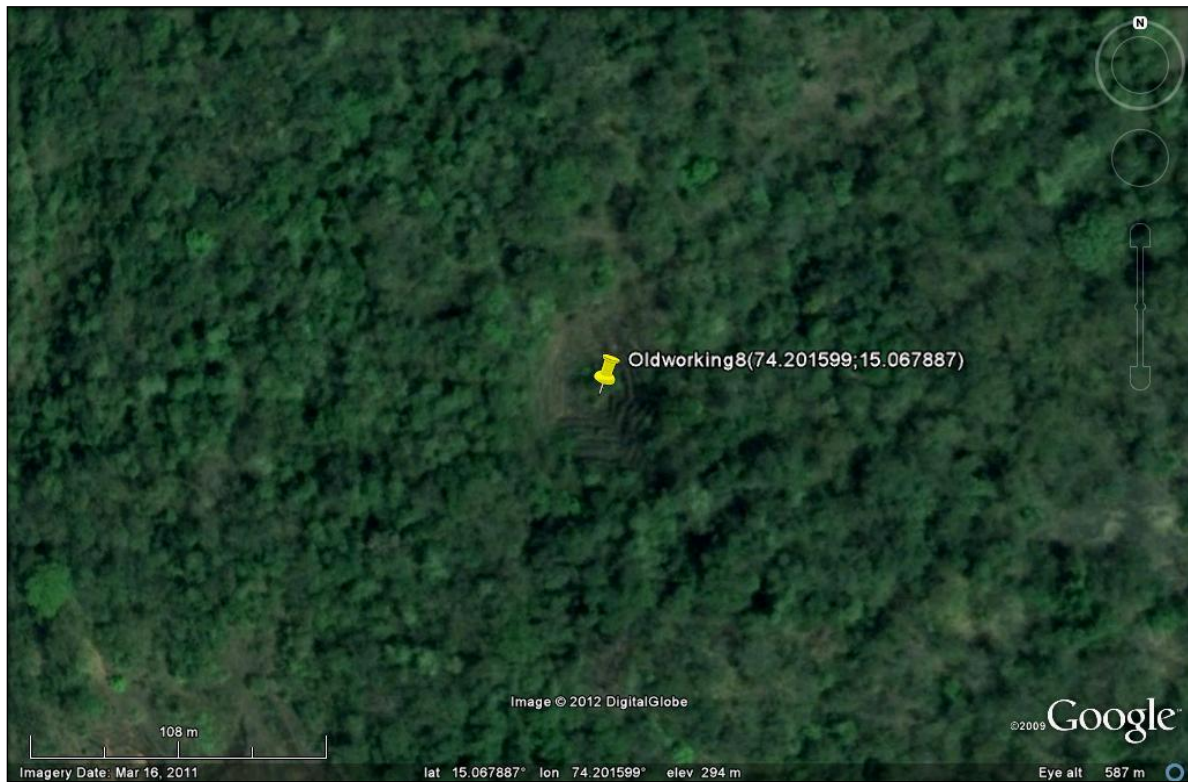


Figure2.23 (h): Site 8: Oldmine



Figure 2.23(i): Site 9: Old mine



Figure 2.23(j): Site 10: Old mine



Figure 2.23(k): Site 11: Old mine



Figure 2.23(l): Site 12: Old mine



Figure 2.23(m): Site 13: Old mine

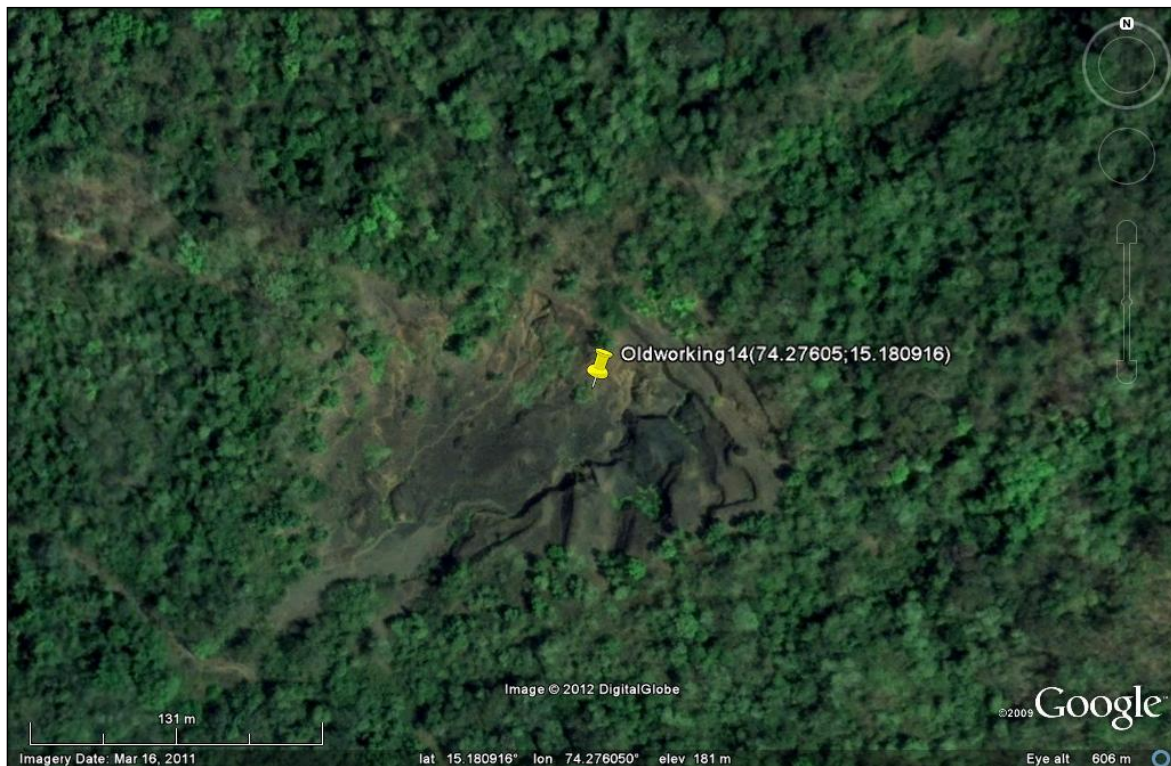


Figure 2.23(n): Site 14: Old mine



Figure 2.23(o): Site 15: Old mine



Figure 2.23(p): Site 16: Old mine



Figure 2.23(q): Site 17: Old mine

2.4.6 Soil Erosion Potential

The major cause of water pollution due to mining are discharge of mine pit water, and storm water runoff from mine dumps and adjoining areas. Erosion of waste dumps due to heavy rainfall leads to turbidity of natural drainage system because of the suspended solids carried by the runoff. It also affects the water quality. Another cause of non-point source of pollution and siltation is runoff from the surrounding areas. Considering this, it is important to understand the soil erosion potential of the Salaulim catchment.

The soil texture in the catchment varies from sandy to fine loamy soil. Owing to the presence of hills and varying degrees of slopes, the catchment is prone to soil erosion. Based on the CWC (2011) data, the catchment has been divided into four classes depending on the erosion potential. These classes are (i) Slight (ii) Slight to moderate (iii) Moderate (iv) Severe. It was observed that around 35.1% and 21 % of the area fall in the categories of moderate and severe erosion intensity respectively. The map showing the very high and high priority micro-watersheds in the catchment that need implementation of soil conservation measures is presented in Figure 2.24.

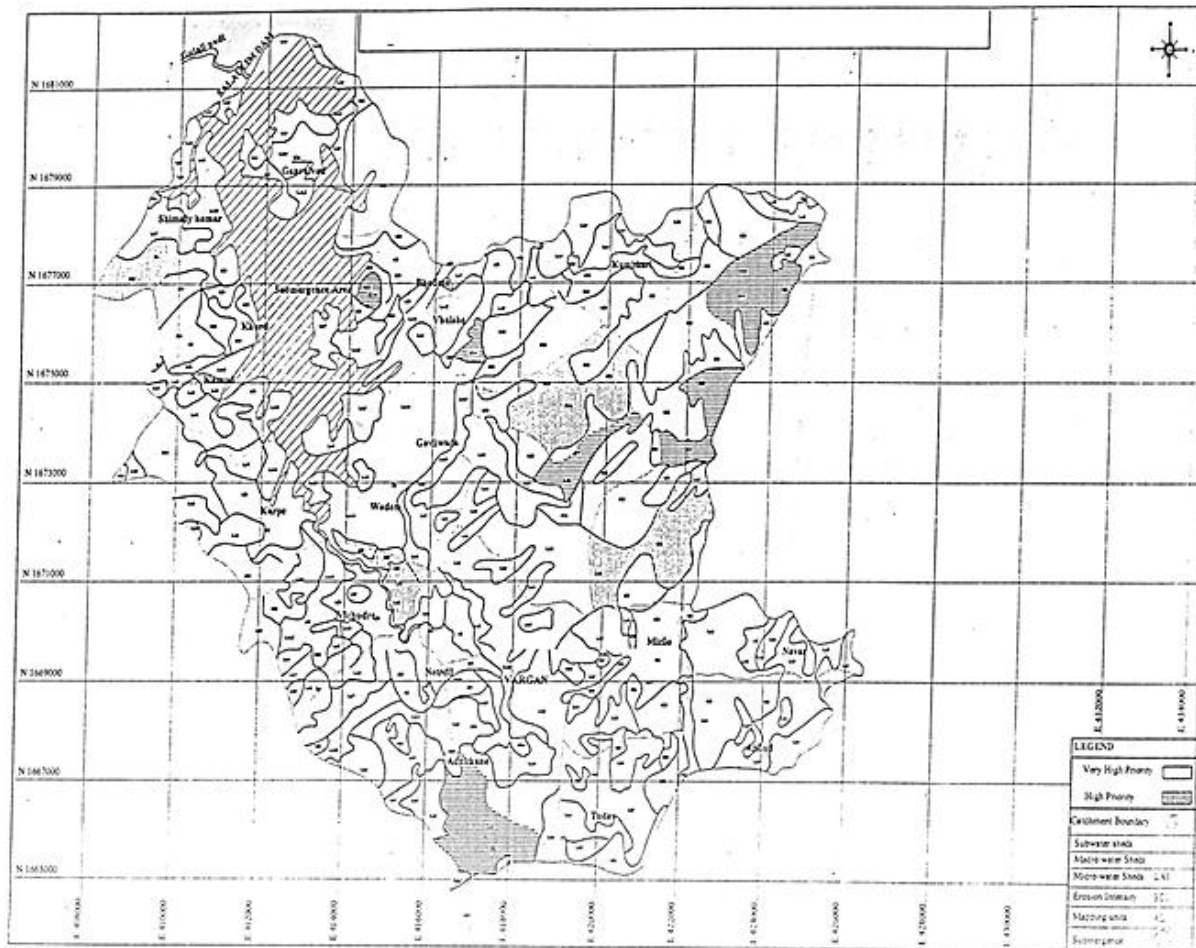


Figure 2.24: Priority areas having high and very high erosion potential

Source: CWC, 2011

2.4.7 Measures taken by the mining companies

Some of the mining companies have adopted measures to prevent/reduce water pollution. As a general practice, storm-water runoff in the active mining area is allowed out of the lease area after passing it through filter bunds and/or intermediate settling ponds. During fair weather, the water pumped out from the working pits is discharged into the natural water course after passing through the filter bunds and settling ponds. For tailings, a series of settling ponds are constructed. The water after settlement of silt is discharged outside the boundary of the lease. There was no working wet beneficiation plant in the study area during the study period. The active mines had dry screening. In general, only a few mining companies have taken measures to reduce the adverse environmental impact on water bodies but these are frequently ineffective especially in the rainy season (TERI, 1997).

3 Baseline status

This chapter describes the field investigations for assessing the impact of mining on surface and groundwater carried out in the study area during post-monsoon (October/November), summer (April/May), and monsoon (July/August) seasons. The methodology that was adopted and the observations made for surface and groundwater are presented in next two sections. The last section of this chapter describes the baseline water quality.

3.1 Surface water

3.1.1 Overall objective

One of the key impacts of mining activity on the surface water is siltation caused by runoff thereby affecting its quality. Non-point pollution from surface runoff further adds to quality deterioration in the receiving water body. Hence to study this, the first objective was to examine the contribution of sediment load to Salaulim reservoir due to mining activity.

3.1.2 Methodology

The steps that were followed to compute the sediment load are shown in the flow diagram (Figure 3.1). The detailed methodology and the results are described later.

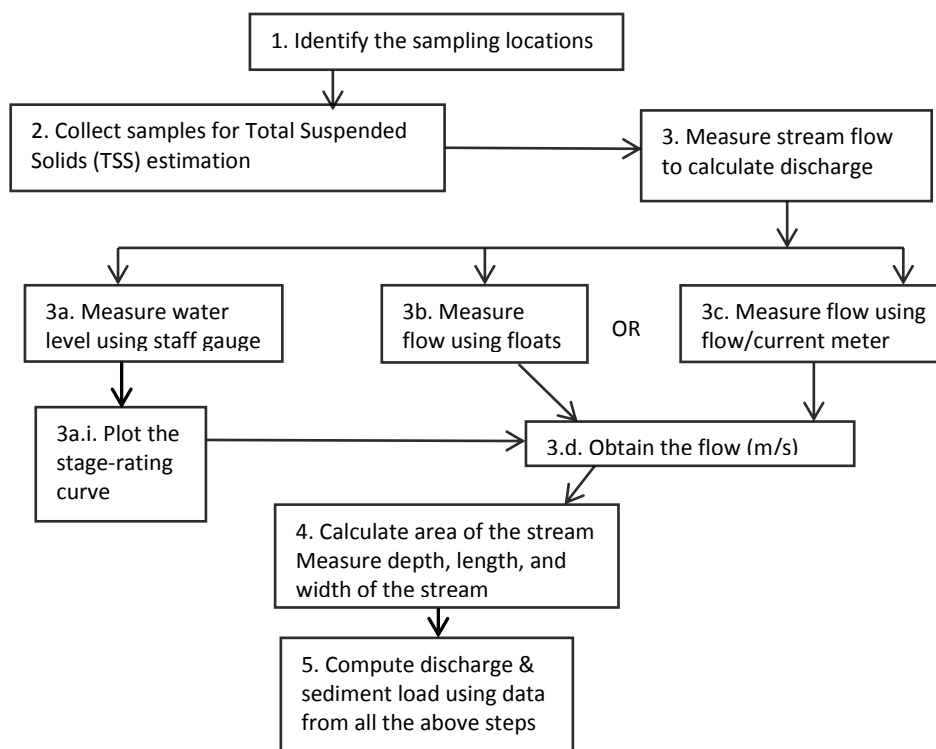


Figure 3.1: Flow diagram showing the methodology for calculation of sediment load

1. Identification of the sampling location:

With a view to compute the sediment load added to the reservoir through the above-mentioned watersheds, seven sampling locations were identified. These sampling locations are shown in the Figure 3.2. The details of each of them are given in Table 3.1. Five sampling locations were selected downstream of the mining areas. This was done to examine the sediment load contributed by the mines through surface runoff. To test this hypothesis, two locations were short-listed as the 'Control Points' which were out of zone of influence. These points are located downstream of forest areas or non-active mining areas. The sampling location at Guleli which is the main feeder to the reservoir has a cumulative effect of mining and non-mining areas. No perennial stream was found in the downstream of laterite quarries and hence there was no sampling location in that area.

The gauging sites were selected so as to ensure that the stage-discharge curve is reasonably constant over a long period of about a few years. To attain this following criterion were adopted:

- perennial streams/rivers were considered
- the stream with well-defined cross-section that does not change considerably in different seasons was considered
- easy accessibility all through the year
- the site within a straight, stable reach
- the gauging site was free from backwater effects

Table 3.1: Details of surface water sampling locations

Location #	Name of the Place/Location	Latitude (N)	Longitude (E)	Altitude (m)	Type of Location (Control Point or Sampling point)
1	Valshi/Valshe Stream	15° 09' 33.3''	74° 13' 45.6''	41	SP
2	Naiquinim	15° 09' 01.4''	74° 13' 40.4''	58	CP
3	Kumbhari River	15° 09' 02.1''	74° 13' 42.8''	66	SP
4	Vaddem Nala (Near bridge)	15° 07' 43.4''	74° 12' 31.7''	47	CP
5	Guleli River (near bridge)	15° 06' 17.3''	74° 12' 39.2''	75	SP (cumulative effect)
6	Netravali Nala (near bridge)	15° 05' 35.3''	74° 13' 11.6''	72	SP
7	Curpem stream (near small culvert/bridge)	15° 07' 44.6''	74° 10' 47.3''	66	SP

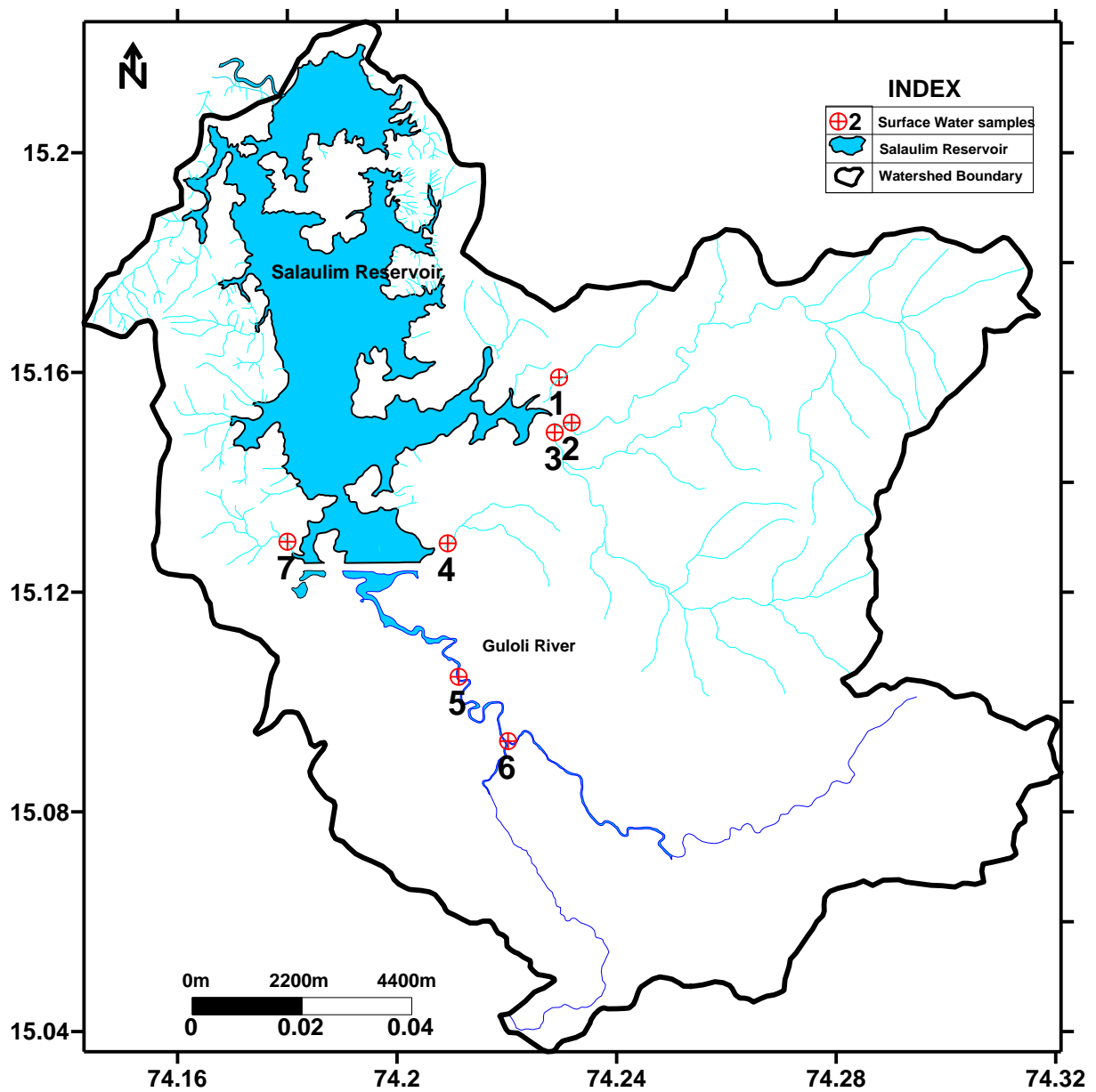


Figure 3.2: Surface water sampling locations

2. Collection of samples for suspended solids analysis:

To estimate the suspended sediment load, grab water samples were collected once a day from all the seven locations described above. Samples were collected daily for one month per season. Samples were composited by taking grab samples across width and depth in proportion to velocity. The samples were taken to the laboratory and total suspended solids concentration was determined using 0.45 mm filter method. Standard method (APHA 2005) was followed during the analysis.



Sample collection being done on site

3. Measure stream-flow to calculate discharge:

3. a. Installation of a staff gage: A staff gage is a long ruler placed semi-permanently in a stream and is used to read water depth. Staff gage information can be used in an indirect way to estimate stream flow. To do this, a relationship between stream depth and stream flow needs to be established. Once the relationship is established through a rating curve, the flow can be estimated from depth without having to take the time and trouble to make a detailed flow measurement.

Site selection is very important in order to install the staff gage. Availability of water throughout the year was used as the primary criteria for site selection. The staff gages were installed at all the seven locations and water level was recorded daily for one month (each season). These water-level readings were used to develop the stage-rating curve.

Developing Stage-rating curve: For every flow measurement, a staff gage reading was noted. Data was collected for wide range of flow conditions across different seasons. Around fifteen data sets were used for developing the scatter plot. These data points were plotted with flow on X-axis and the stage height on the Y-axis. The relationship between the two variables was established by plotting the curve. Recalibration of the curve was done based on the periodic checks. The rating curves for all the seven locations were developed. Datum correction was included while developing the stage-discharge relationship for all locations. The rating curve equations are shown in Table 3.2. The 'y' co-ordinate represents the stage above datum (m) and 'x' represents the discharge (m^3/s) values. The rating curves for all the locations are presented in Appendix VII. The close examination of the scatter revealed that single channel simple rating curve could be fitted for all the locations. It was found that the flow was contained in the main channel section and could be assumed to be fairly steady in most cases. There was no indication of any backwater affecting the relationship. The bed of the river or stream also does not change significantly so as to create any shift in the stage discharge relationship.

Table 3.2: Rating curve equation for various sampling locations

Location	Rating equation	Coefficient of determination (R ²)
Valshe	$y = 0.7324x^{0.1895}$	0.9
Naiquinim	$y = 0.6117x^{0.2084}$	0.9
Kumbhari	$y = 0.4908x^{0.1202}$	0.7
Vaddem	$y = 0.2719x^{0.3488}$	0.7
Guleli	$y = 0.1132x^{0.8187}$	0.8
Netravali	$y = 0.2609x^{0.5358}$	0.7
Curpem	$y = 0.5379x^{0.53}$	0.8

3. b. Velocity measurement using floats: The flow was measured using floats to get an estimate. A partially filled plastic water bottle was used as a float. Care was taken to ensure that about an inch of it is below the water line⁴. Around 7-10 m was measured along the bank of a straight section of stream. This was followed by estimation of the cross-sectional area of the stream. The float was released at the upstream site. Using a stopwatch, the time it took to reach the downstream was recorded. Three readings were taken for accuracy. The velocity was calculated as the distance travelled divided by the average amount of time it takes the float to travel the distance. The surface versus mid-depth velocity correction was done by multiplying the surface velocity by 0.85 (correction factor). Velocity is being expressed as m/s.

3. c. Velocity measurement using current meter:

To measure the flow, pygmy type current meter was used. The choice of this current meter was apt because the depth of the streams was less than 1m and had a low flow during non-monsoon seasons. The number of revolutions per minute was recorded at a depth 0.5 depth. Three readings were taken to increase the accuracy of the data. The meter-specific calibration equation (shown below) was used to get the flow values.

For $R \leq 7.1481$; $V = 0.0305 + 0.2978R$

For $R \geq 7.1481$; $V = -0.0197 + 0.3048R$

Where R = Current meter revolutions per second,

V = Velocity (m/s)



Using pygmy current meter to measure flow

⁴ Source: <http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/5float.html>, Last accessed on September 1, 2011

1. **Calculate cross-sectional area of the stream:** The cross-sectional area of the stream was estimated by using total stream width and the average depth (Figure 3.3). The average depth was calculated from depths measured at fixed intervals. The area was computed using the following formula:

$$\text{Area (m}^2\text{)} = \text{Total width (m)} * \text{Avg depth (m)}$$



Measuring the width of the stream

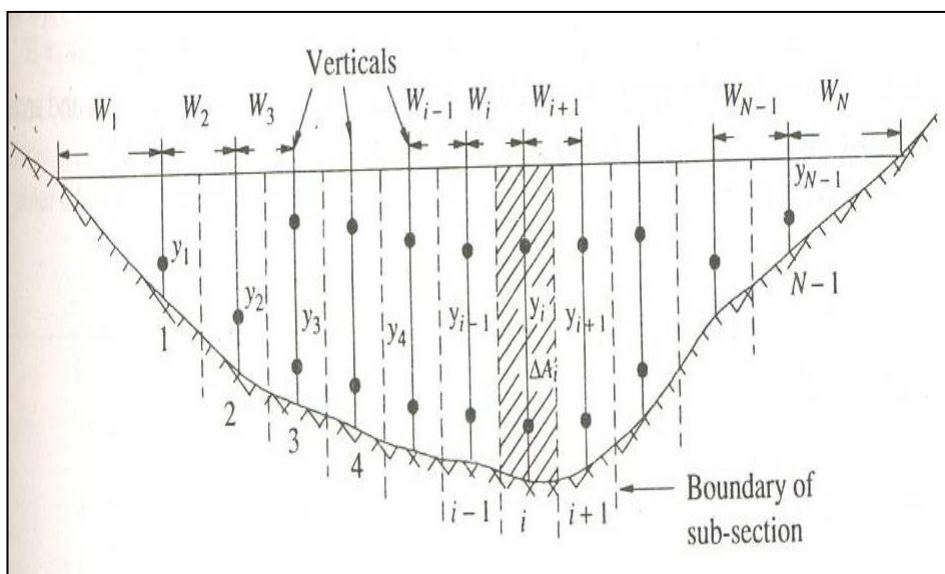


Figure 3.3: Stream section for area-velocity method

2. **Compute discharge and sediment load:**

The discharge was calculated using the following formula:

$$\text{Discharge (m}^3\text{/s)} = \text{velocity of flow (m/s)} * \text{area (m}^2\text{)}$$

The sediment load was calculated using the following formula:

$$\text{Sediment load (kg/day)} = \text{Total suspended solids concentration (mg/l)} * \text{discharge (m}^3\text{/s)} * \text{conversion factor}$$

3.1.3 Sediment load

The sediment load for all the seven locations was estimated using values for Total Suspended Solids (TSS) and discharge using the equation described in the earlier section.

Daily samples were taken from all the locations for (TSS) analysis for a period of one month in each season. The average TSS values for the seven locations are depicted graphically in Figure 3.4. It was observed that the average suspended solid concentration was highest during monsoon season for all the locations. The increase in the TSS concentration was evident soon after or during the heavy rainfall events for most of the locations and an example is illustrated in Figure 3.5. This may be due to the first flush effect which is generally defined as the first proportion of the runoff volume containing the main proportion of the related pollutant load (Gnecco et al., 2005; Delectic, 1998). In the present study simple correlation between the rainfall depth and the TSS was investigated. A simple regression was carried out for all the locations and the coefficient of correlation (R^2) values varied from 0.023 to 0.55. The best fit amongst them was at Curpem indicating that with the increase in the rainfall depth or intensity the TSS concentration would rise at this location. It must be noted that this location lies in the watershed which had the active mines. During the monsoon season, the average TSS concentration (Figure 3.4) at all the sampling locations was more than Vaddem (control point) demonstrating that the concentration was more at the locations that have mining effect. The second control point was chosen at Naiquinim considering that it did not have mining occurring at its upstream. Also, it is a major river contributing to the reservoir. The second highest TSS concentration was observed at Naiquinim. This may be because it is downstream of 'high and very high' erosion potential areas that were identified by CWC (2011). The two control points have different levels of TSS indicating the variability in potential of soil erosion due to geogenic reasons (soil type and slope). The highest TSS concentration was recorded at Kumbhari which is affected by mining as well as high erosion potential areas.

It was observed that as compared to the 'control point' at Vaddem the TSS concentrations are higher for all the sampling locations indicating the possible impact of mining activity occurring upstream. TSS concentration in non-monsoon periods (i.e summer and post-monsoon season) was nearly same at all monitoring stations (control as well as others) and the variability in TSS amongst monitoring stations was only during monsoon period. This indicates that the surface run-off has major impact on water quality and areas that have mines are found to have higher impact.

The seasonal average discharge values for all the locations are shown in Figure 3.6. It was evident that the highest discharge at all the locations was during monsoon season. The highest discharge was recorded at Guleli followed by Kumbhari. The annual sediment load (Figure 3.7) was estimated using the TSS and discharge values for all the seasons. It was observed that though the discharge was more at Guleli than Kumbhari, the sediment load was found to be highest at Kumbhari followed by Guleli. This indicates that the areas upstream of Kumbhari have high erosion potential. Also, during field visits, washing of mine trucks was observed at Vakurkumya and into the reservoir on the old Curdi road. This could further add silt into the Guleli river.

The total annual sediment load (Annexure VIII) from these seven locations is estimated to be 33993 tonnes. This is an indicative figure and may increase with sediments coming with runoff from non-point sources especially during monsoon season.

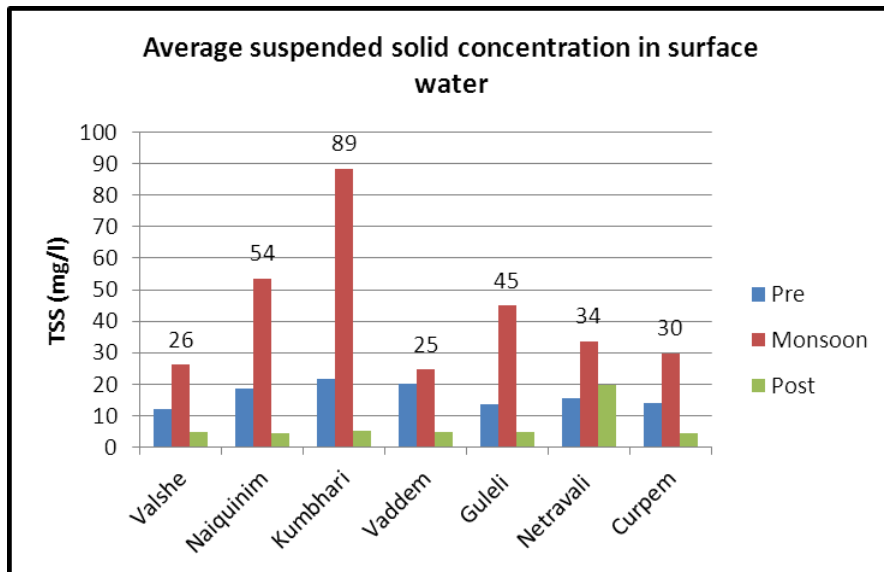


Figure 3.4: Average total suspended solid concentration in surface water in three seasons

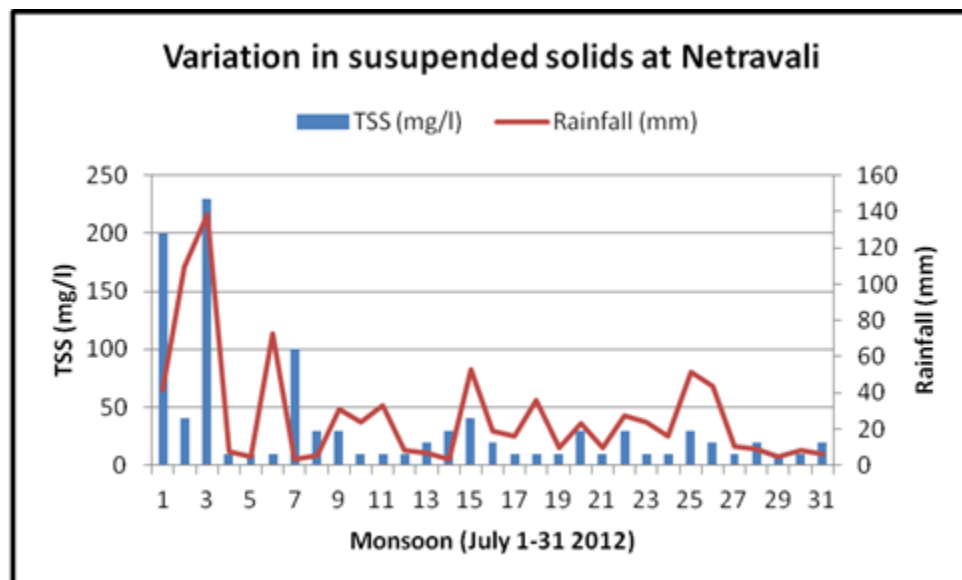


Figure 3.5: Variation in the average total suspended solid concentration with respect to rainfall depth at Netravali

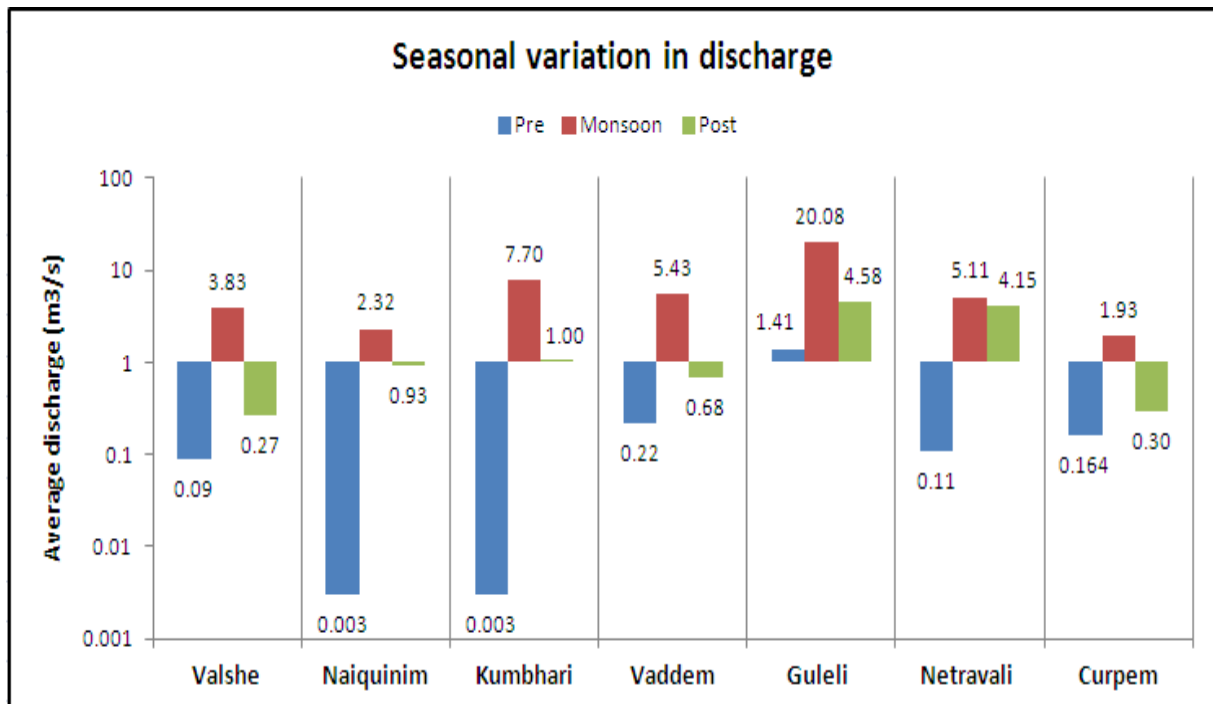


Figure 3.6: Seasonal variation in discharge at different sampling locations

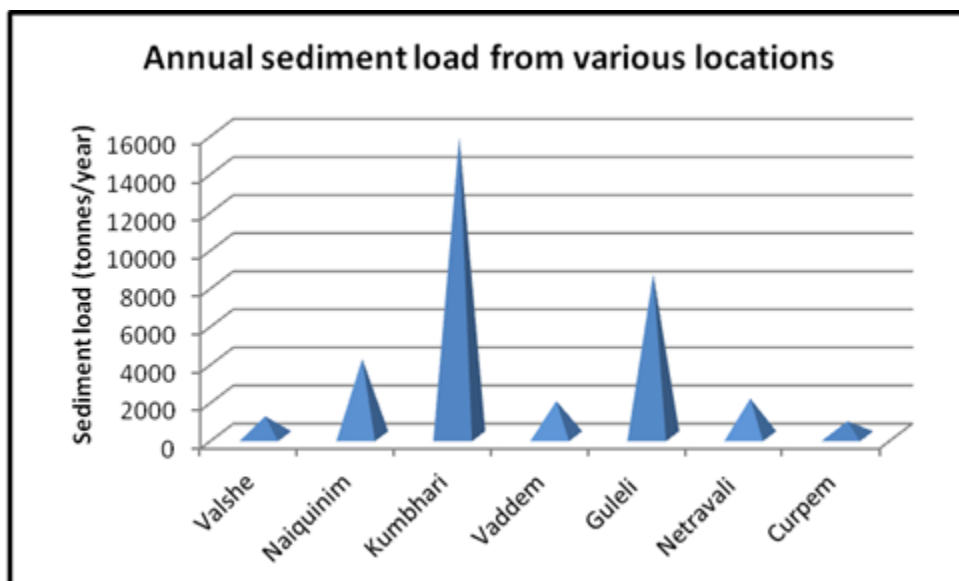


Figure 3.7: Annual sediment load across various monitoring stations

3.2 Groundwater

The human induced impacts on the groundwater regime can be evaluated by a comprehensive analysis and study of all the aspects of hydrogeology. The hydrogeological investigations are important facets of any groundwater management strategy. Groundwater balance is a book keeping of the total recharges and discharges from a groundwater regime during a given hydrological calendar year. The estimation provides information about the groundwater stress or availability status of groundwater in a watershed.

Objective

To carry out a hydrogeological study to evaluate the status of groundwater resources and estimate groundwater balance in the contributing watersheds of Salaulim reservoir. It also envisaged identifying mines and their impacts on local groundwater regime in terms of groundwater stress or availability status in the watersheds

Methodology

Groundwater balance was arrived at using water table fluctuation and rainfall infiltration factor methods. The step-wise approach that was used is as follows:

1. Survey of India (SoI) toposheets (1:25,000 scale) was procured. The drainage pattern & contour/ground elevation was studied and the watershed boundaries and areas contributing to the reservoir were demarcated.
2. Base maps (drainage) were prepared by scanning and then digitizing the maps. Digitization was done using DIDGER 3 software. Field visits were carried out for ground truthing. Main watersheds and sub-watersheds were identified. Watershed areas and drainage density was estimated. Topographical map for the study area was prepared and ground level gradient distribution was analysed to assess the aerial distribution of the rainfall infiltration potential in the watershed. Land-use and soil pattern was used to assess the areas of potential groundwater recharge.
3. Based on the size of the watershed, groundwater monitoring wells were established. Existing wells were used. Pre-Monsoon, monsoon and Post-monsoon water levels were measured. Other parameters that were measured include GPS coordinates of the wells, diameter of the wells, depth, static water level, geological information in terms of soil/rock strata, msl height of each monitoring station, measuring point height above ground.
4. These monitoring well stations were transferred on the digitized base maps after assigning identification numbers to each of them.
5. Rainfall data was collected from WRD for water balance computation. Other data like unit draft per groundwater abstraction structure were collected from CGWB. Domestic per capita use and water used by cattle was estimated based on field survey and literature review.
6. The number of operating mines in the region, their area and draft was collected from the Department of Mines & Geology and from the respective mining companies.
7. Pumping tests were carried out to estimate specific yield of the aquifer. Specific yield, water level fluctuation and watershed area are the basic inputs in the water balance equation. The watershed was classified into different categories depicting feasibility of rainfall recharge as per 1997 guidelines of Groundwater Estimation Committee, Government of India.

8. Flow-net analysis was carried out after completion of data collection for pre and post monsoon seasons using contour plotting software called SURFER.
9. Interpretation was done on groundwater recharge & discharge areas, groundwater level gradients and hydraulic conductivity variation. Based on the groundwater balance calculations, the watershed was categorized into class of groundwater development. (Groundwater classes are: Safe, partially exploited, over-exploited)
10. In order to overcome the complexities of representing the field situations in the hydrogeology component some assumptions were made which are (a) the aquifer in the study area is homogeneous and all the monitoring open wells tap the same aquifer (b) the topography is fairly uniform

3.2.1. HYDROGEOLOGICAL INVESTIGATIONS

Groundwater Monitoring Stations

For hydrogeological investigations monitoring of the groundwater levels at different locations in the watershed at different times is an essential data required for various calculations. Existing open wells tapping shallow groundwater were used for water level monitoring. Care was taken to represent the maximum possible area. However, in the dense forest areas existing open wells were not available.

In the present study, 66 groundwater monitoring wells were established out of which 19 were in Kumbhari, 39 were in Guleli and 8 were in Curpem watersheds. The water levels were measured during monsoon, post monsoon and pre monsoon seasons at all these wells. These sampling locations are shown in Figure 3.8. The other details such as village, shape, well diameter and use are given in Annexure IX. The watersheds are mainly mountainous and population density is very sparse therefore the wells were also rare to find. As seen from the map, the wells are concentrated only in the settlements zones and no wells were found in the forest area. In order to analyse the past trend in groundwater level, secondary data from Central Ground Water Board (CGWB) was collected for the stations lying within and close to the present study area. The location of these CGWB water level monitoring wells is shown in Figure 3.9. As shown in the figure, only two CGWB wells fall in the watershed.



Groundwater monitoring wells



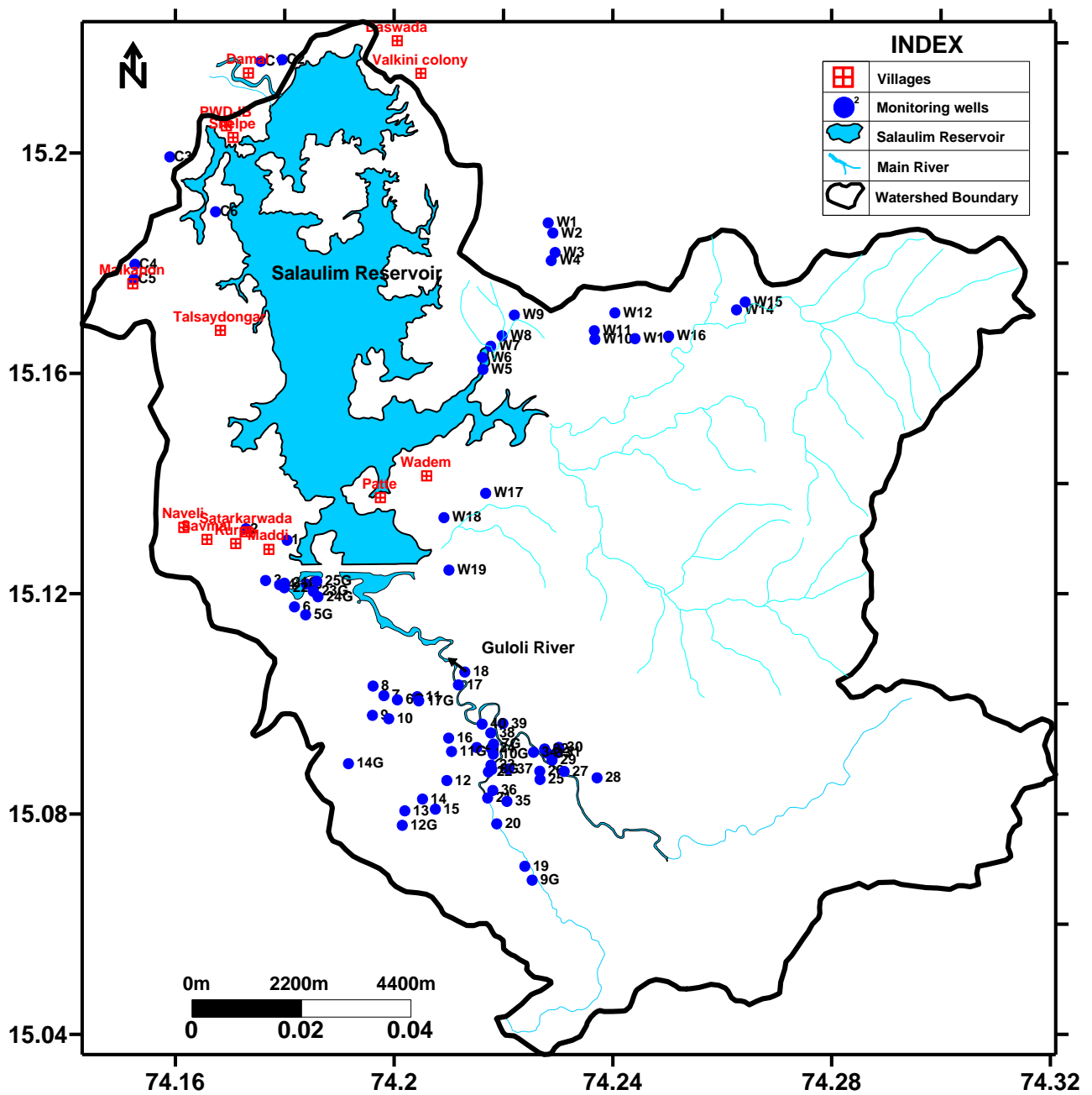


Figure 3.8: Map showing the location of groundwater monitoring wells

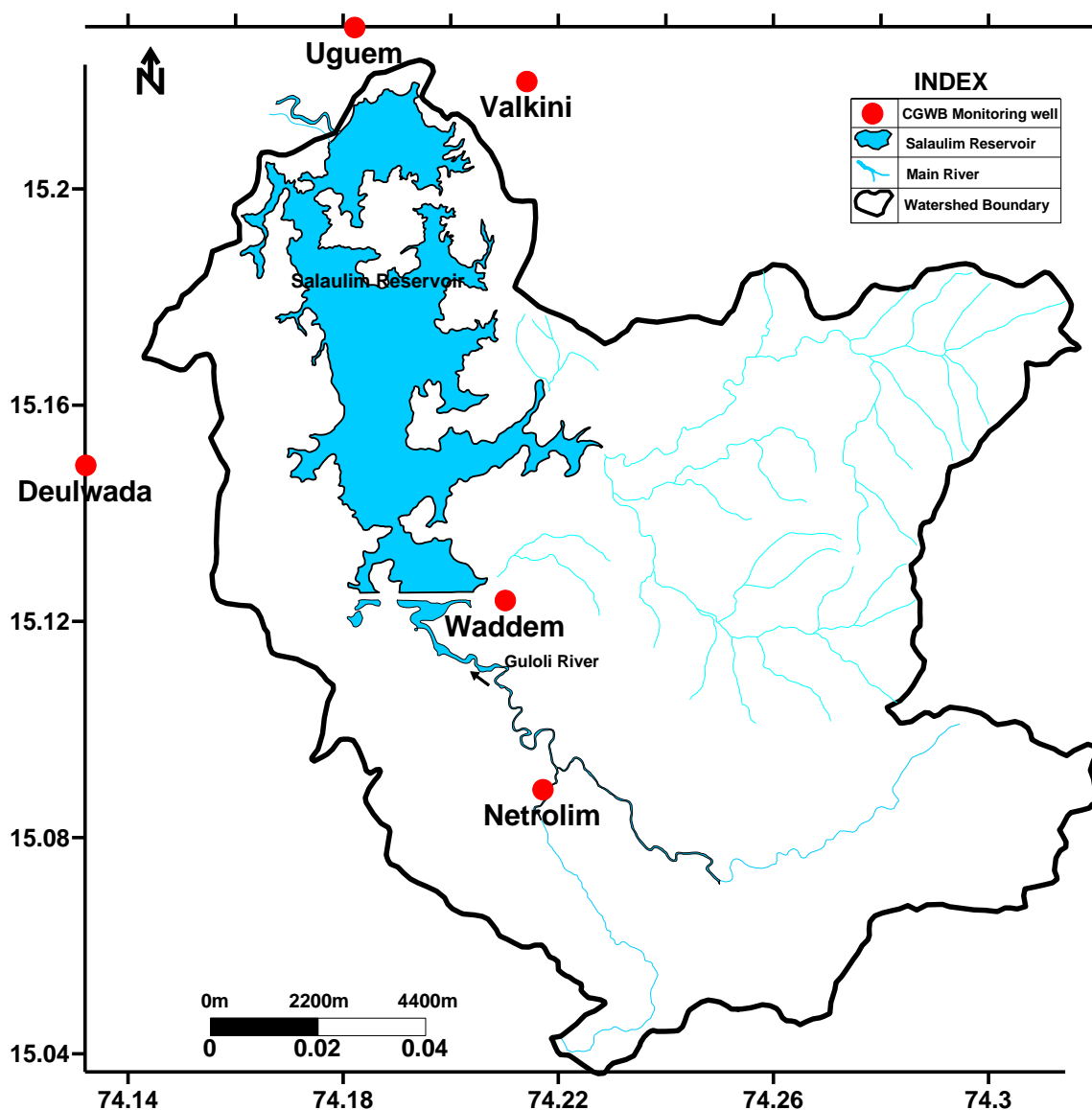


Figure 3.9: Location map showing CGWB monitoring stations in the watershed

Groundwater Data Collection

The groundwater level data (below ground) was collected for 3 seasons i.e. pre monsoon, monsoon and post monsoon seasons during 2011-12. The monitored groundwater levels at the wells in Guleli, Kumbhari and Curpem watersheds are shown in Figure 3.10, 3.11, 3.12 respectively. The average water level fluctuation (between pre-monsoon and post-monsoon) was found to be 1.06, 0.97 and 1.14 m for the wells in Guleli, Kumbhari and Curpem watersheds respectively. The mean sea elevation of the ground surface at the site of monitoring wells was derived both from GPS as well as from Survey of India topographical maps. In the study area the open wells exist in and around the settlements only. Therefore the monitoring well distribution in the entire study area is concentrated around the settlements. The open wells generally tap shallow unconfined aquifers made up of laterites and alluvium. The water levels are generally shallow and the depths of wells are less than 10m below ground. The data on latitude, longitude, well diameter, total well depth, and measuring point height was recorded during the field studies.

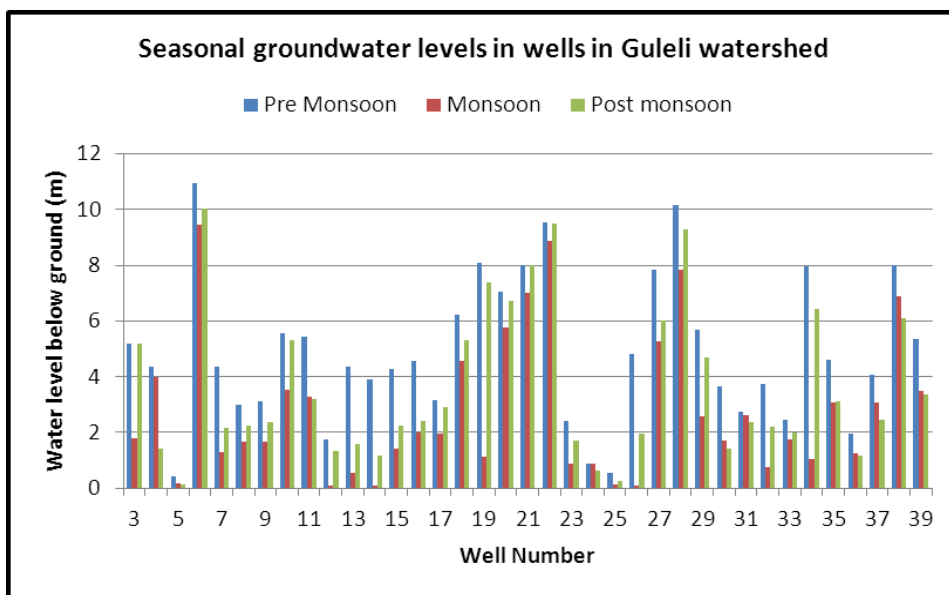


Figure 3.10: Groundwater levels in three seasons in Guleli watershed

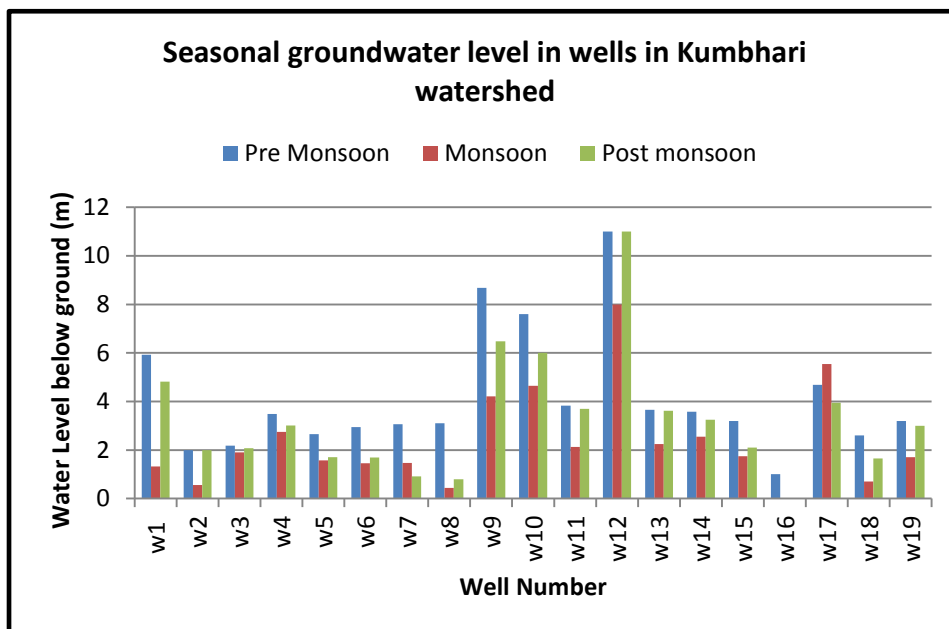


Figure 3.11: Groundwater levels in three seasons in Kumbhari watershed

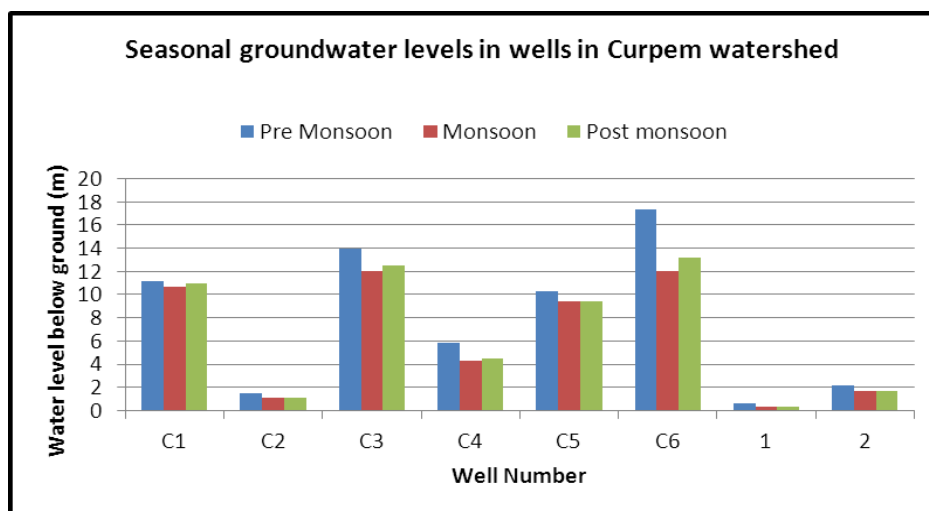


Figure 3.12: Groundwater levels in three seasons in Curpem watershed

Groundwater Flow net Construction and Analysis

A flow net is a sketched representation of the flow paths taken by water molecules through the subsurface. The “grid” of a flow-net is comprised of flow-lines (idealized paths followed by water molecules in moving from position of high hydraulic gradient to those of low head represented by smooth curves at right angles to equipotential lines) and equipotential lines (lines along which the hydraulic head is equal). Flow-net is a very powerful analytical tool for studying the groundwater behaviour. Flow-nets may be constructed by a number of procedures including trial-error sketching; physical modelling, electrical analog method, and computer assisted mathematical modelling.

In the present study computer assisted flow-net sketching was adopted using SURFER 7.0. The input to the program included X and Y co-ordinates of the observation wells and the z coordinate representing water level data above msl, depth to water level below ground and water level fluctuation. Kriging technique was used for plotting various equipotential contours as it was found that it is the best-fit method for plotting of smooth contours.

In order to understand the dynamics of groundwater movement and occurrence, it is necessary to construct flow nets for different seasons. In the present study the groundwater flow nets were constructed for three seasons of pre monsoon, monsoon and post monsoon for each of the watersheds. As the groundwater basin generally coincides with the surface water basin particularly in hard rock areas the flow net construction and other related maps have been prepared separately for each sub-basin. The flow nets for the study area during pre-monsoon season for Guleli, Kumbhari and Curpem watersheds are given in Figures 3.13, 3.14 and 3.15 respectively. These groundwater flow nets are approximate representations of the actual field condition.

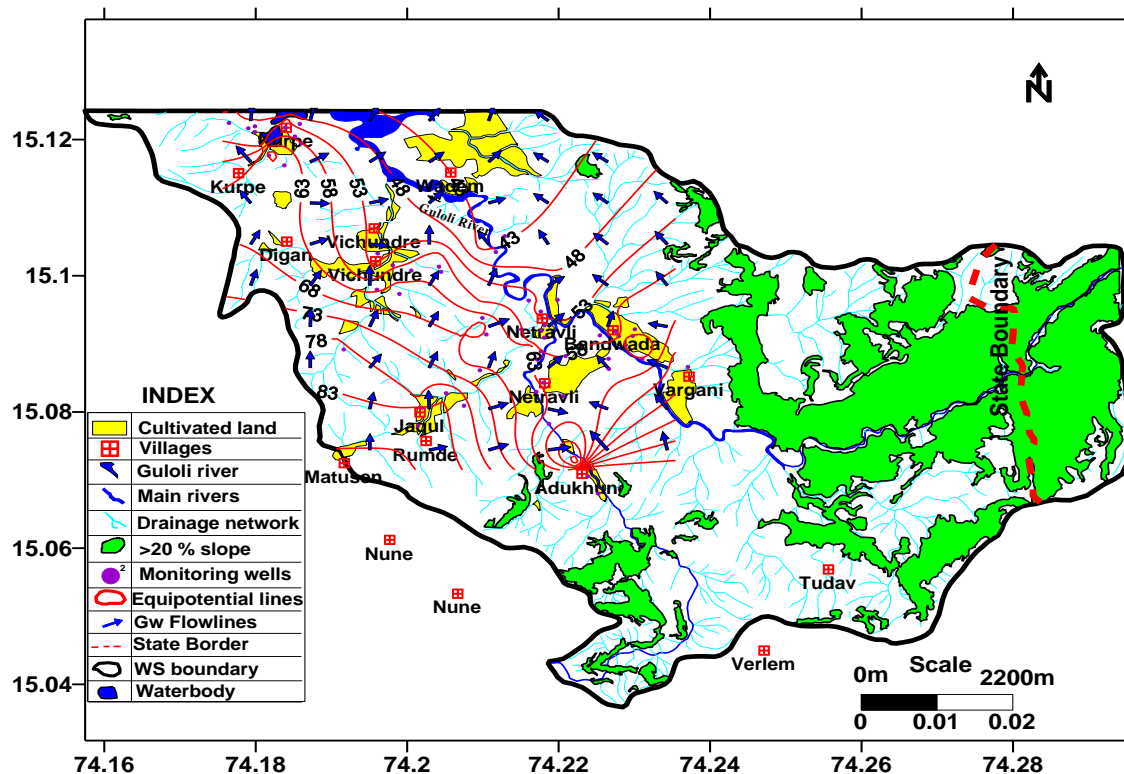


Figure 3.13: Groundwater flow net during pre-monsoon season in Guleli watershed

Groundwater seepage into a stream or a river is called *baseflow*. A river is called as ‘effluent’ when it receives groundwater and ‘influent’ when the river water is discharged into groundwater. As seen from the above figure (3.13) the groundwater mostly follows the ground topography. Flow of groundwater is generally northwest and in north east directions. Guleli river receives groundwater in the western side making it effluent in nature even during pre-monsoon season. Downstream in northeast the river behaves as influent in nature. The groundwater level gradients were moderate and so was the hydraulic conductivity of the saturated zone. Many of agricultural lands receive groundwater flow from the base of the hills for summer cultivation of crops. The hilly areas act as main groundwater recharge zones as seen from the flow lines. At Adkune south of Netravli a small groundwater trough has developed. Otherwise there are no major troughs and groundwater mounds in the area.

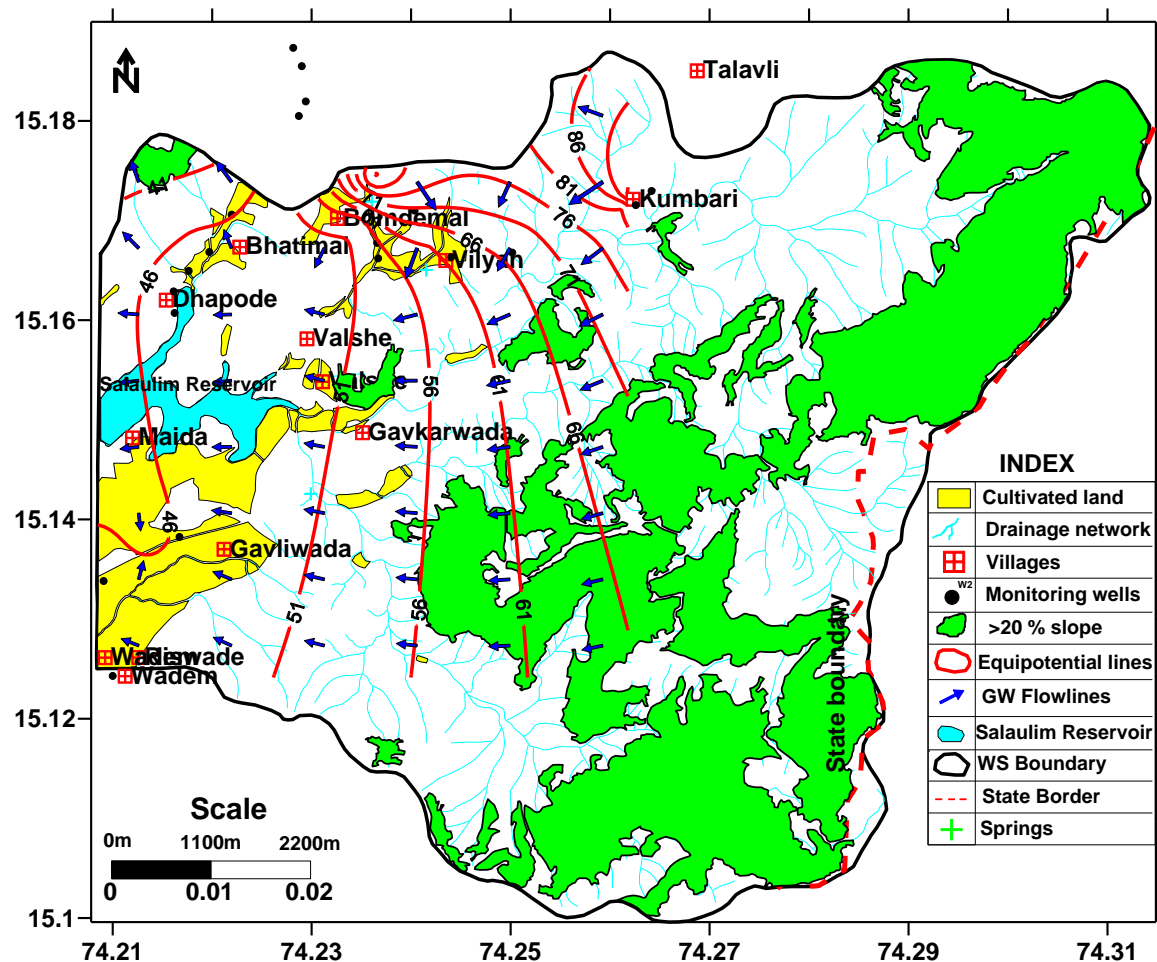


Figure 3.14: Groundwater flow net for pre monsoon season in Kumbhari watershed

The groundwater mostly follows the ground topography in Kumbhari watershed (Figure 3.14) with the flow towards west. Salaulim reservoir receives groundwater from the eastern side making it effluent in nature even during pre-monsoon season. The groundwater level gradients were low to moderate and so was the hydraulic conductivity of the saturated zone. In the north central part, steep hydraulic gradients were seen. Many of agricultural lands receive groundwater flow from the base of the hills for summer cultivation of crops especially around Waddem and Gavliwada villages. The hilly areas act as main groundwater recharge zones as seen from the flow lines. There are no major troughs and groundwater mounds in the area.

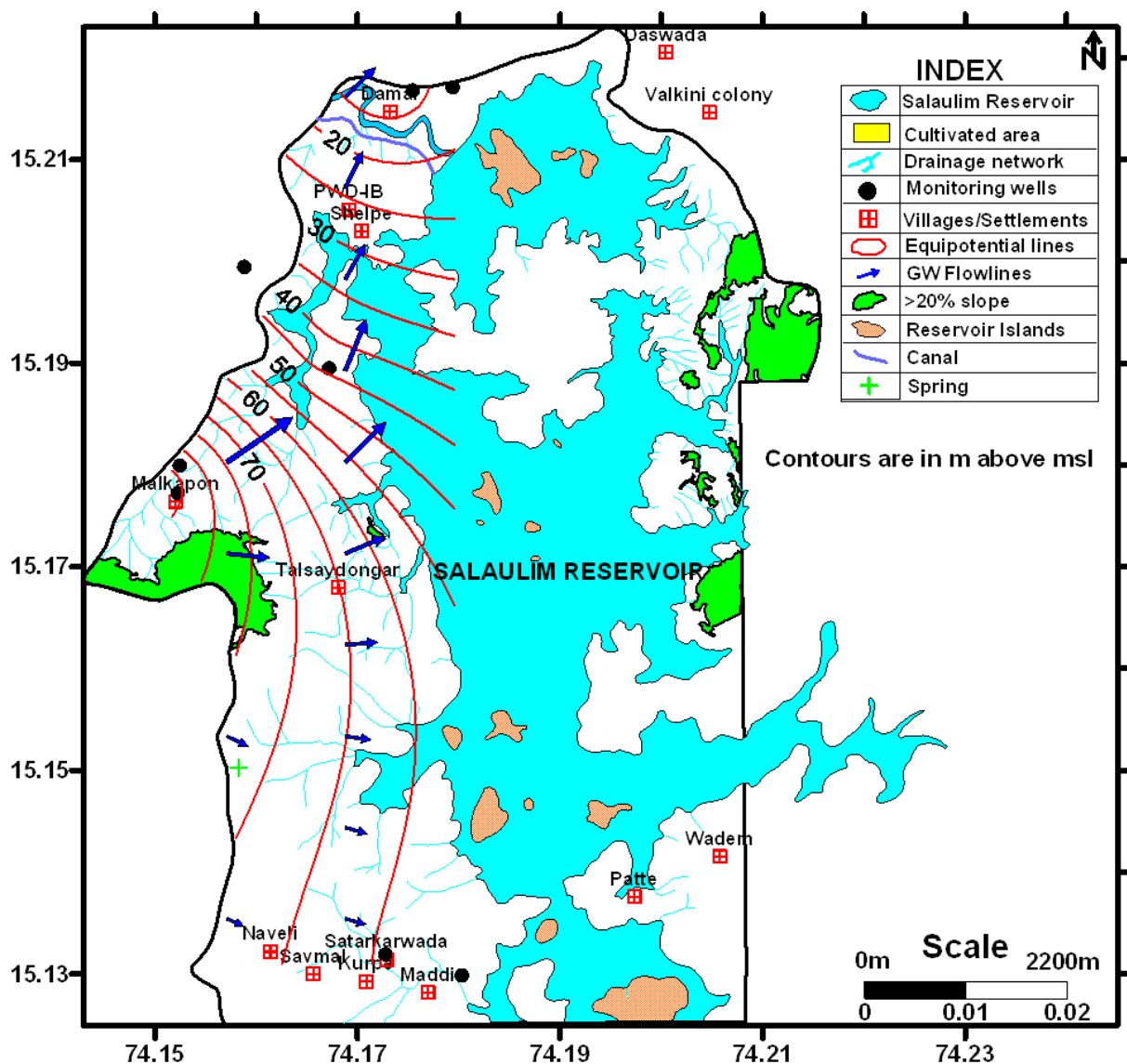


Figure 3.15: Groundwater flow net for pre monsoon season in Curpem watershed

In case of Curpem watershed (Figure 3.15), the groundwater flow mostly follows the ground topography and is in the east direction towards Salaulim Reservoir. Salaulim reservoir receives groundwater in the western side making it effluent in nature even during pre-monsoon season. The groundwater level gradients were low to moderate along with the hydraulic conductivity of the saturated zone. The hilly areas act as main groundwater recharge zones as seen from the flow lines. There are no groundwater troughs and mounds in the area.

The groundwater flow net pattern remain almost identical during monsoon and post-monsoon seasons with minor changes for all the watersheds and therefore these flow net maps have not been given here to optimize space.

Depth to Groundwater Level Analysis in the Study Area

The depths to groundwater levels below the ground surface are the simplest and interesting observations that can be made in the field. These observations indicate the status of potential aquifers at shallow depths. The depths vary from season to season on both short term and long term basis. Under natural conditions the water level variations in different seasons are under dynamic equilibrium. However, any anthropogenic stress on the groundwater regime will be reflected in changing trend in the water levels over a period of time. If the depths to water levels are shallower then it is easier to develop the resource. In the present study the depth to groundwater levels for pre monsoon season for all the three watersheds i.e. Gulelim, Kumbhari and Curpem watersheds are given in Figures 3.16, 3.17 and 3.18 respectively.

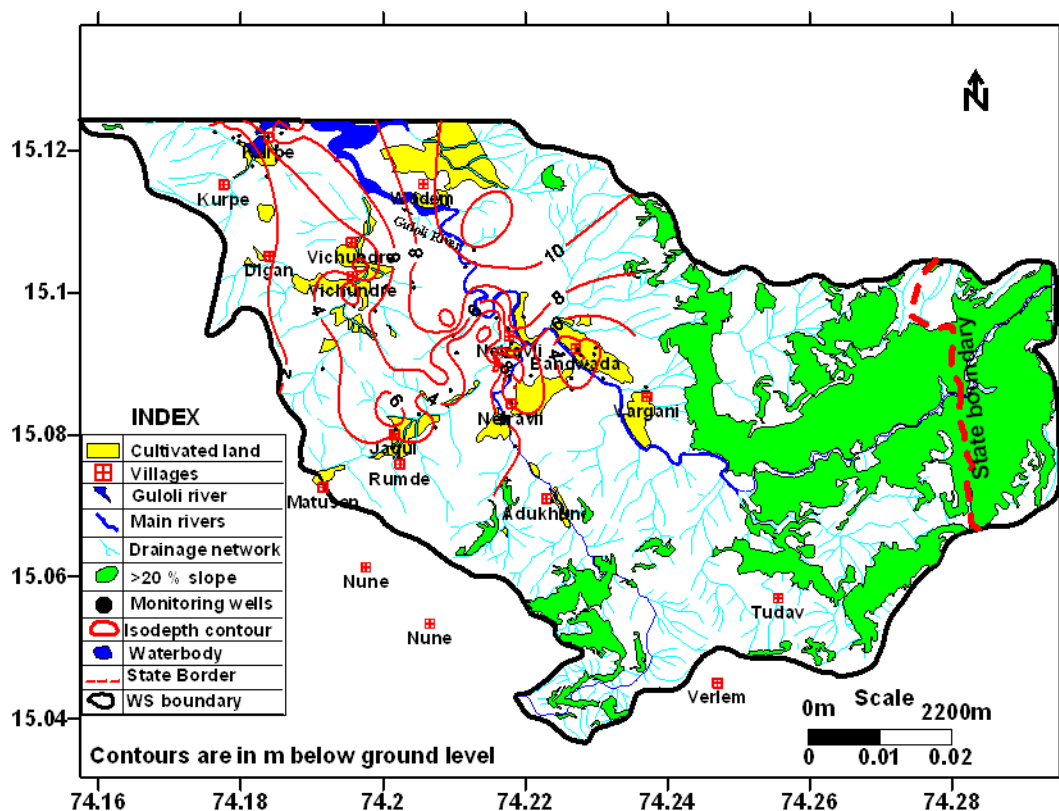


Figure 3.16: Map showing pre monsoon depth to groundwater levels in wells in Guleli watershed

As seen from the map the shallow to very shallow water table depths are seen around Netravali village and Curpem village. The depths are fairly more around the Waddem area. Similarly in the Kumbhari watershed the depth are more around Bomdemal in the north central part of the area as shown in Figure 3.17. Depths are shallow around Gavliwada village. The groundwater levels progressively increase in depth from south to northwards in Curpem area and become deepest between Malcozona and Shelpe villages as shown in Figure 3.18. The depth to water level maps have also been prepared for monsoon and post monsoon periods however these are not included in the report for optimization of the report volume.

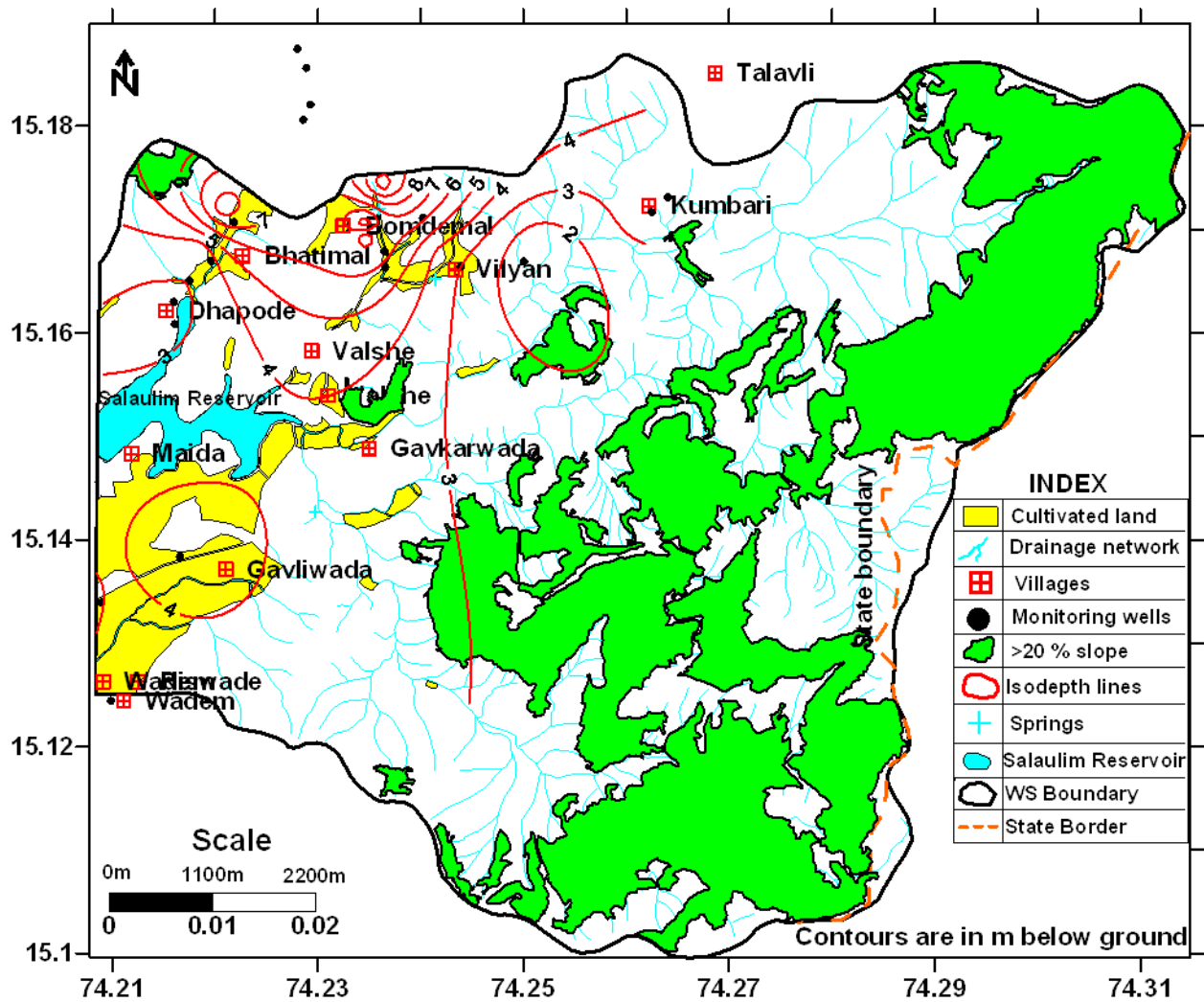


Figure 3.17: Map showing pre monsoon depth to groundwater levels in wells in Kumbhari watershed

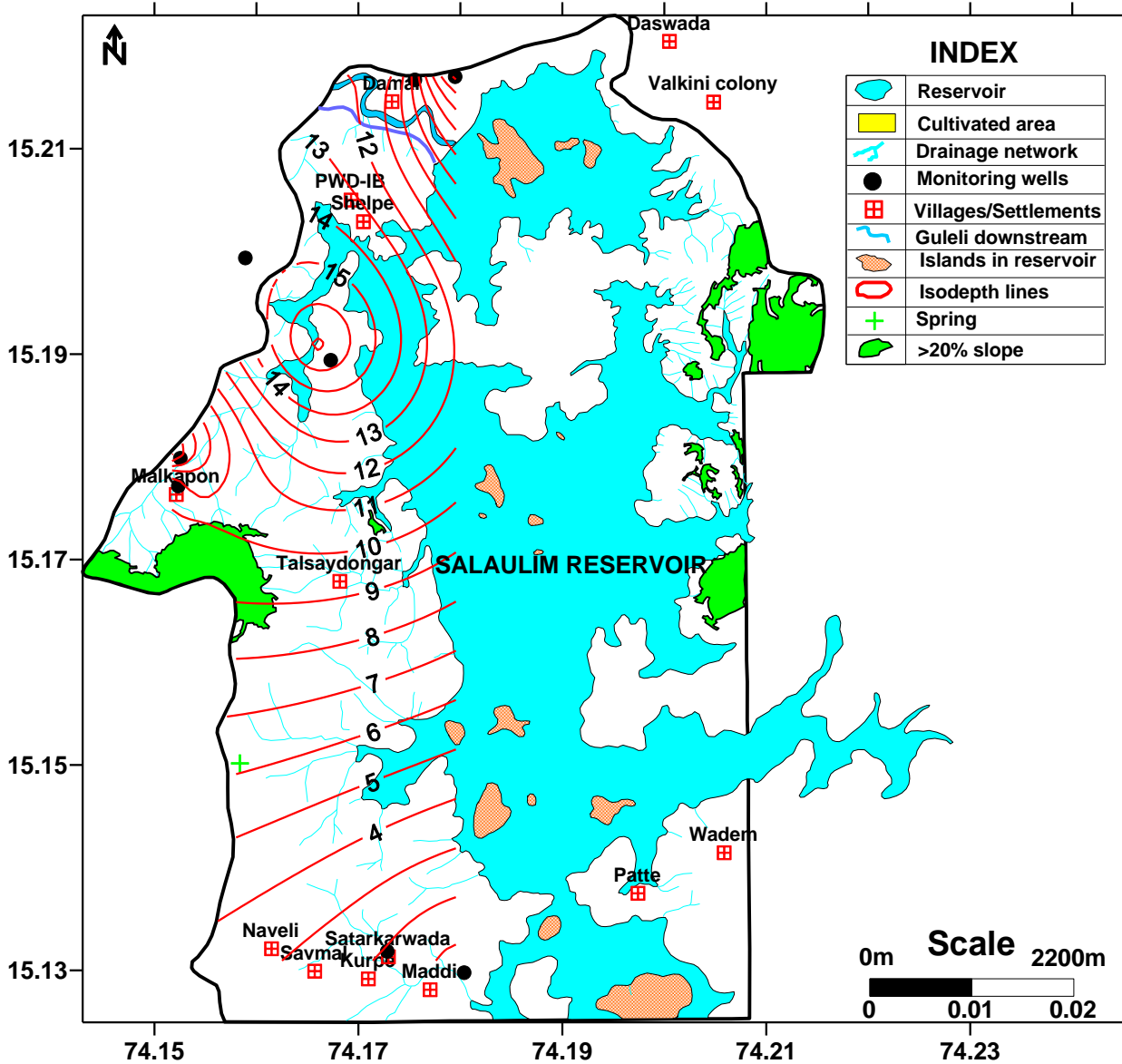


Figure 3.18: Map showing pre monsoon depth to groundwater levels in wells in Curpem watershed

Water Table Fluctuation Maps and Analysis

The computed difference in the water levels in wells measured during May and November of a given hydrological year is termed as water table fluctuation. The magnitude of this fluctuation depends on several variables like rainfall, groundwater pumping in the area, natural out flows, artificial recharges, land use changes etc. Therefore long term measurement of this fluctuation at a point would provide important information. In the groundwater recharge computation the value of water table fluctuation plays an important role. The magnitude of groundwater level fluctuation is an indicator of quantum of groundwater recharge from rainfall. Lower magnitude fluctuations are indicative of low groundwater recharge and vice versa.

In the present study the water table fluctuation have been calculated and presented for all the three watersheds in Figures 3.19, 3.20 and 3.21 respectively for Guleli, Kumbhari and

Curpem watersheds. As seen in Figs. 3.19 and 3.20 the groundwater table show moderate fluctuation in these watersheds indicating low rainfall recharge in general. In Curpem watershed the fluctuations are quite large at one location between Malcozona and Shelpem. This may be due to active mining activities in the area. In rest of the area the water table fluctuations are again low to moderate. Therefore in general the rainfall recharge in the low lying plain areas in Salaulim watershed should be considered as low. This could be due to shallow water table conditions as seen from the depth to water level maps.

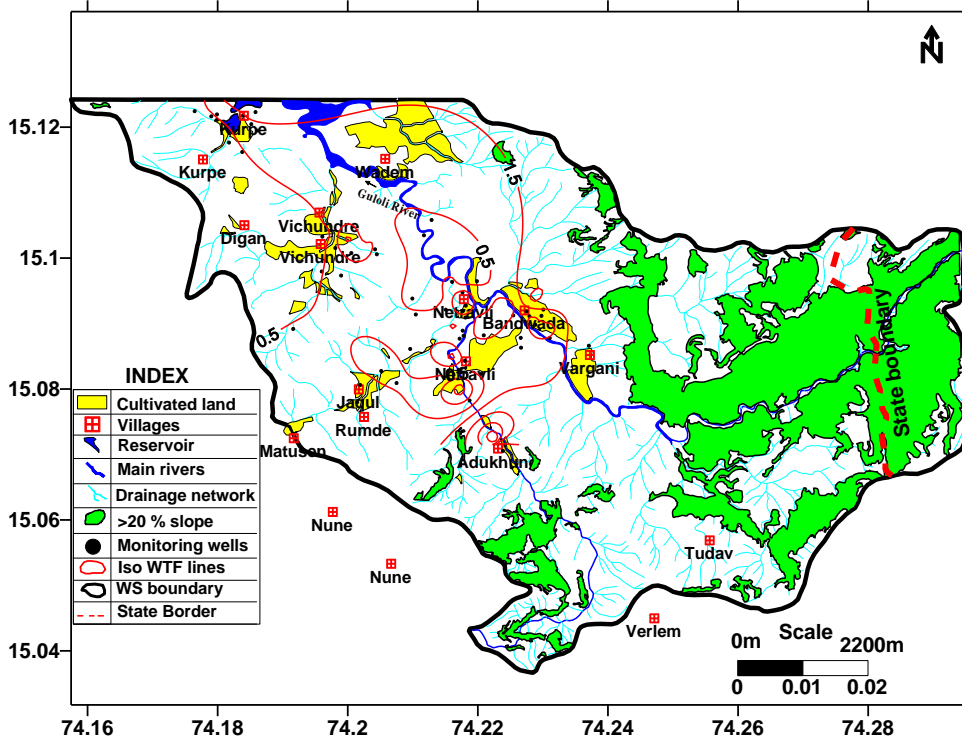


Figure 3.19: Groundwater level fluctuation in Guleli watershed

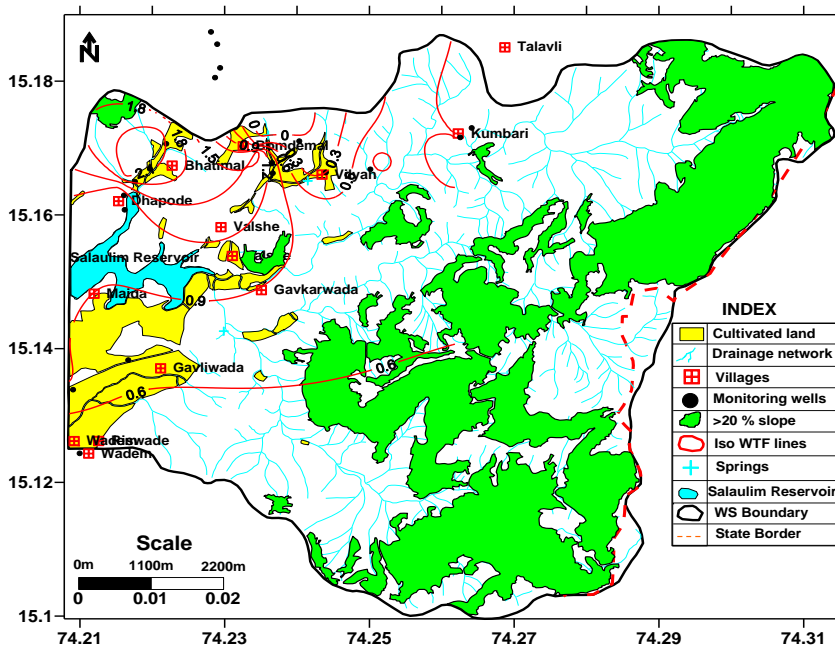


Figure 3.20: Groundwater level fluctuation in Kumbhari watershed

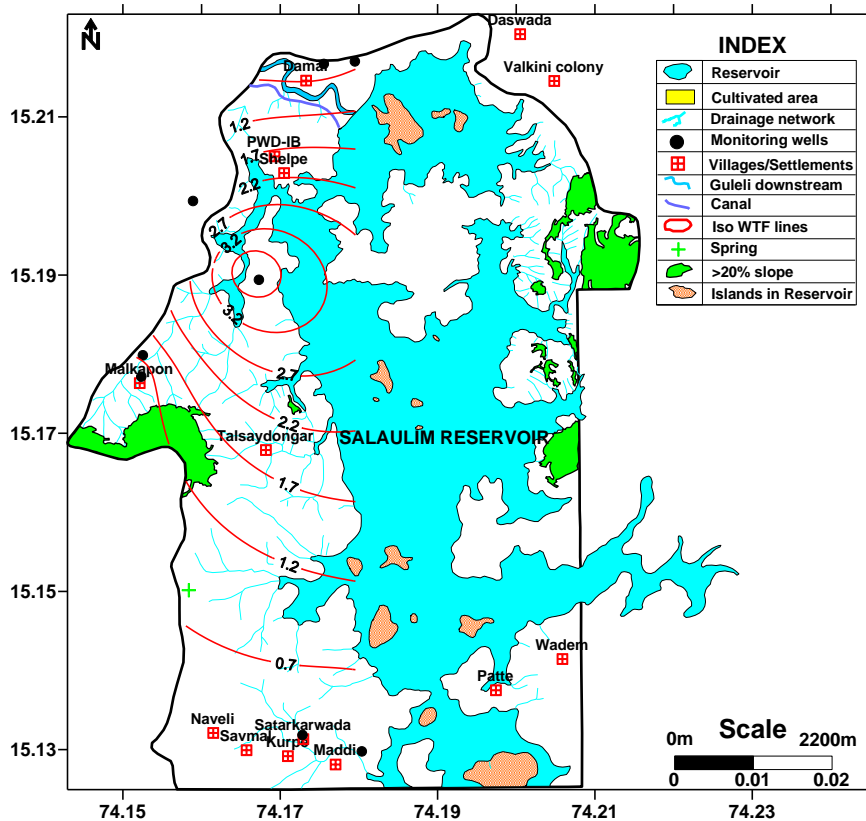


Figure 3.21: Groundwater level fluctuation in Curpem watershed

Water Column in Wells during Summer Months

It is interesting to evaluate and understand the variation in the thickness of water column in the open wells which indicate the thickness of available saturated zone assuming that all the wells tap the entire aquifer thickness. Smaller water column during summer months may be indicative of little or no groundwater storage available and vice versa. Therefore efforts are made in the present study to map and evaluate the variation in this water column in the study area and comment on the areas of potentiality of groundwater. The maps showing water column thickness variation in the watershed are shown in Figures 3.22, 3.23 and 3.24 respectively for Guleli, Kumbhari and Curpem watersheds.

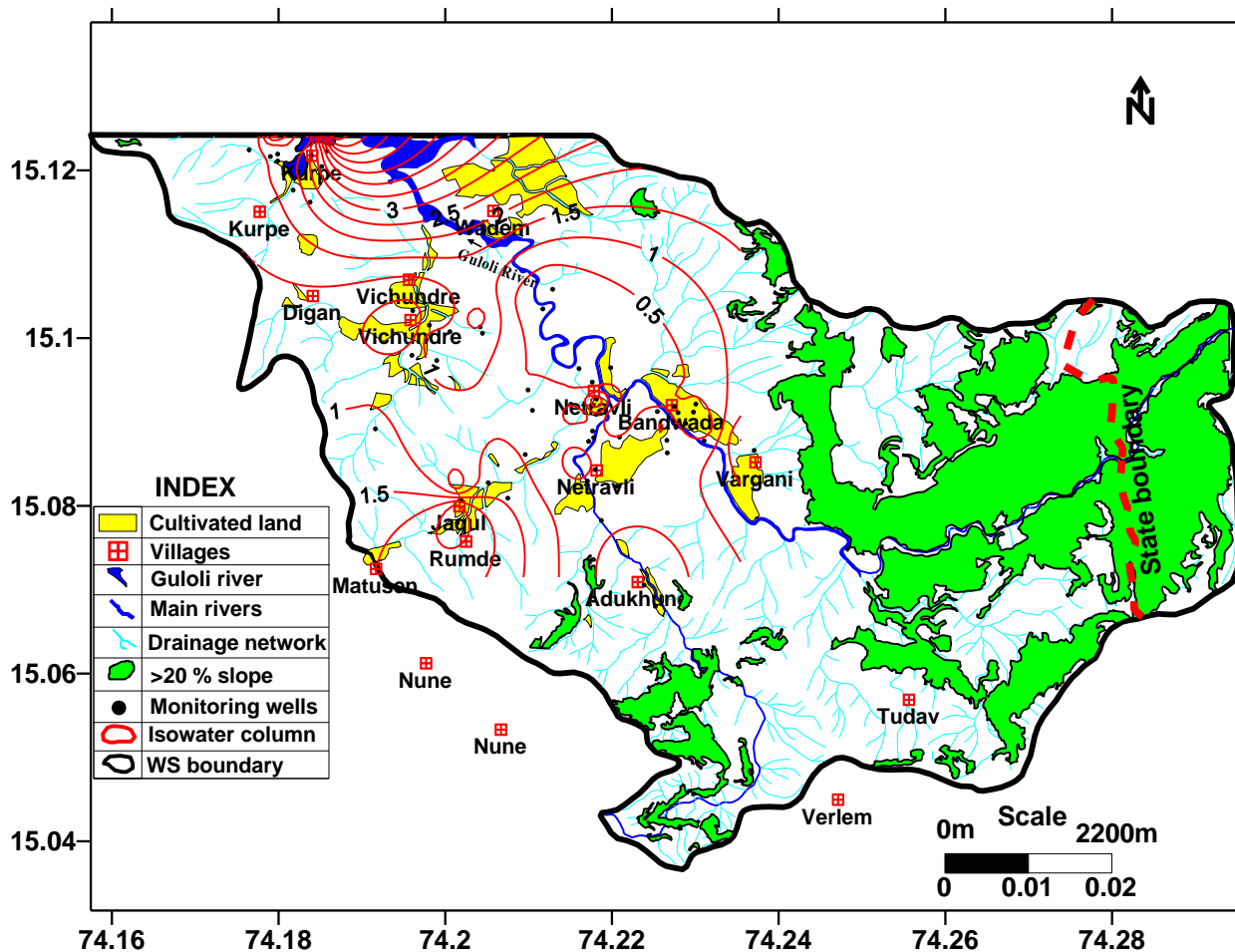


Figure 3.22: Variation of summer season groundwater column thickness in the Guleli watershed

As seen from the above figure the water column thickness around Netravali area is less than 0.5m indicating that the groundwater availability is low in the area. Whereas in rest of the area the thickness is quite good and it increases towards the northern side and downstream areas around Wadem. The water column thickness in Kumbhari watershed as seen in Figure 3.23 is quite good except around Bomdemal. The western part of the area show more than 5m of water column in wells. Therefore the groundwater availability in this basin seems to be good. In Curpem watershed seen in figure 3.24 the water column thickness is quite low between Malcozona and Shelpem villages where maximum rainfall recharge takes as seen in the water table fluctuation map. It seems that the groundwater either drains faster from this area or it is withdrawn artificially.

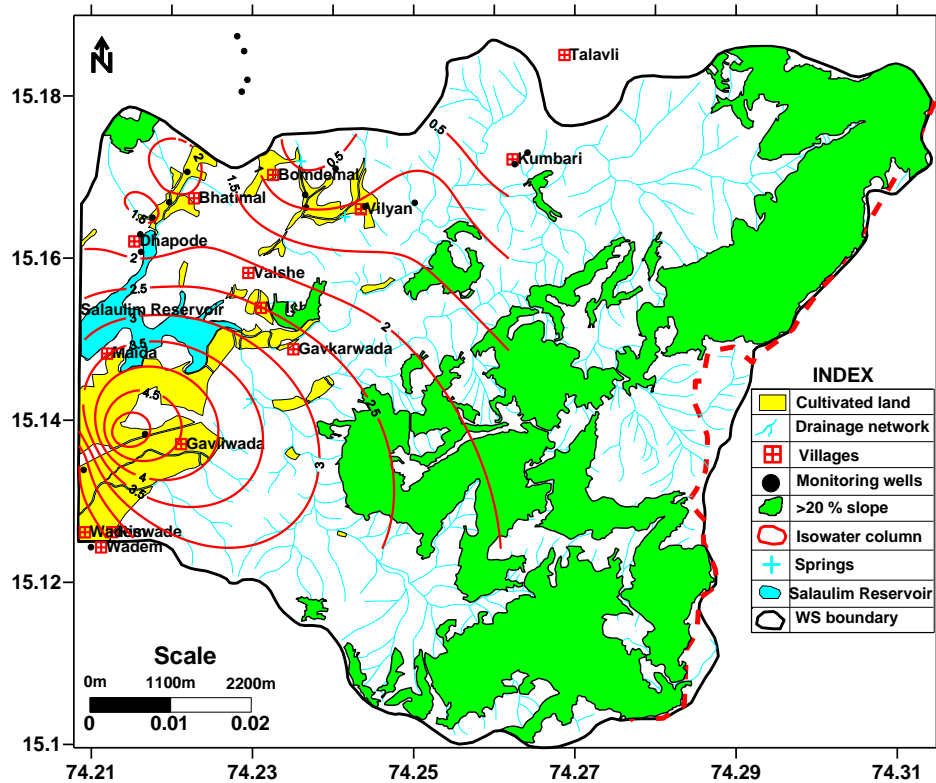


Figure 3.23: Variation of summer season groundwater column thickness in the Kumbhari watershed

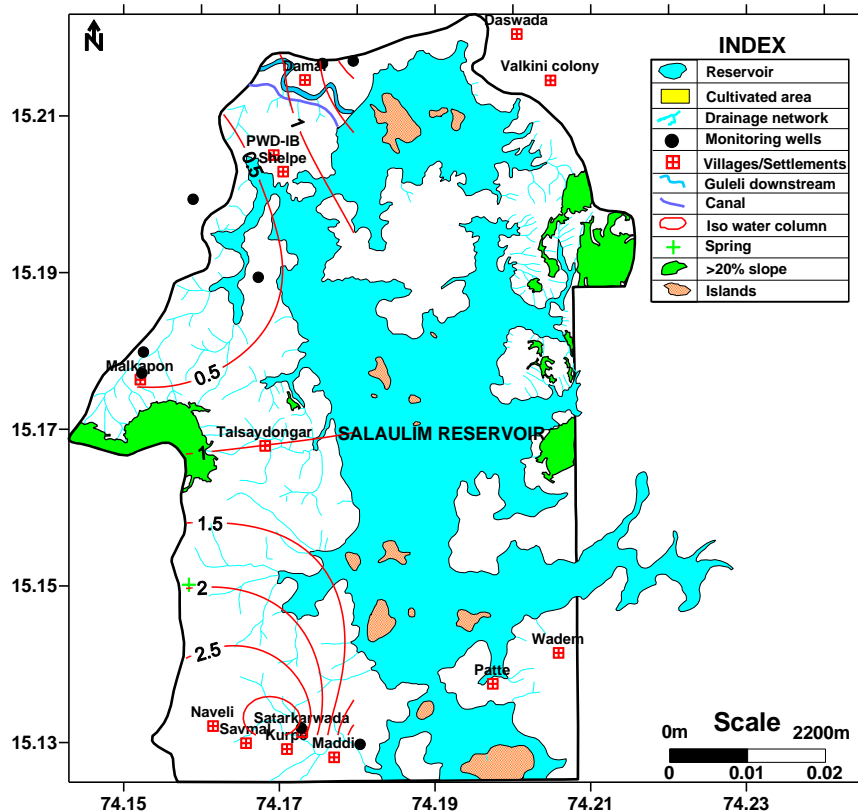


Figure 3.24: Variation of summer season groundwater column thickness in the Curpem watershed

Variation in Total Well Depths of Open Wells in the Study Area

The general observation of the variation in total depths of open wells in an area gives fairly good idea of the general depth of the shallow saturated zone. In the study area the maps showing the variation of total well depths recorded is plotted as contours and is shown in Figures 3.25, 3.26 and 3.27 respectively for Guleli, Kumbhari and Curpem watersheds. The variation of total well depth in Guleli watershed as shown in figure 3.25 indicate that well depths are more in the northeastern part of the area compared to western sides. Similarly around Netravali village the depth are shallow which could be the reason for smaller water column during summer months as indicated earlier. In figure 3.26 the well depth variation in Kumbhari watershed also indicates that greater depth areas coincide with the larger water column depth zones. Therefore the areas with small water column in summer season seem to suffer from partial penetration of saturated zone by the wells in those areas.

It is interesting to note that in Curpem watershed the deep wells are present in the area where water column thickness is found to be low during summer unlike other two watersheds discussed above and there is maximum rainfall recharge in this zone as witnessed from the water table fluctuation map of the area.

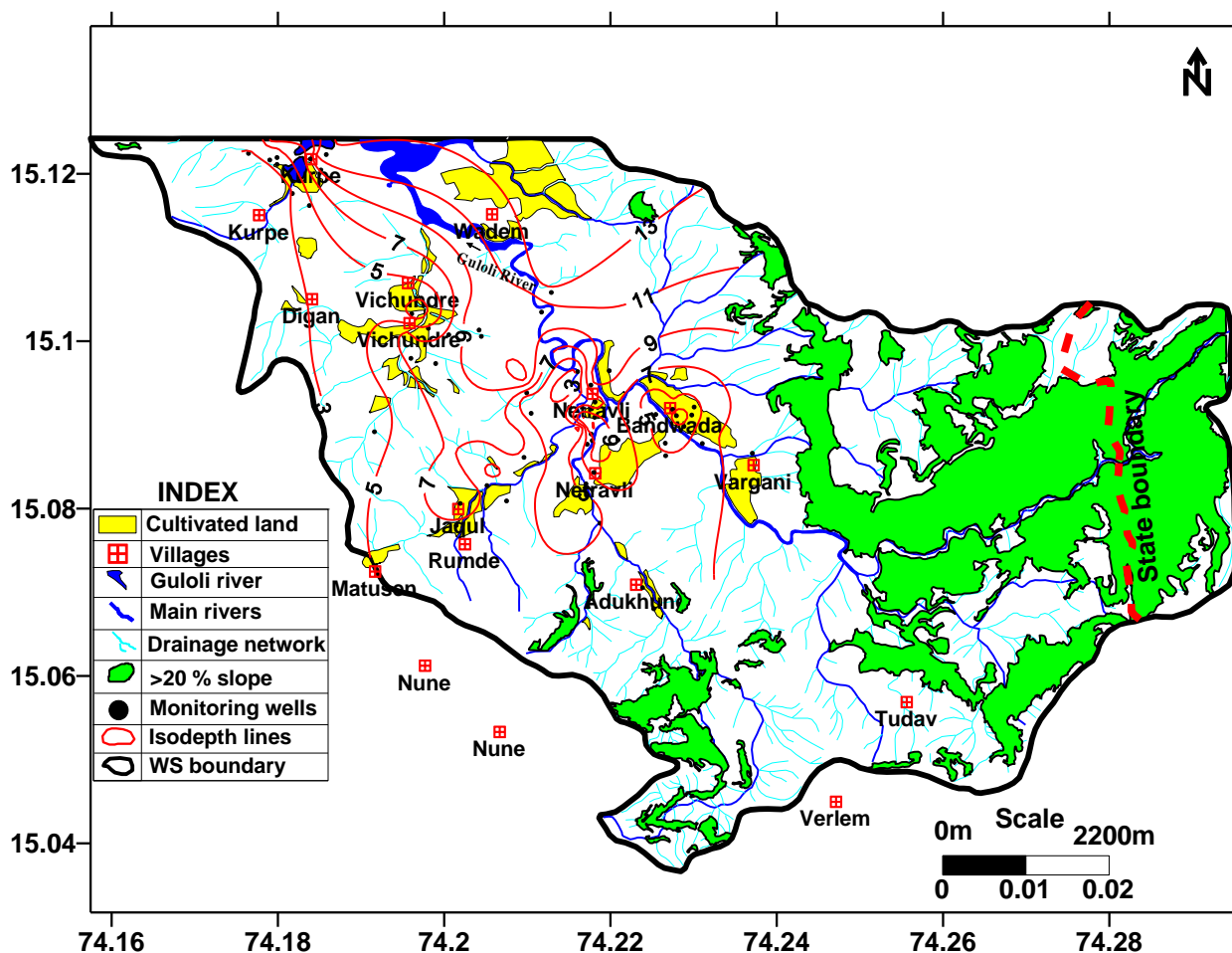


Figure 3.25: Variation in total well depths in Guleli watershed

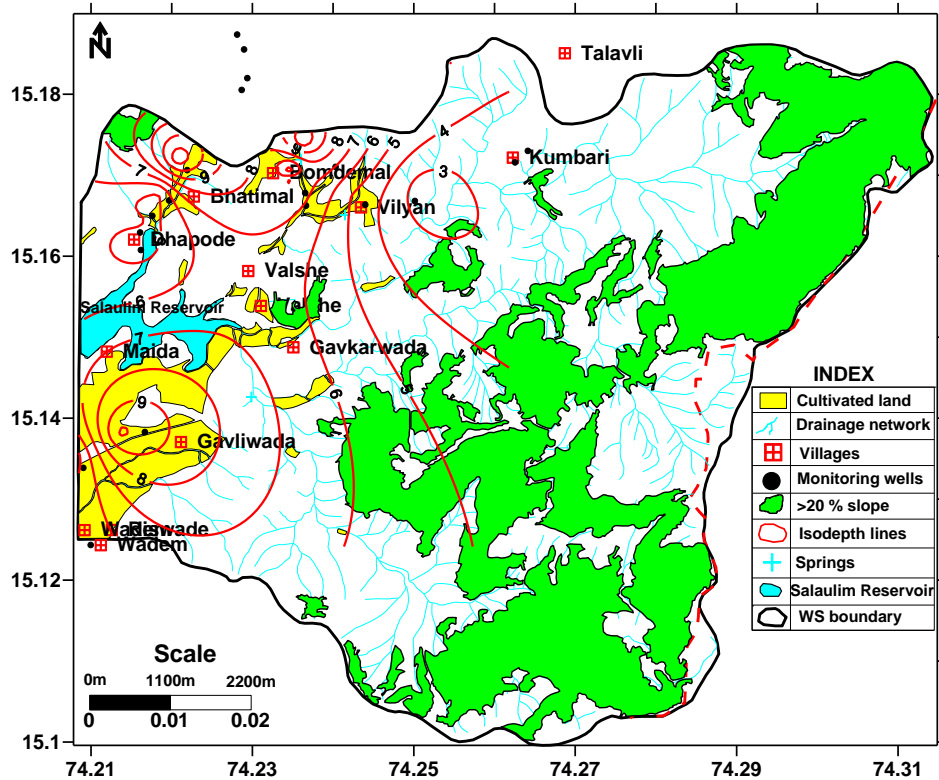


Figure 3.26: Variation in total well depths in Kumbhari watershed

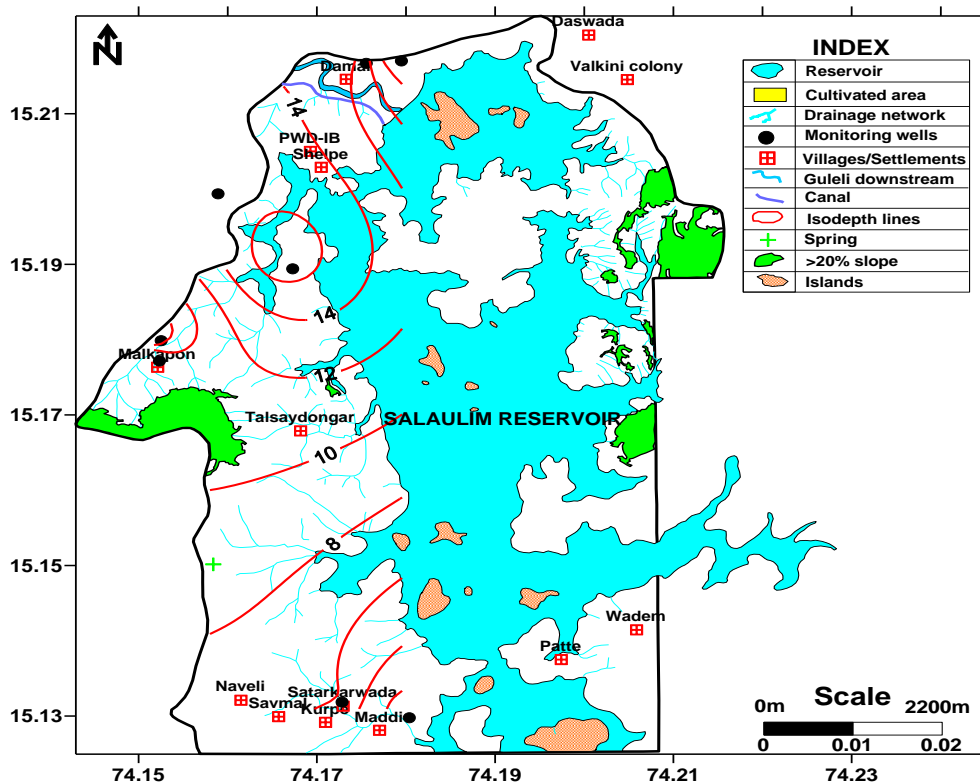


Figure 3.27: Variation in total well depths in Curpem watershed

Groundwater Level Hydrograph Trend Analysis

Long term and regular records of groundwater levels at a point provide temporal variations in the groundwater levels. The temporal groundwater level variations can be classified as due to natural cause, anthropogenic cause or combination of both the causes. In order to assess the nature of the cause in water level changes over a long period of time one can plot the water levels with time and assess the trends. In the present study, five water level recording points of Central Ground Water Board (CGWB) have been identified and water level data for last five years was collected from CGWB. The five sites identified are Waddem, Netrolim, Uguem, Valkini, and Deulwada. The details are given in Table 3.3. The location of the monitoring wells is shown in Figure 3.9. Only first two sites were found to fall within the present study area and consistent data was not available for Waddem. The well hydrographs were plotted along with the corresponding rainfall data. The well hydrographs for open wells located at Netrolim and Deulwada are shown in Figure 3.28 and 3.29 respectively.

Table 3.3: Details of the groundwater monitoring wells by CGWB in the study area

S.no.	Location	Latitude	Longitude	Well no.	Well type	Well depth(m)	Record date
1	Waddem	15 07 27	74 12 37	48I4A8	Bore well	24.45	Jan 2007 to May 2011
2	Netrolim	15 05 22	74 13 00	48I4A9	Dug well	11.42	Jan 2007 to Nov 2011
3	Uguem	15 13 47	74 10 55	48I4A2	Bore well	49.80	Jan 2007
4	Valkini	15 13 12	74 12 53	48I4A3	Bore well	26.30	May 2007 to May 2008
5	Deulwada	15 08 56	74 07 55	48I4A7	Dug well	04.52	Jan 2007 to Nov 2011

It is seen from the figures that within the study area the Netrolim well hydrograph does not show any decreasing trend whereas the well hydrograph at Deulwada located outside the study area in the western part does show decreasing ground water level trend. The analysis of the bore well hydrographs located at three other sites did not show any decreasing trends.

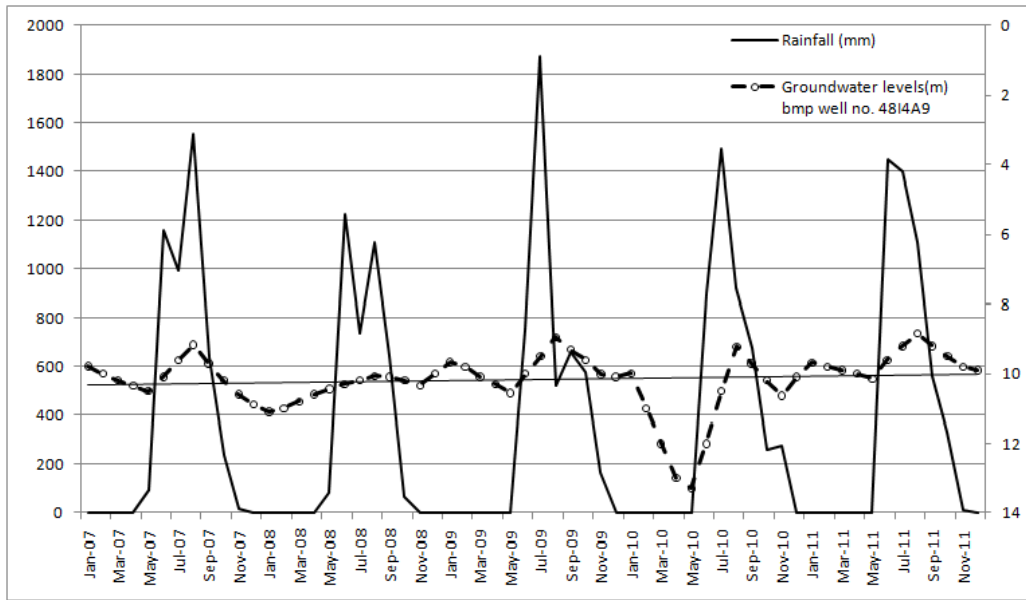


Figure 3.28: Well hydrograph at Netrolim site

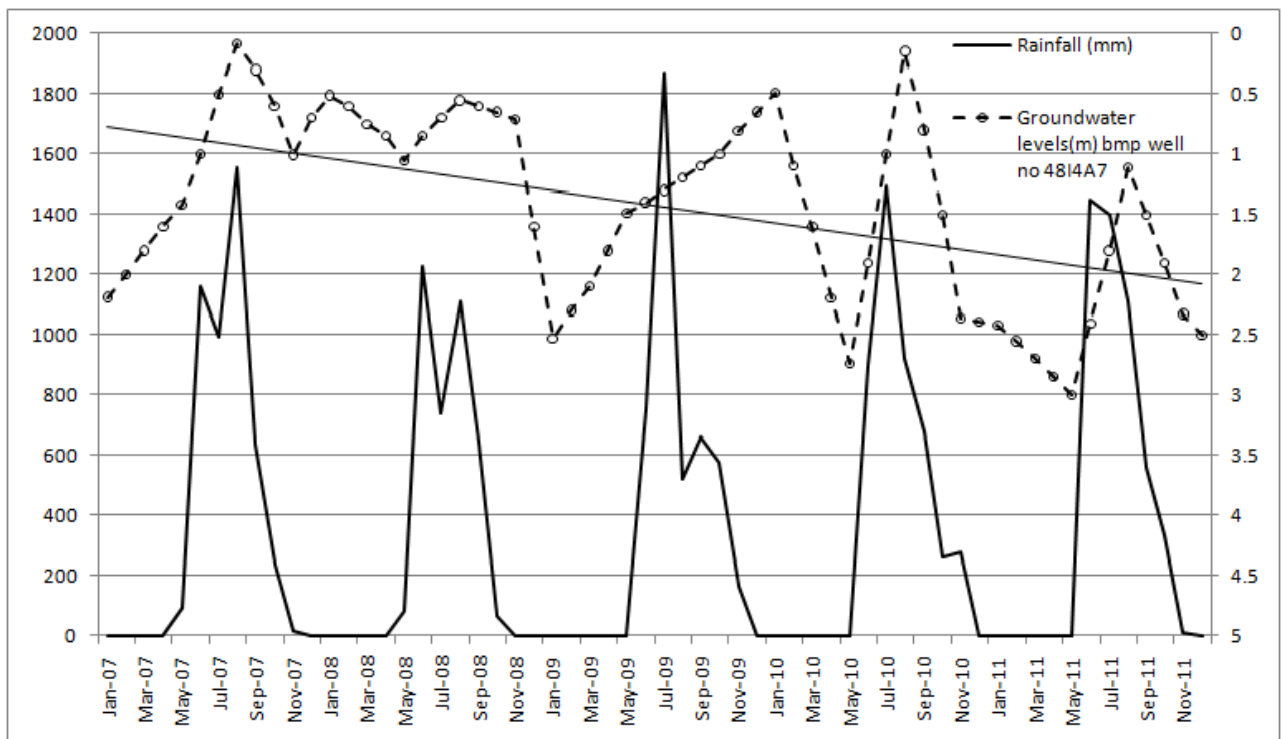


Figure 3.29: Well hydrograph at Deulwada site

Aquifer Tests in the Study Area

Aquifer parameters like transmissivity, storativity and hydraulic conductivity computed using the data collected through aquifer performance tests are generally considered as point values and they vary largely in hard rock and lateritic terrain due to rapid changes in the degree of weathering and fracturing (Stallman, 1971). Aquifer tests have been conducted at two different locations in the study area in order to estimate the aquifer transmissivity,

storativity and hydraulic conductivity to determine how much groundwater can be safely withdrawn perennially from the aquifers. The description of the data collection and analysis is described in the next section.

Field data

It is generally difficult to convince the well owners for conducting the pumping tests because they feel this will empty their well and water will never come back. However, in the present study two wells were identified typically in a lateritic terrain to carry out the pumping tests. These wells were open shallow dug wells. The aquifer was made of laterite with some degree of fracturing and weathering. The drawdown and recoveries in the pumped wells were recorded using the tape with millimetre division and a digital watch (Table 3.4). The plots of field data and interpreted results are shown in Figures 3.30 and 3.31. The aquifer parameters determined are given in the following Table 3.5.

Table 3.4: Field data of pumping tests carried in the study area

Well 6T (Neturlim)		Well 14D (Curpem)	
Time (sec)	Drawdown (cms)	Time (sec)	Drawdown (cms)
20	0.2	30	0.5
35	0.35	50	0.7
45	0.65	71	1
76	1	101	2
130	3	121	3
157	4	140	4
176	5	160	5
214	6	182	6
242	7	209	7
299	8	233	8
323	9	253	9
347	10	281	10
377	11	304	11
413	12	335	12
450	13	365	13
491	14	377	14
508	15	398	15
537	16	441	16
560	17	458	17
599	18	487	18
630	19	510	19
646	20	528	20
680	21	568	21
715	22	604	22
778	23	Time (sec)	Recovery (cms)
839	25	675	21
873	26	1075	20
914	27	1418	19

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Well 6T (Neturlim)		Well 14D (Curpem)	
Time (sec)	Recovery (cms)		
		1732	18
1001	26	2423	17
1130	25	3450	16
1891	24		
2459	23		
2977	22		
3215	21		
3650	20		
3660	19		
4000	15		
4500	12		
6000	10		

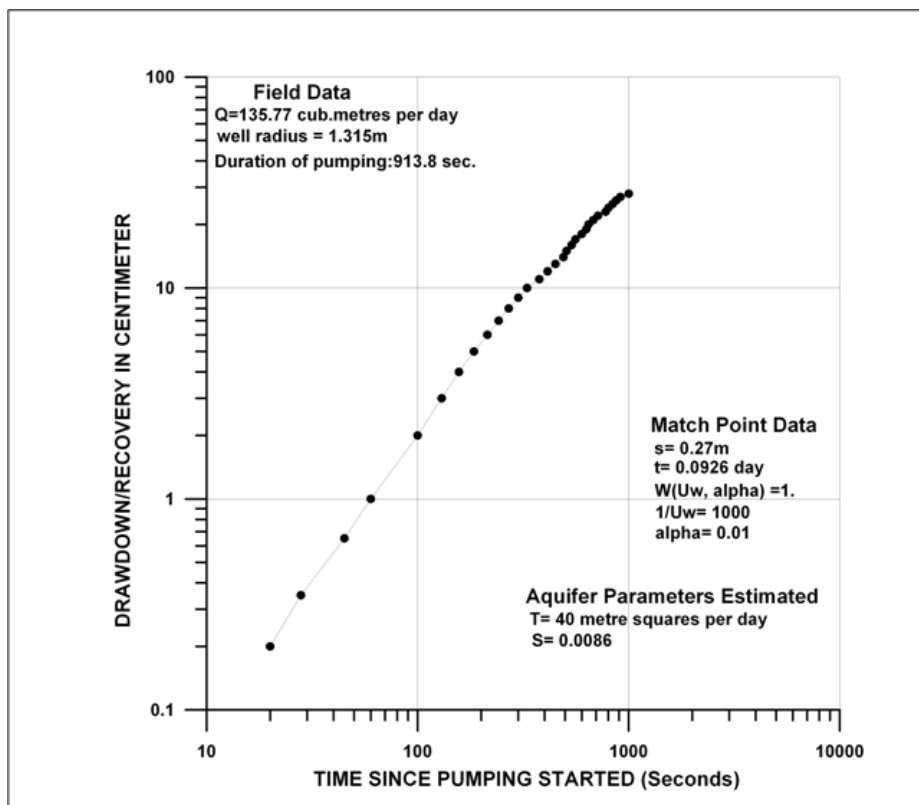


Figure 3.30: Plot of time-drawdown and time-recovery data for well no.6T and estimated aquifer parameters

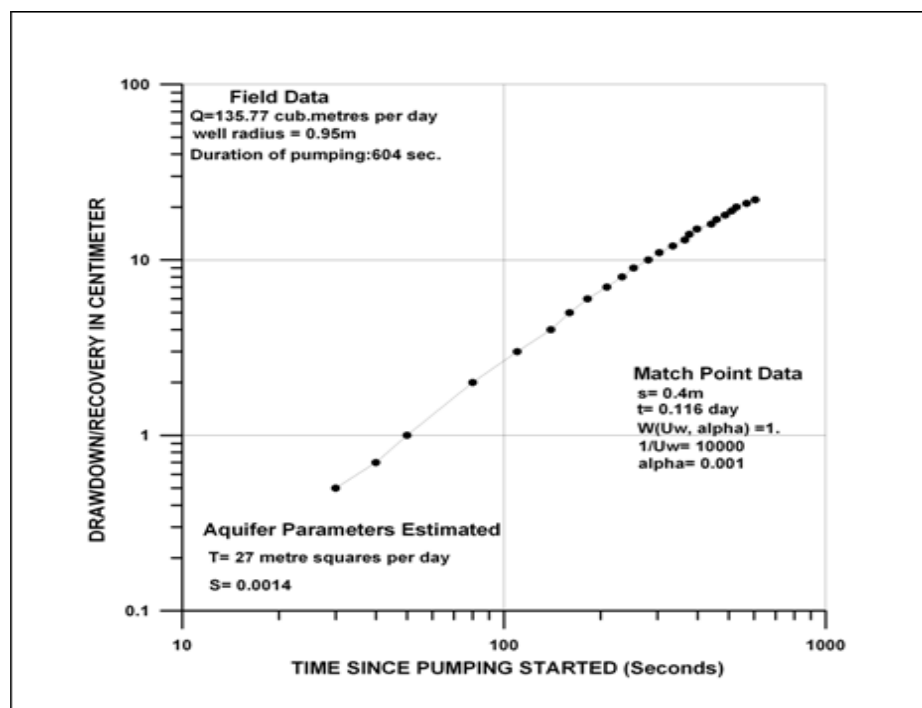


Figure 3.31: Plot of time-drawdown and time-recovery data for well no.14D and estimated aquifer parameters

Table 3.5: Summary of aquifer parameters in the study area

Well No.	Transmissivity 'T' (m ² /day)	Storativity (fraction)	Hydraulic Conductivity, 'K' (m/day)	Saturated aquifer thickness (m)
14D	27	0.0014	16	1.69
6T	40	0.0086	15	2.67
Average	33.5	0.005	15.5	2.18

Note: The saturated thicknesses of the aquifer for estimating the hydraulic conductivity are derived from vertical electrical sounding (VES) data on the well sites.

Results

The values of aquifer transmissivity vary between 27 m²/day to 40 m²/day. The hydraulic conductivity also varies more largely due to variable saturated thickness of the water bearing layer around the area. Based on the magnitude of aquifer hydraulic conductivity the top shallow lateritic aquifer can be classified as moderate yielding aquifer. The average storativity values indicate that the aquifer can be classified as semi unconfined aquifer. The aquifer parameters estimated in the above tests would represent the area in the immediate vicinity of the tested wells and hence they can be considered as point values.

Computation of water demands and groundwater withdrawals for different sectors in the watershed

I. Demand Estimations:

1. Domestic water requirement

Water shed	Area (ha)	Population density/ km ²	Population distribution in %		Per capita water usage Lpcd *		Total demands Per year		Total demand (Ham)
			Urban	Rural	Urban @200 lpcd	Rural @175 lpcd	Urban @73K lpc/yr	Rural @63875 lpc/yr	
Salaulim	18000	88 Sanguem	0	100	0	2772 X10 ³	0	1012 x10 ⁶	101

*As per IS: 1172; 1993, population density as per 2011 censuses in Sanguem Taluka is 88/km². The rural and urban water demand values are realistic and based on the primary survey. Lpcd stands for litres per capita per day.

2. Agriculture water requirements

Watershed	Area under irrigation (ha)	Average annual water requirement *	Annual water demand (ham)
Salaulim	1800 ⁺	0.55m	990

*CGWB and Department of Agriculture, Gov. of Goa 1997, +10% of the watershed area that is 1800 ha assumed to be under irrigated agriculture mainly under paddy.

3. Industrial water requirements

Watershed Name	Industrial Estate/Unit	Water requirement (ham/year)
Salaulim	0	0

4. Livestock water requirements

Watershed Name	Livestock population	Water requirement per year @ 30 lpcd (10950lpc/yr)	Total requirement per year(ham)
Salaulim	3600*	39420000	3.9

*2007 census data, Govt of Goa, 0.2 cattle per ha of area

5. Water requirements for wet beneficiation and ore washing

Watershed Name	Name of Beneficiation Plant	Ore concentrate per year(tones)*	Total water demand (ham)
Salaulim	0	0	0

*The quantity of water required for wet beneficiation varies from 1.3 to 1.5 m³/ton of ore concentrate averaging to about 1.4 m³/ton of ore concentrate (BRGM Report, 1999, p.32). In reality 12-15 m³/ton of ore concentrate is the water requirement for wet beneficiation of which 80% of the water is derived from recirculation via tailing ponds. Remaining 20% (i.e. 2.7 m³/ton of ore concentrate) is added afresh (BRGM Report, 1999, p.33).

Therefore the total water demand for domestic, irrigation, industry, livestock and beneficiation works out to be 1095 ham

II. Groundwater draft estimations:

6. Irrigation draft estimation from groundwater source in the study area

Watershed Name	Area (ha)	Number of structures*		Unit Drafts*(ham)/yr		Total Drafts		Gross groundwater Draft(ham)/year
		DW	BW	DW	BW	DW	BW	
Salaulim	18000	22	88	0.27	0.54	5.94	47.43	53.37

*The unit drafts and number of groundwater withdrawal structures are adopted from the report on “dynamic groundwater resources of Goa-March 2009”, Department of Water Resources, Gov of Goa and CGWB, SW Region, Bangalore, published in February 2011, 35p.

In Sanguem Taluka there are 106 irrigation dug wells and 426 bore wells spread over an area of 87375 hectares of the taluka. The number of units per hectare of area therefore works out to be 0.0012/ha and 0.00488/ha respectively of dug wells and bore wells.

7. Domestic water draft estimation from groundwater source in the study area

Watershed Name	Area (ha)	Number of structures*		Unit Drafts*(ham)/yr		Total Drafts		Domestic groundwater Draft(ham) per year
		DW	BW	DW	BW	DW	BW	
Salaulim	18000	90	0	0.073	-	6.57	-	6.57

*Each of the domestic well is estimated to draw about 2m³ of water per day and therefore the unit draft adopted in the present study is 0.073 ha.m per year (or 0.0002 ha.m per day). The domestic wells are used throughout the year. The density of domestic wells is estimated to be about 10 per km² of settlement area which is about 5% of the total catchment area.

8. Mine pit dewatering of the groundwater from active mines

S.No.	Watershed	Annual groundwater discharge(KL)	Total discharge (ham)
1	Curpem	150000	15

Total groundwater draft =74.94 ham

III Groundwater recharges estimations:

9. Groundwater recharge by water table fluctuation method

S.No.	Watershed Name	Area suitable for GW recharge(ha)	WT fluctuation(m)	Specific yield of shallow aquifer(fraction)	Monsoon recharge(ham)
1	Salaulim	5400*	1.063	0.03+	172

*30% of the watershed area is considered suitable for recharge, +specific yield value of 0.03 is adopted from CGWB report on “dynamic groundwater resources of Goa-March 2009”, Department of Water Resources, Gov of Goa and CGWB, SW Region, Bangalore, published in February 2011, 35p.

Groundwater balance for the watershed

In the present study a detailed account of groundwater balance has been carried out using both primary as well as secondary data. It is estimated that the groundwater availability in the watershed is to the tune of 192 hectare meter and the stage of groundwater development is 38.84%. It can be classified into 'Safe' category as per the CGWB norms. The details of the computation are given in Annexure X.

3.3 Water Quality

This section illustrates the background level or past trend of raw water quality at the Salaulim reservoir based on the secondary data. It further describes the surface water quality that contributes to the reservoir and the groundwater quality in the catchment that was monitored during the project period.

3.3.1 Background raw water quality

The water from the reservoir is drawn from the depth of around 25m and taken to the treatment plant in Xelpem. The pump house is located in the northern side of Curpem watershed (Figure 2.20). The total depth of the reservoir at the pump house is approximately 30m (PWD, 2012)⁵. The raw water quality is tested in the laboratory prior to treatment to adjust the dose of the chemicals used for treatment. The step-wise treatment methods employed at the water treatment plant include: (i) Aeration (ii) Addition of hydrated lime, alum and pre-chlorination (iii) Clariflocculation (iv) Sand beds for filtration (v) Post-chlorination (vi) Supply. When the concentration of manganese is more, pre-chlorination is decreased to avoid oxidation of Mn and post-chlorination is increased.

To ascertain the background levels of iron and manganese in the raw water in the reservoir, past ten years data on raw water quality was collected from the laboratory based at the water treatment plant in Xelpem, Salaulim. The total iron and manganese is estimated using Hach DR 5000 spectrophotometer at a wavelength of 510 and 525 nm (for higher range) respectively. As described earlier, total iron and manganese concentration in the raw water were selected as indicator parameters for the study.

The variation in the iron and manganese concentrations over the years vis-a-vis rainfall is presented in the Figures 3.32 and 3.33 respectively. It was observed that both iron and manganese concentration rise beyond the permissible limit mostly during the monsoon season indicating the contribution due to surface runoff during this period. Further, there is an increasing trend in the highest value of iron concentration over the years. As shown in the graph, the highest value did not surpass the prescribed limit in 2004; however it has been going beyond the limit in the later/current years. In case of manganese, the increase in concentration is also during monsoon season and has been exceeding the limit since the year 2000 with the current value being 2.9 mg/l in 2012⁶. A past study (NEERI, 1993) also indicated elevated iron and manganese concentration in insoluble fraction at the far end of the Salaulim reservoir. The anticipated reason was runoff from the mining activities mainly

⁵ The information was collected from Assistant Engineer, PWD, Government of Goa

⁶ A discrepancy was found in terms of the highest recorded value for manganese concentration. The laboratory data showed 2.9 mg/l while the media published 3.5 mg/l. It may be noted that in both the cases, the value has exceeded the standard limits.

through the Neturlim nallah. It should be noted that there were several iron and manganese mines submerged in the reservoir (Sinha 2003) which could be contributing to the background levels.

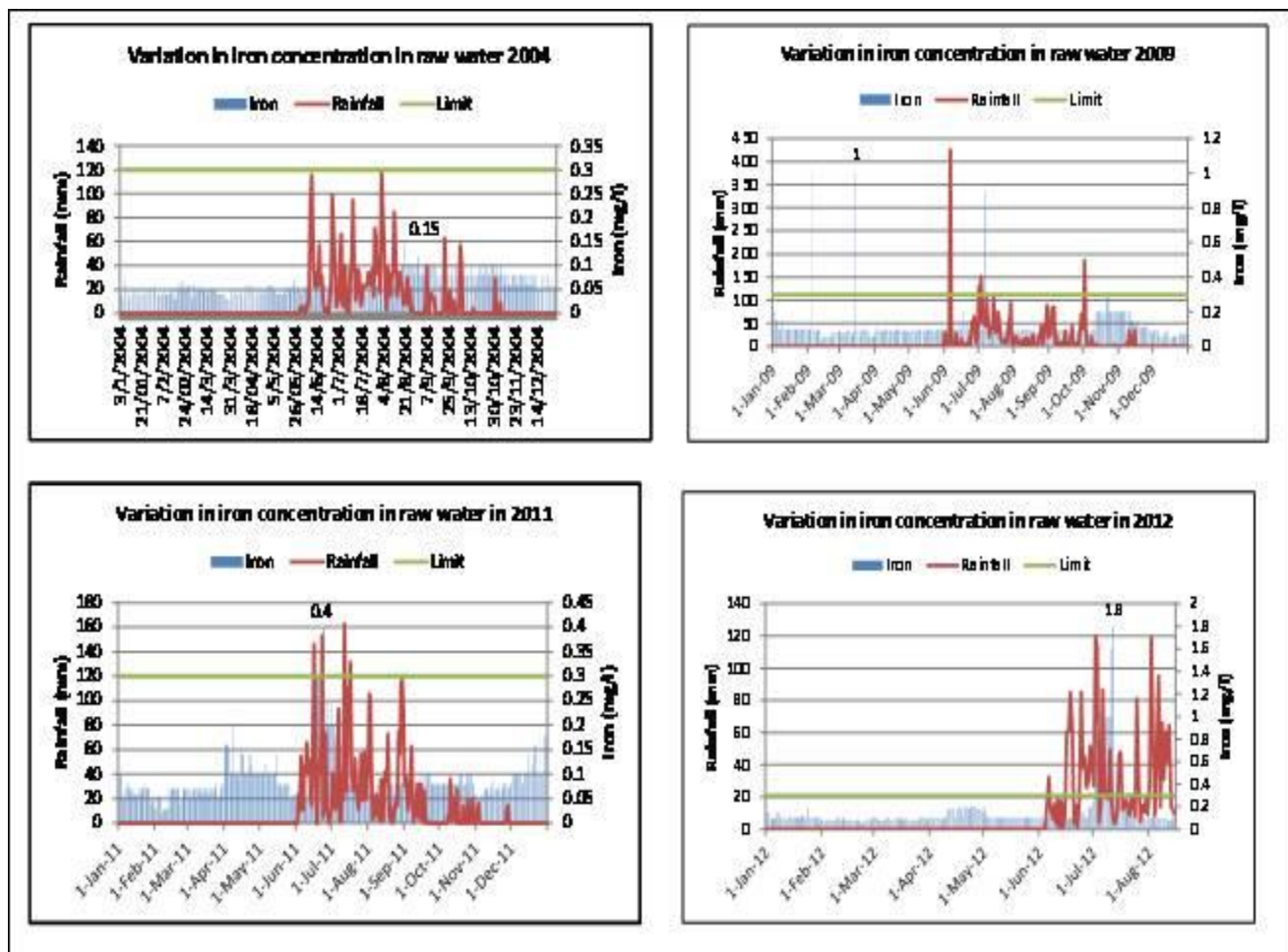


Figure 3.32: Variation in iron concentration in raw water over the years

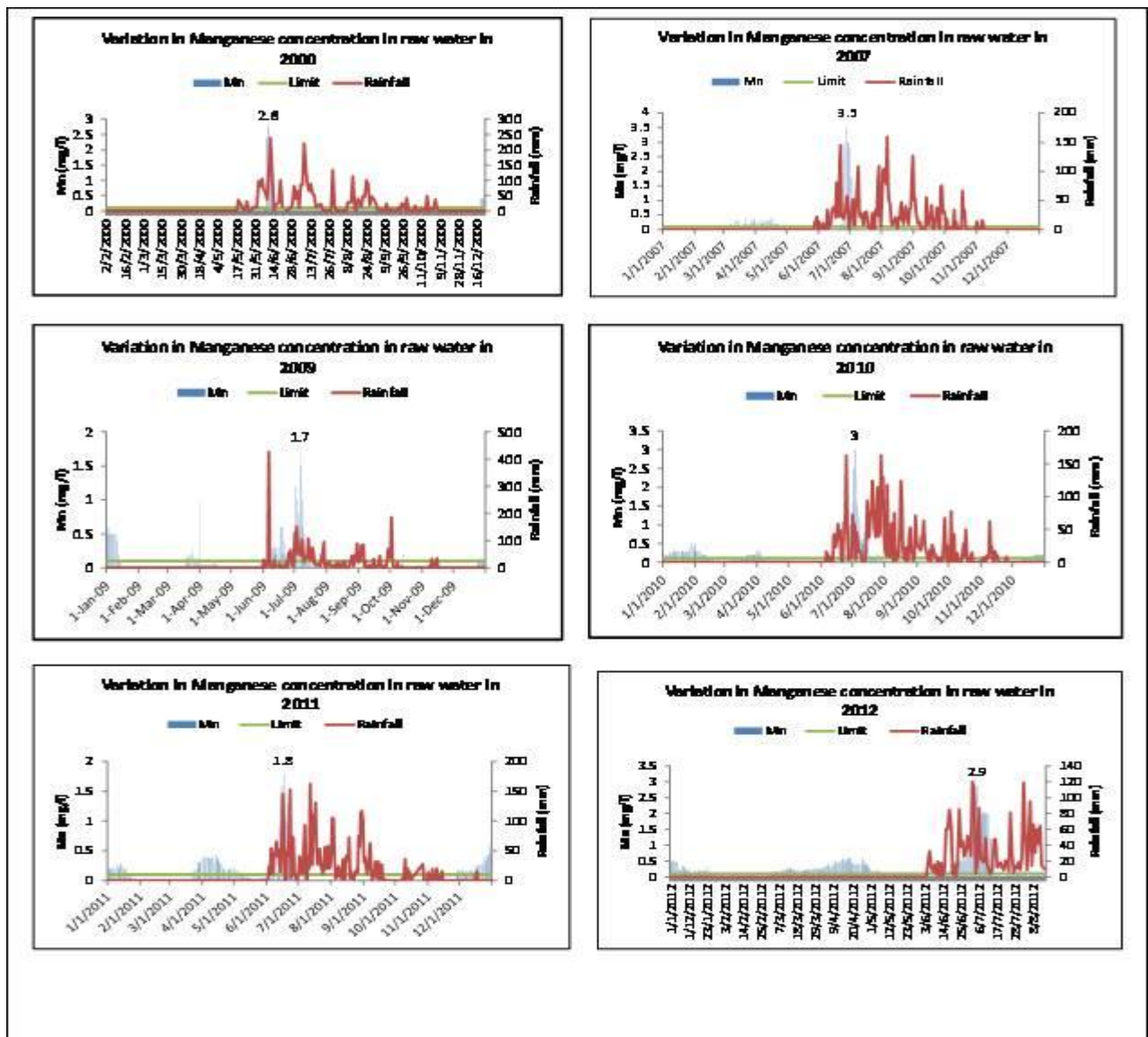


Figure 3.33: Variation in manganese concentration in raw water over the years

3.3.2 Surface water quality

The water quality examination was carried out for three seasons during the course of the study. The samples were collected for pre-monsoon, monsoon and post-monsoon season. Samples were analysed in the laboratory for the physico-chemical parameters such as pH, conductivity, total dissolved solids, total suspended solids, chloride, hardness, alkalinity, potassium, sodium, nitrate, iron, manganese, BOD, COD and DO using the standard methods (APHA 2005). The details of seven sampling locations are given in Table 3.1 and shown in Figure 3.2. These sampling locations contribute their water to the reservoir. The results of analysis are shown in Table 3.6. The iron and manganese concentration was selected as the indicator parameters to examine the impact due to mining activity. Their respective concentrations during the three seasons are depicted in Figure 3.34 and 3.35 respectively. It was observed that iron concentration at all the locations was highest during monsoon season. It exceeded the permissible limit of 0.3 mg/l (IS: 2296, Surface water quality standard for Class A in Annexure XI) at all locations except Vaddem which was the control point on July 18 2012. This indicates that the water needs treatment before drinking. There is a huge variation in the iron and manganese concentrations on day to day basis during monsoon season. To scrutinize this, few extra samples were collected for five days during early monsoon. The daily rainfall during this period is shown in Figure 3.36 and the iron and manganese concentrations are given in Figures 3.37 and 3.38 respectively. It was observed that 54.3% of the total number of samples that were collected exceeded the prescribed limit for iron whereas 11.4% were beyond limit (IS: 2296, Surface water quality standard for Class A in Annexure XI) in case of manganese. Further, though the rainfall was highest in early August, both iron and manganese values were more during early July indicating the first flush effect. The highest values for both iron and manganese were observed at Kumbhari location. This can be supported by the fact that the maximum average TSS concentration was also reported at the same location indicating that it is prone to erosion.

The values for other physico-chemical parameters were within the respective permissible limits (Annexure XI, IS: 2296: Surface water quality standard) for all the locations and are shown in Table 3.6. The TDS values were found to be more during post-monsoon season as compared to the other seasons.

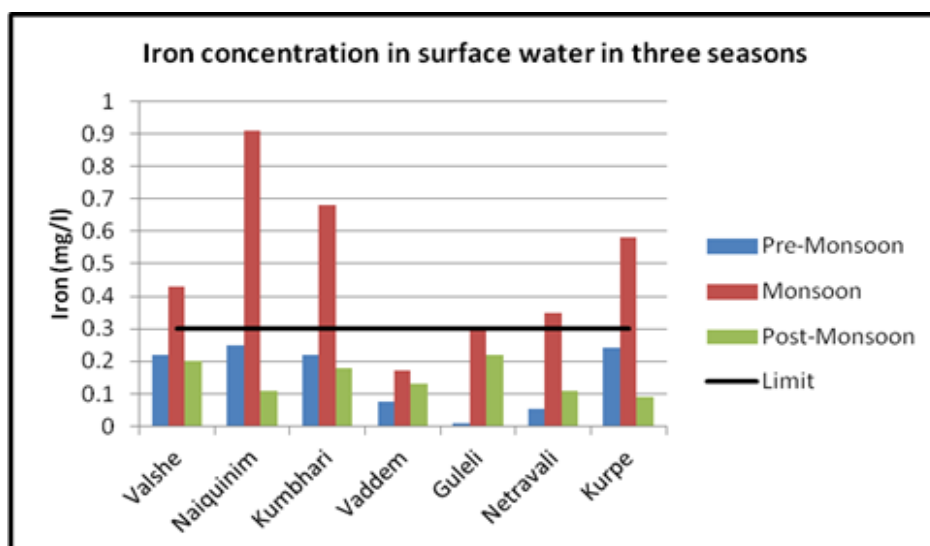


Figure 3.34: Seasonal variation in iron concentration in surface water

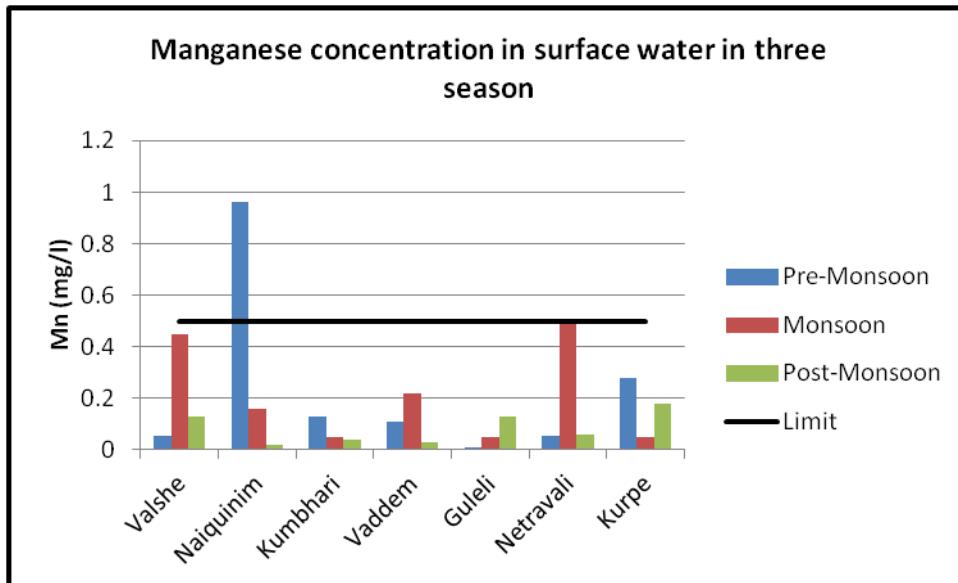


Figure 3.35: Seasonal variation in manganese concentration in surface water

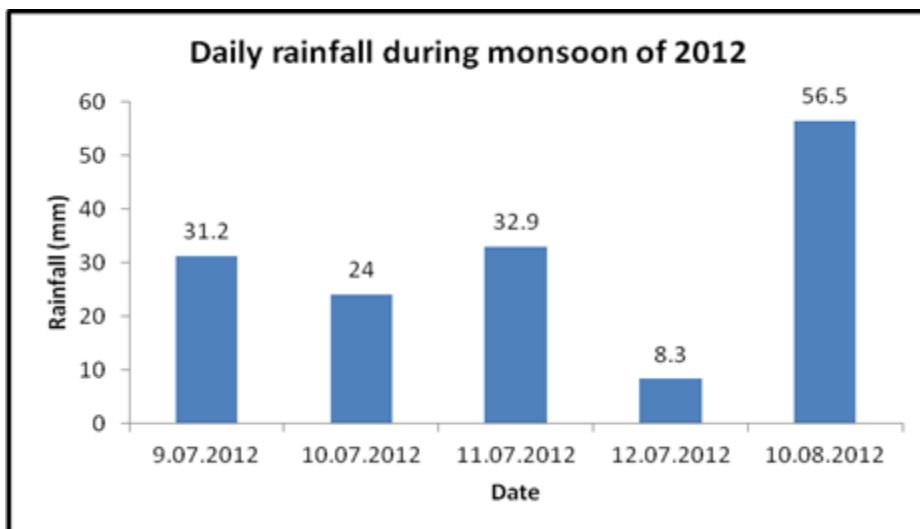


Figure 3.36: Daily rainfall during early monsoon

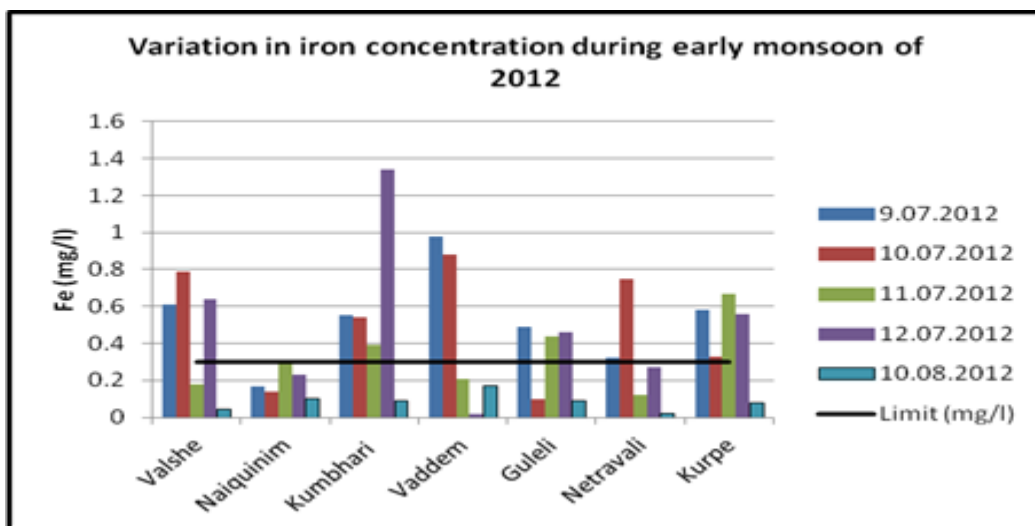


Figure 3.37: Variation in iron concentration during early monsoon

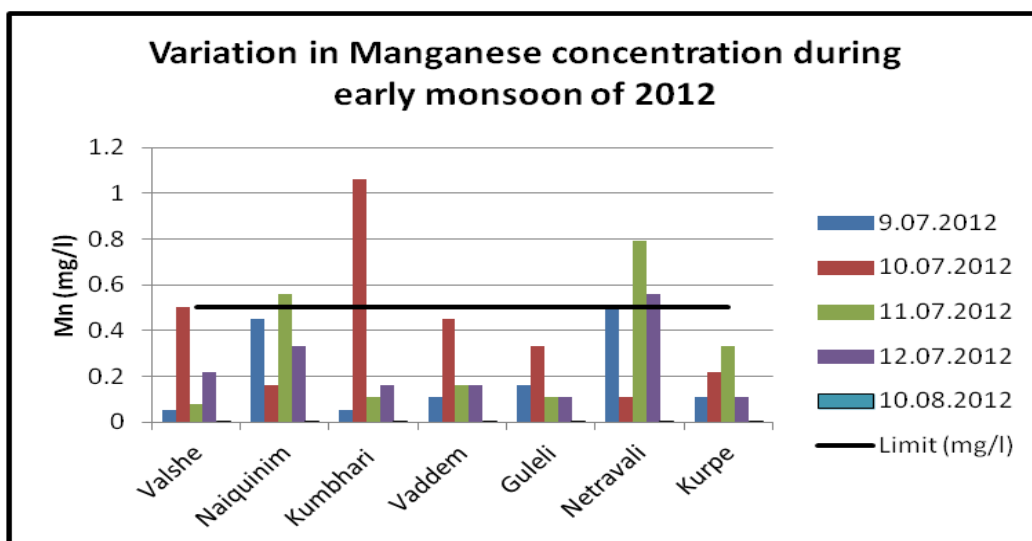


Figure 3.38: Variation in manganese concentration during early monsoon

Table 3.6: Seasonal surface water quality

Parameter	Valshe			Naiquinim			Kumbhari			Vaddem			Guleli			Netravali			Kurpe		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
pH	7.0	6.9	6.6	6.9	7.0	6.7	6.9	6.8	6.8	6.9	6.5	6.6	6.9	6.1	6.8	6.5	6.2	6.8	6.7	7.2	6.5
Total Alkalinity (mg/l) as CaCO ₃	2.2	3.0	3.2	1.5	2.7	3.0	1.2	3.4	2.8	0.8	2.3	1.4	1.0	1.6	1.2	1.7	2.8	1.9	2.5	2.0	2.9
Conductivity (mS/cm)	0.04	0.03	1.6	0.03	0.03	1.6	0.04	0.03	1.39	0.05	0.04	1.34	0.04	0.03	1.42	0.04	0.03	1.80	0.05	0.03	1.90
Total Dissolved Solids (mg/l)	33	51	404	37	56	380	30	52	388	50	89	341	51	60	610	42	57	506	84	49	523
Chemical Oxygen Demand (mg/l)	10	10	6	10	10	6	10	10	7	10	10	4	10	10	5	11	10	6	10	10	6
Biochemical Oxygen Demand (mg/l)	3	3	<3	3	3	<3	3	3	<3	3	3	<3	3	3	<3	3	3	<3	3	3	<3
Nitrates (mg/l)	1.0	0.7	0.2	1.3	0.4	0.2	1.1	0.7	0.2	1.1	0.4	0.49	0.08	0.1	0.03	1.73	0.4	0.36	1.9	2.6	0.18

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Parameter	Valshe			Naiquinim			Kumbhari			Vaddem			Guleli			Netravali			Kurpe		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Total Hardness (mg/l) as CaCO ₃	55	17	34	28	22	22	26	22	26	32	25	14	31	18	20	29	15	14	53	20	18
Chlorides (mg/l)	6.8	35.9	6.0	6.4	28.1	7.0	5.4	26.3	8.5	17.6	56.0	7.0	9.8	37	12	6	33	6	8	35	8
Dissolved Oxygen (mg/l)	6.2	5.0	6.8	4.7	5.4	7.2	7	5	7.2	6.9	5.4	6.5	6.7	5	7	7.0	4.8	7.1	7.2	5.3	7
Sodium (mg/l)	BDL	17.3	10.0	BDL	26.1	12.0	20	39	19.0	15.9	52.2	20.0	BDL	19	11	14.8	24.4	12.0	13.9	13.6	12
Potassium (mg/l)	2.5	3.1	3.0	1.6	1.6	1.8	2	3	2.5	1.2	1.5	1.3	1.0	2	2	BDL	BDL	BDL	0.5	2.4	1

BDL = Below Detectable Limit

Runoff from mine lease areas

The study area receives heavy precipitation in the range of 3500-4000 mm from the South-West monsoon causing surface run-off. On the onset of monsoon, additional samples were collected from five sampling locations which included (a) Seasonal nallah/runoff at outlet of Mine 1 (TC No. 10/51) (b) Seasonal nallah/runoff at outlet of Mine 2 (TC No. 3/51 & 40/54) (c) Seasonal nallah/runoff at outlet of Mine 3 (TC No. 63/51) (d) Seasonal nallah at Curpem : This was surface runoff flowing to the reservoir outside Mine 3 in Curpem located at 15° 08' 41.4" N 74° 10' 24.07" E (e) Salaulim reservoir in south-west direction at Curpem located at 15° 08' 49.0" N 74° 10' 27.04" E.

The total suspended solids, iron and manganese concentrations found at these locations are shown in Figures 3.39, 3.40, and 3.41 respectively. The locations in the graphs are shown according to their proximity with the SW point of the reservoir (at Curpem) with Mine 1 being farthest and Mine 3 being the closest. The highest value for TSS was observed at the outlet of mine 3 which is close to the reservoir while iron was high at the outlet of mine 2. It must be noted that the fourth location i.e seasonal nallah received the runoff from the haul/mine roads which also contribute to the pollution. The manganese concentration was highest in the reservoir indicating the background levels.

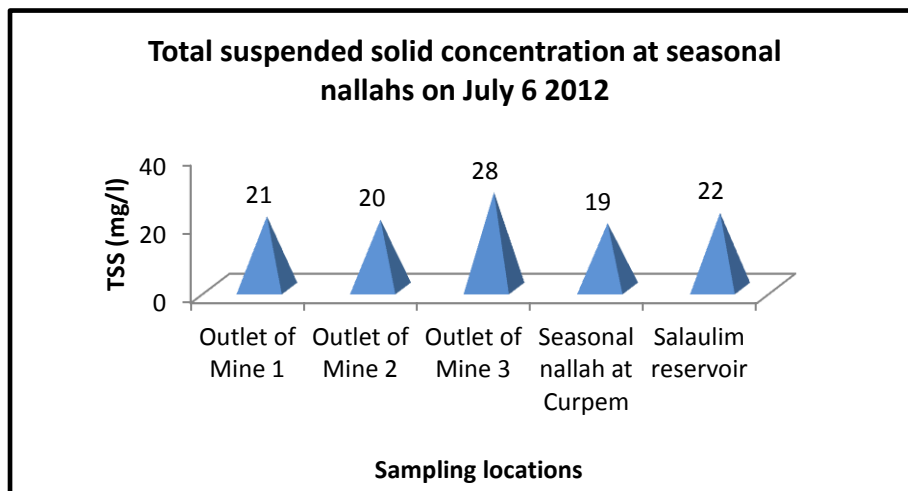


Figure 3.39: Total suspended solids in seasonal nallahs

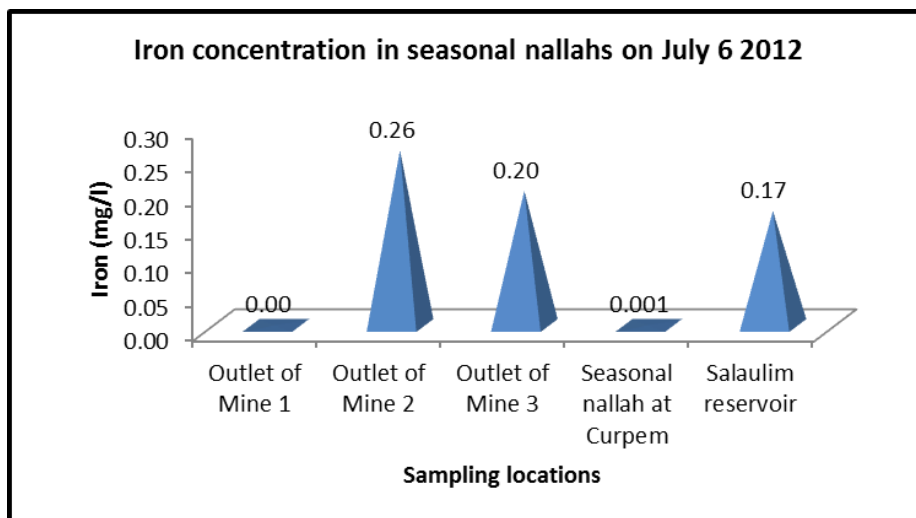


Figure 3.40: Iron concentration in seasonal nallahs

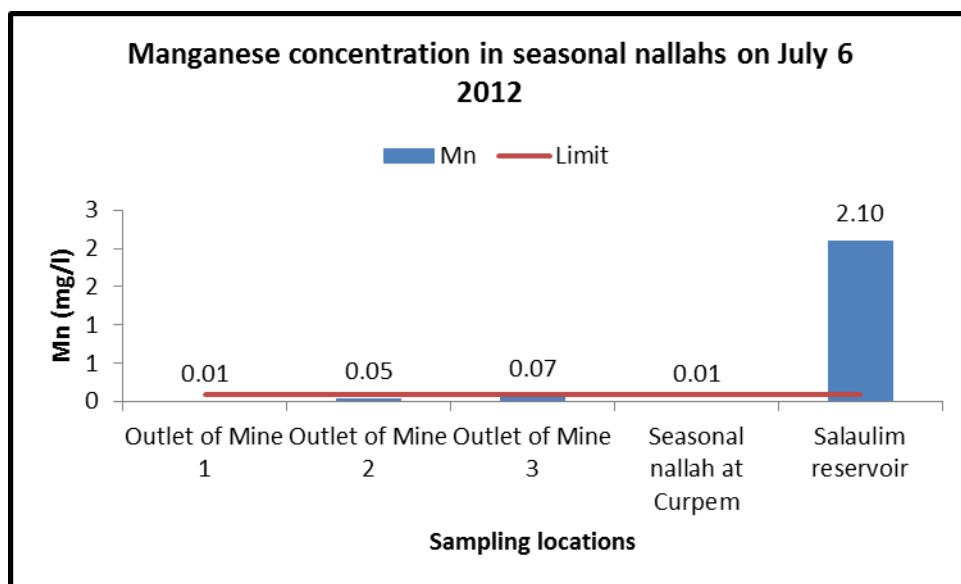


Figure 3.41: Manganese concentration in seasonal nallahs

3.3.3 Groundwater quality

The groundwater quality was monitored for three seasons. The details of the sampling locations and their distance from the mine are presented in Table 3.7 and shown in Figure 3.42. Samples were collected and analysed in the laboratory for the physico-chemical parameters such as pH conductivity, total dissolved solids, total suspended solids, chloride, hardness, nitrate, iron, manganese, BOD, COD and DO using the standard methods (APHA 2005). The iron, manganese, and suspended solid (TSS) concentrations were used as indicators to assess impact of mining. The variation in TSS, iron and manganese during various seasons is graphically depicted in Figures 3.43, 3.44, 3.45 respectively. The TSS values at locations such as Bhatimal, Neturlim, Curpem, Vichundrem, and Jaqui were high as compared to the other locations. Since they are open wells, the possibility of contamination is high.

The results for other parameters are presented in Table 3.8. All the values were well within the prescribed limit of Drinking Water Standards IS 10500 (Annexure X). The parameters such as BOD, COD and DO are not included in IS 10500 standards. Hence their values were compared to water quality criteria (Annexure X) and were found to be within limit. Bacteriological analysis of some well water in Curpem watershed revealed that total coliform was in the range of 23 – 1600 MPN/100 ml and E.coli was present at one location (Savri) which warrants for treatment before drinking.

Table 3.7: Details of groundwater quality monitoring locations

S.N	Well No.	Location	Latitude	Longitude	Watershed	Mine status / Approximate distance (km)
1	WQ 2	Sattarkarwada	15°07'55"	74°10'21.2"	Curpem	Active mine, 0.7
2	WQ 1	Naveli	15°07'47.6"	74°09'37.8"	Curpem	Active mine, 0.5
3	WQ 3	Savri	15°04'43.5"	74°13'5.4"	Guleli	Old mine, 2.0
4	Well 4	Curpem	15°07'28.1"	74°10'38.3"	Curpem	Active mine, 1.1
5	Well 10	Vichundrem	15° 05'59.4"	74°11'52.9"	Guleli	Abandoned mine, 1.5
6	Well 18	Vichundrem jamgar	15°06'26.9"	74°12'44.6"	Guleli	Old mine, 3.5
7	Well 40	Neturlim	15°05'47.6"	74°12'57.5"	Guleli	Old mine, 2.4
8	Well W8	Bhatimal	15°10'04.7"	74°13'06.4"	Kumbhari	Old mine, 2.5
9	Well 15	Jaqui	15°04'58.1"	74°12'18.8"	Guleli	Old mine, 1.0

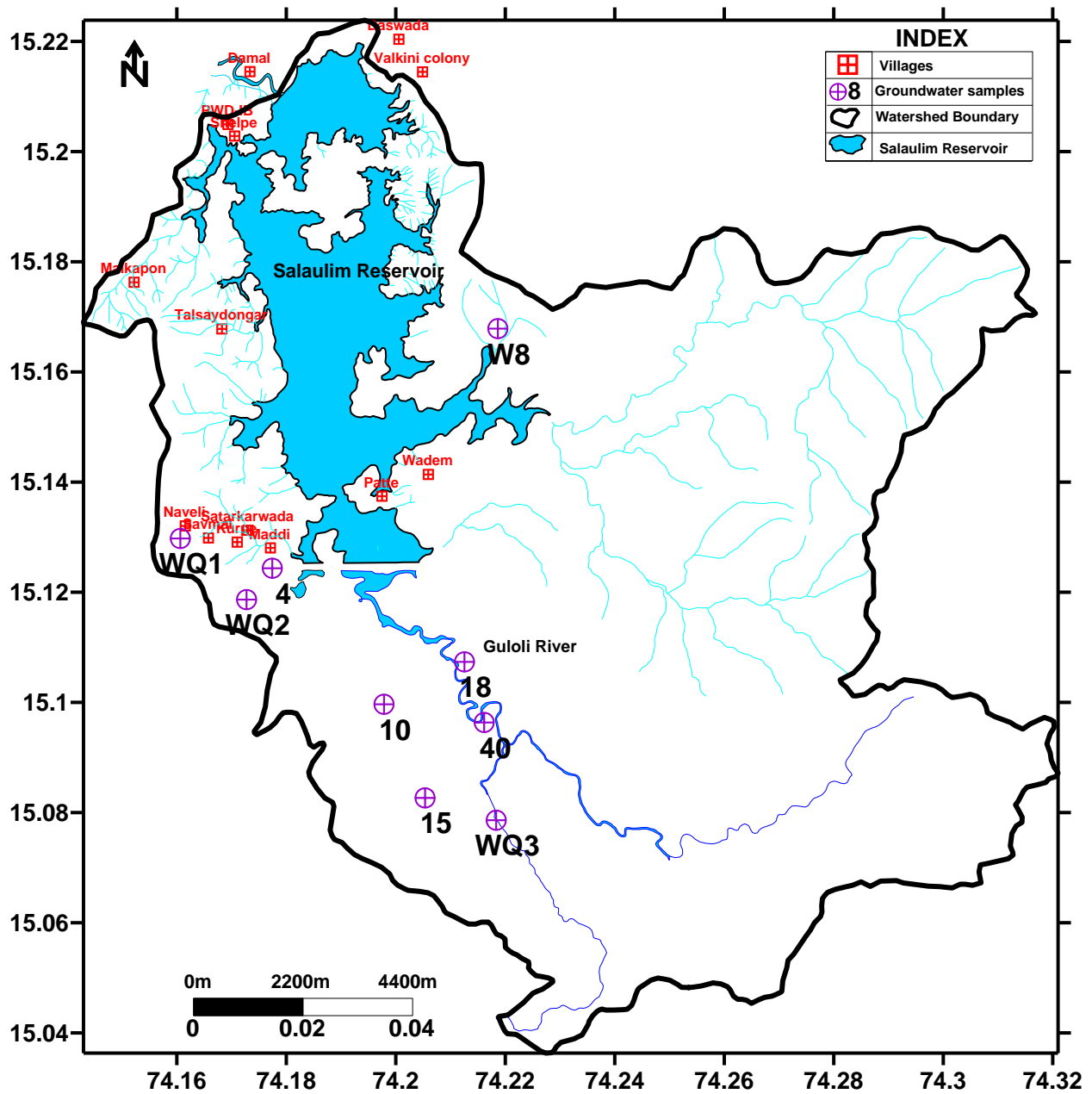


Figure 3.42: Locations for monitoring of groundwater quality

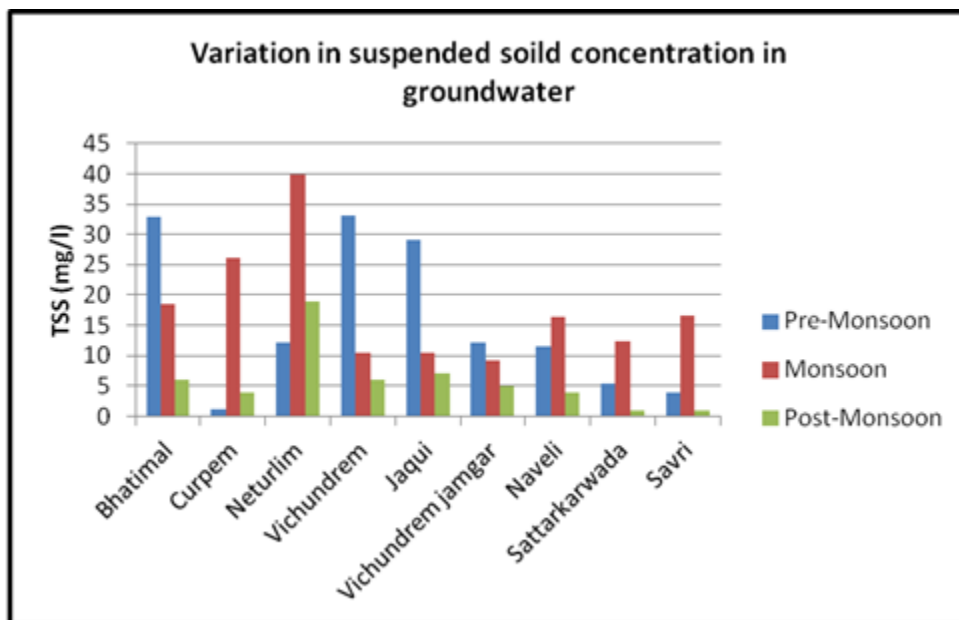


Figure 3.43: Seasonal variation in suspended solid concentration in groundwater

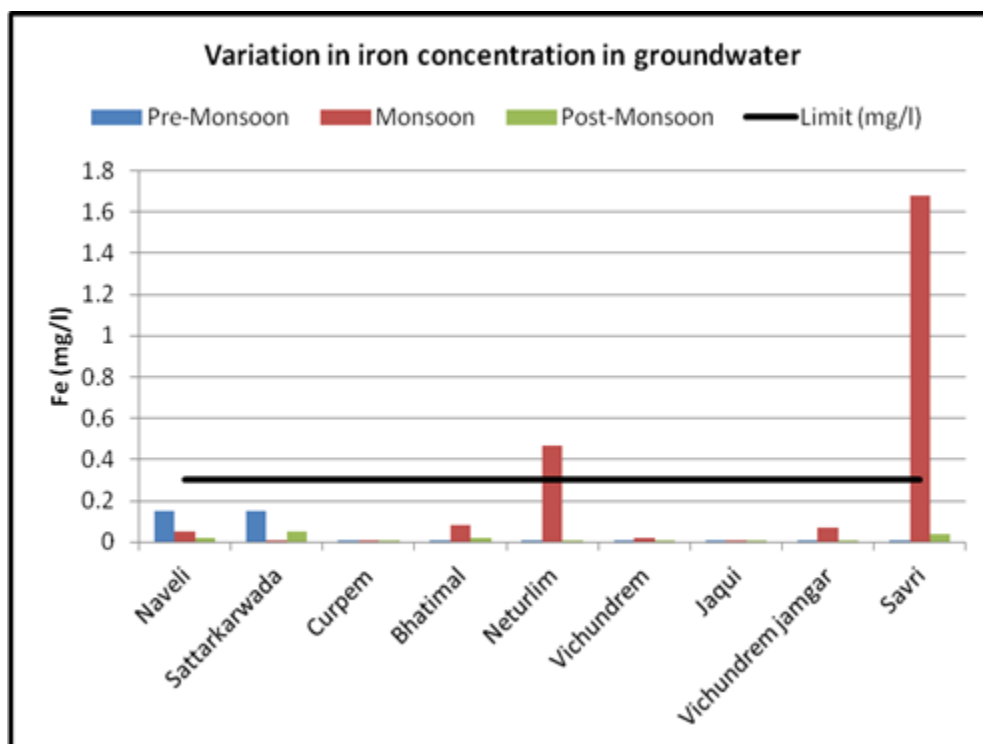


Figure 3.44: Seasonal variation in iron concentration in groundwater

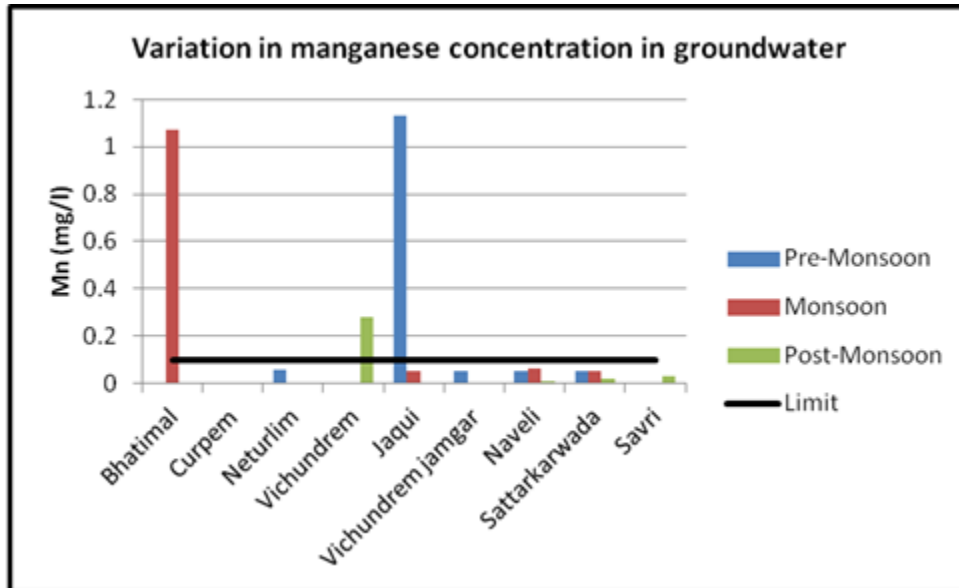


Figure 3.45: Seasonal variation in manganese concentration in groundwater

Table 3.8:Groundwater quality during three seasons

Parameter	Bhatimal			Curpem			Neturlim			Vichundrem			Jaqui			Vichundrem Jamgar			Naveli			Sattarkarwada			Savri		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
pH	5.8	6	5.9	5.5	5.5	6.0	6.8	7.3	7.4	6.8	6.7	6.5	6.1	6.9	6.4	5.6	5.6	5.6	5.5	5.5	5.6	5.5	5.8	5.8	6.0	6.7	6.5
Total Alkalinity (mg/l) as CaCO ₃	20	7	1	6	2	1.01	12	6	2	10	12	2.02	16	18	1.01	BDL	BDL	1.01	2	3	1	6	4	2	8	8	4
Conductivity (mS/cm)	0.04	0.06	0.04	0.05	0.05	0.03	0.05	0.07	0.07	0.05	0.06	0.06	0.04	0.08	0.07	0.05	0.05	0.03	0.04	0.05	0.04	0.03	0.07	0.06	0.03	0.06	0.05
Total Dissolved Solids (mg/l)	54	63	27	32	42	27	20	74	41	14	64	30	28	92	24	24	44	86	54	77	70	38	57	63	30	48	17
Chemical Oxygen Demand (mg/l)	106	37	<10	216	37	<10	186	18	15	39	28	15	200	18	10	206	9	10	98	41	20	198	28	10	88	9	10
Biochemical Oxygen Demand (mg/l)	3	3	<3	3	3	<3	13	3	<3	7	3	<3	5	3	<3	8	3	<3	4	3	3	9	3	3	3	3	3

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Parameter	Bhatimal			Curpem			Neturlim			Vichundrem			Jaqui			Vichundrem Jamgar			Naveli			Sattarkarwada			Savri		
	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post	Pre	Mon	Post
Nitrates (mg/l)	0.8	NIL	0.2	2.1	NIL	0.1	0.7	0.1	0.1	0.6	0.4	BDL	0.8	BDL	0.1	0.6	NIL	0.1	0.7	0.1	0.1	0.5	0.1	0.1	0.8	0.3	0.1
Total Hardness (mg/l) as CaCO ₃	50	14	13	8	5	21	28	26	33	20	30	30	38	67	31	24	4	16	12	34	6	20	31	12	14	29	9
Chlorides (mg/l)	9	11	9	11	7	12	11	8	10	13	11	10	7	7	10	9	5	9	10	9	2	9	11	2	6	8	5
Dissolved Oxygen (mg/l)	4.3	4.7	4.0	6.2	6.0	4.0	6.1	6.6	4.2	6.5	6.3	3.9	6.9	6.5	4.0	6.5	6.7	4.0	5.8	6.1	6.5	6.1	4.3	4.2	6.5	6.4	6.5
Sodium (mg/l)	49	16	20	40	5	11	45	15	21	31	15	17	50	13	19	45	4	16	42	17	20	37	17	16	36	16	14
Potassium (mg/l)	BDL	NIL	0.1	BDL	1	1.0	3	2	1.5	3	NIL	1.0	3	1	1.5	2	2	1.5	2	1	1.0	2	1	1.7	2	1	1.8

BDL = Below Detectable Limit

Mine pit water

The mine pits are classified into dry and wet pits. The dry pits are those where the mines operate above the groundwater table and therefore remain dry throughout the year except in monsoon. Wet pits operate below the groundwater table and therefore discharge water throughout the year. Both dry and wet pits were present in the study area. The characteristics of pit water are given in Table 3.9 from the results of samples those were collected in various seasons. The values were high in the rainy season since the runoff from the mine lease area gets accumulated in the pit.

Table 3.9: Characteristics of mine pit water

Parameter	Range
pH	5.3 - 7.1
Total Dissolved Solids (TDS)	22 - 55 mg/l
Total Suspended Solids (TSS)	4 - 152 mg/l
Iron	0.23 - 1.2 mg/l
Manganese	0.04 - 0.58 mg/l
Chemical Oxygen Demand (COD)	59 - 89 mg/l
Biochemical Oxygen Demand (BOD)	13 - 84 mg/l
Dissolved Oxygen (DO)	2.5 - 5.32 mg/l

Groundwater quality near active mines

All the three locations (Naveli, Sattarkarwada and Curpem) in Curpem watershed which are close to the active/working mines showed increase in TSS concentration during monsoon season. This could be because the erosion potential is more in the area as discussed in the earlier section. From the groundwater flow net diagram (Figure 3.15) it was observed that the flow is from Naveli towards Sattarkarwada, Curpem and finally towards reservoir. Their proximity to the active mines is also in the same order as shown in Table 3.10. This could also be the potential pathway of contaminant transport. The iron and manganese concentration at these locations were within the prescribed limit. The preliminary observation was that the iron concentration was more at the wells closer to the mine and decreased with the increase in the distance. However, more data would be required to analyse the trend, expected rate and chemical alterations during transport before drawing any conclusion.

Table 3.10: Seasonal variation in iron concentration in groundwater samples

Sampling Location	Iron (mg/l)			Limit (mg/l)
	Pre-Monsoon	Monsoon	Post-Monsoon	
Naveli	0.15	0.05	0.02	0.3
Sattarkarwada	0.15	0.01	0.05	0.3
Curpem	0.001	0.001	0.001	0.3
Bhatimal	0.001	0.08	0.02	0.3
Neturlim	0.01	0.47	0.001	0.3
Vichundrem	0.001	0.02	0.001	0.3
Jaqui	0.001	0.01	0.001	0.3
Vichundrem jamgar	0.01	0.07	0.001	0.3
Savri	0.001	1.68	0.04	0.3

Groundwater quality near abandoned/old mines

The groundwater quality was monitored for three seasons at six locations that lie in the vicinity of abandoned or old working mines. Out of these, five were in Guleli watershed and one in Kumbhari watershed (Table 3.7). The highest value for TSS concentration was recorded at Neturlim during monsoon season. Further, the iron concentration was more than the standard limit in case of Neturlim and Savri (Figure 3.44). These two locations fall downstream in the direction of groundwater flow line (Figure 3.13) coming from the old working mines (Figure 2.22) indicating the possibility of pollution. In case of manganese, the concentration exceeded the limit at Bhatimal, Vichundrem, and Jaqui (Figure 3.45). After closely looking at the groundwater flow line for Guleli and Kumbhari watersheds (Figure 3.13 and 3.14) it was revealed that these locations are also in the downstream direction of the old working mines which could be the reason for pollution. Further, Yellishetty (2009) examined the soil-water interactions occurring in mining area close to the current study area where leachability studies revealed that the ground and surface water in this region is highly vulnerable to heavy metal contamination. Extensive datasets and geological examination along with contaminant modelling studies are essential to further validate these preliminary findings.

4 Management strategies for control and prevention of impacts

A holistic approach is essential to control and prevent further adverse impact on the Salaulim reservoir owing to point and non-point sources of pollution. The management strategies hence should be comprehensive or looked in totality. For attaining the desired objective of minimizing the negative impact on water quality and quantity, four strategies are proposed which should be implemented in conjunction with each other. These include:

- Preventive measures for control of soil erosion at sensitive areas in the watershed
- Control measures at the mining sites/leases and dumps
- Treatment measures to improve raw water quality at the reservoir
- Institutional and governance measures

4.1 Preventive measures for control of soil erosion

The general problem of loss of capacity due to soil erosion and deposition in the reservoirs is a natural process and is illustrated all over India (Kothyari 1996). However, anthropogenic activities such as mining can hasten the rate of sedimentation affecting its capacity and water quality and hence needs immediate attention. This is true in case of Salaulim reservoir where the decrease in the capacity has been estimated in the range of 13.3 – 15.3 % (CWC, 2011 and MERI, 2012) over a period of 21 years. The systematic approach to manage sediment in the reservoir includes:

1. Detailed screening analysis to identify areas of severe erosion and sedimentation sites
2. Gauging of greater number of streams to estimate sediment load
3. Review of measures that could be adopted
4. Actual implementation in phased manner

The first step of identifying the areas of severe erosion was done by (CWC, 2011). An exercise based on Sediment Yield Index (SYI) method was undertaken to identify very high priority micro watersheds. SYI was computed through erosion intensity mapping units (EIMU) which were calculated using physiography, land use, soil depth, slope, colour, texture, surface gravelly and rocky phases, erosion status and adopted soil conservation measures in the area. The result of prioritization study, indicated that out of 23 micro watersheds in the catchment, 4 micro-watersheds covering 10.8% or 19.97 sq.km of the land area belong to *very high* priority; while 6 micro-watersheds covering 27.6% or 51.32 sq.km have a *high* priority status. These micro-watersheds need soil conservation measures immediately. The map showing the very high and high priority micro-watersheds in the catchment is presented in Figure 2.24 (Chapter 2). It can be seen that most of these areas fall in Kumbhari and Guleli watersheds with one falling in Curpem watershed. Accelerated erosion by water and at places by gravitational creep or road side soil erosion was prominent in this catchment. Sheet, rill, and gully erosion was observed in this area (CWC, 2011).

The next task of gauging key streams to compute sediment load was done in this study. As discussed in the earlier chapter, the highest sediment load comes from Kumbhari river followed by Guleli indicating erosion potential areas in the upstream direction. These areas would need treatment and they were found to coincide with the priority areas described in earlier section. The total annual sediment load from seven locations that were gauged was calculated to be 33993 tonnes.

There are various measures available for diminishing sedimentation and increasing life of the reservoirs. A schematic diagram displaying the various options is given in Figure 4.1. These treatment methods can be broadly categorized into (a) removal of deposited sediment (b) reconstruction of dam wall (c) control silting. The first two methods are complex and would need detail independent study as their technical, economic and environmental feasibility depend on a number of specific factors (Qamar et al., 2012) such as:

- the availability of suitable engineering facilities at the dam to control water levels and outflows
- the availability of 'surplus' water and its value if used for other purposes
- the predictability of river flows, including seasonal variations
- the characteristics of the sediments entering and within, the reservoir
- the availability of disposal sites for dredged sediments
- the effects on the downstream reach of evacuating sediments through dam
- the effects on the normal operation of the scheme and the financial and social consequences
- institutional and political problems among the affected stake-holders

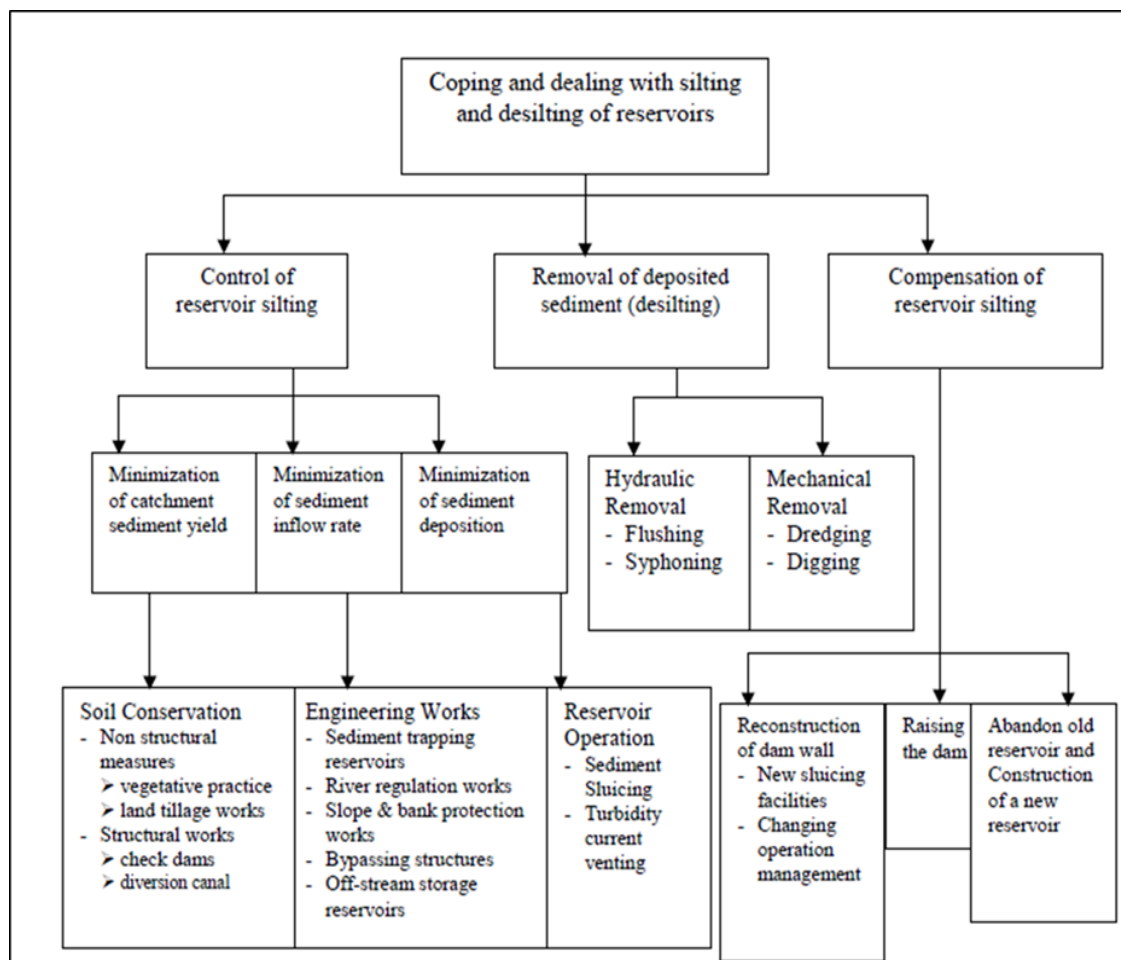


Figure 4.1: Options for sediment management in reservoirs

Source: Adapted from Qamar et al., (2012)

The third option of minimizing the silt through soil conservation (non-structural) and engineering works has been tried, tested and recommended by National Watershed Development Project for Rainfed Areas (NWDpra), Government of India. Hence these measures should be immediately undertaken by Water Resources Department in case of Salaulim reservoir. Some of these methods are as follows:

Non-Structural measures

- Stream bank protection should be practiced by managing a riparian zone or a vegetative buffer
- Hillside erosion should be prevented by means of afforestation. Deforestation should be discouraged
- Establish more representative hydrological network
- Conduct reservoir sounding periodically
- Involve local community in the implementation of land and water conservation

Structural measures/Engineering works

- Sedimentation ponds: These can be a good option to trap the sediments along the channel at selected locations. They are helpful in stabilizing the gullies and channels that are subjected to severe bed erosion and enhance infiltration. Another method could be excavation in vicinity of reservoir as was done at Wonogiri reservoir in Java. It was found that though expensive, it was a practicable method of curtailing sedimentation (Soewarno and Sutikno Hardjosuwarno, 2008). In case of Salaulim, feasibility studies are required to check the efficacy of this method.
- Slope greater than 10% should be stabilized by adopting graded trenches and contour cultivation and conservation agronomic practices should be promoted
- Contour bunds spaced at 10 m for slope upto 30% should be built while farming along the slope
- Earthen embankments or terraces should be constructed to reduce slope gradient and surface flow velocity
- Bio-mechanical measures should be encouraged on slopes that have plantations. This would include opening of contour ditches across slope wherever possible and stacking the dugout soil matrix in semi-circular way to arrest maximum runoff for plant growth
- Regulation, torrent and gully control works in the channel of the Guleli and Kumbhari river would be useful as they are main feeders to the reservoir and carry high sediment load

The last but the most important task is to apply these soil conservation measures at the micro-watersheds that have been identified as 'very high' and 'high' priority areas. The efficacy of the measures to reduce sedimentation rate should be monitored and then further expanded to other parts of the catchment including amendments if there are any.

4.2 Control measures at the mining sites

The major adverse impact of mining activity on the reservoir is increasing level of siltation. The key sources within the mining lease area that add to the sediment load are (i) runoff within the mine lease area (ii) dewatering of mine pit water (iii) runoff from the dump. To address these localized issues robust measures entailing the best management plan (BMP) for handling mine site water should be strictly practiced by all the mine operators. Some of these measures are as follows:

Managing runoff within lease area

- Garland drains should be constructed to divert all the surface runoff from the lease area into series of settling ponds. There should be emphasis of providing these drains around the ultimate boundary of the dump
- Treatment with lime for settling of solids in the water collection chambers and settling ponds
- Functional basic analytical laboratory to test water on regular basis should be on site. Maintain standard pH of the water going out from lease area at all times. It should be

between 6-8.5 for sustaining a healthy ecosystem and aquatic fauna. Other minimum parameters such as suspended solids, iron and manganese concentration should be monitored regularly and treated with lime before releasing out of the lease boundary

- Size of the settling ponds should be able to accommodate 24 hour rain or flood event and placing of ponds in sites with steep topography or in buffer areas should be avoided
- Inspect BMP structures within 24 hours of each rainfall event and take immediate corrective action if erosion or soil runoff is observed
- Immediately revegetate any disturbed areas not actively mined

Managing mine pit water

- Mine pit water should be treated to meet the prescribed standards before being used for agriculture or domestic purpose or discharged
- An appropriate treatment method should be adopted depending on the use.
 - For discharge into natural streams, the pit water should be pre treated with lime to reduce TSS, pH, iron and manganese. This should be followed by two laterite walls of minimum 1m thickness separated by a distance of 100m. The height and the width of the laterite walls should be sufficient enough to allow water to percolate and filter through laterites. The schematic diagram showing the treatment option is presented in Figure 4.2
 - For agricultural use, the pit water should pass through additional filtration unit at the downstream of laterite wall to reduce the silt load on the fields
 - For domestic and drinking purposes, the pit water should be pre-treated with lime followed by filtration. It could be further treated with granular activated charcoal and then disinfected before supply

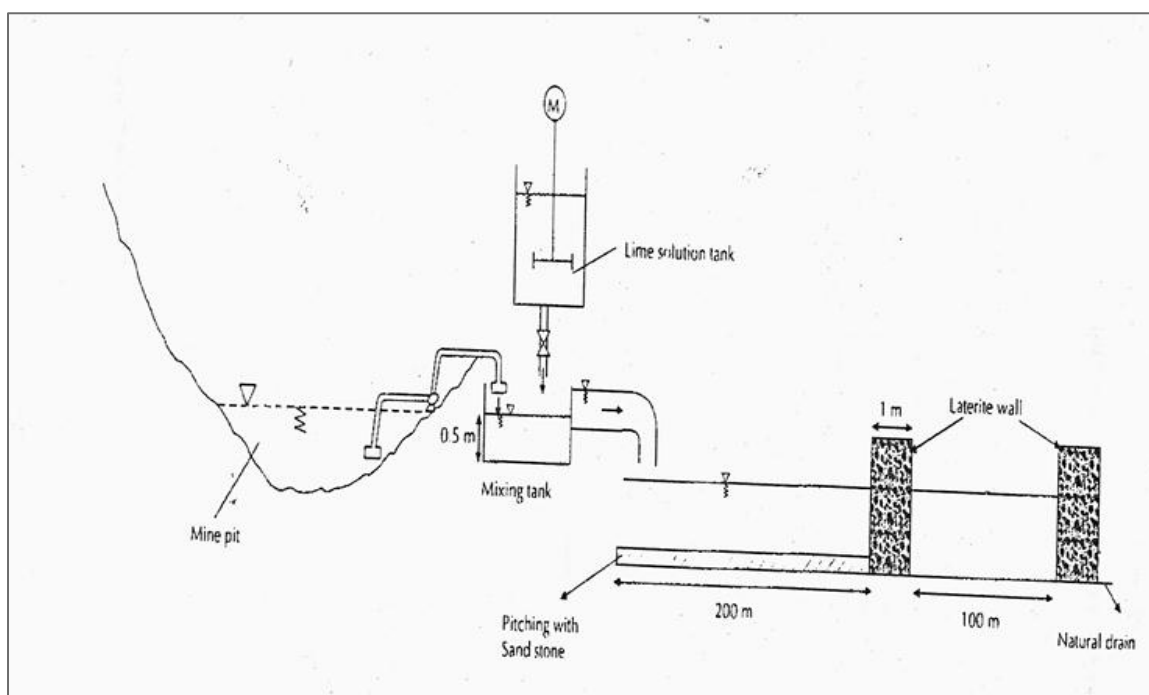


Figure 4.2: Schematic diagram for pit water treatment

Source: Adapted from TERI (1997)

Dump Management

The rehabilitation of dumps includes establishment of an adequate cover of vegetation to stabilize the dump slopes. For details on the scientific methods of making planting pits, spacing, choosing relevant plant species, and maintenance please refer to (TERI, 1997) report. Until an adequate cover of vegetation has been established, it becomes imperative to make provision to control erosion from these disturbed sites. Some of these measures are described below:

- The slope of the dumps should be less than 30% to control erosion. The slopes should be reduced to 20-30% by adopting terrace land forms. To make the dumps hydraulically compatible, terraces should be made at intervals of 10-12 m of about 8-10m width. Terraced landforms with short steep slopes are stable and less obtrusive. The terraces are generally sloping inward to allow rain water to concentrate at the centre and in filter instead of running down the slope.
- Laterite walls of about 2 m thick and 3m height at a distance of 100m from the toe of the dumps should be constructed. The filtered water from the laterite wall should be collected in a drain and should pass through a settling tank before discharge into the natural drains. These drains should be of sufficient width and depth to carry the storm water to the settling tank.
- The settling tank should have at least 3 hrs holding capacity and maximum depth of the tank could be 2m. The surface overflow rate should be in the range of 32-48 m³/m²/d
- Dumps should be covered with silpauline or geo-textiles to reduce erosion
- Old dumps which have stabilized over the years and has full grown vegetation should not be disturbed. In future dumping of mining rejects should not be allowed within 1 km from the reservoir as per The Goa, Daman and Diu Irrigation Act, 1973 and Rules, 1975.

Other best management practices

- Rainwater harvesting should be practised through construction of check dams and/or direct injection after treatment
- Monitoring of groundwater levels and quality should be done on regular basis. Zone of influence should be established and pumping of groundwater should be regulated based on the levels. Recycle and reuse of treated wastewater should be practiced.
- Strict compliance and implementation of these preventive measures by the mining companies is of utmost importance
- The mining sector should design a robust policy entailing the best management plan for handling mine site water. It should take into account sound water management practices during various phases i.e. exploration, development, operation and closure. The key elements that should be considered for better water management are described in Box1.

Box 1: Main requirements in the development and operation of a mine water management system (Adapted from Environment Australia 2002)	
Stage	Important water management elements
Exploration	<ul style="list-style-type: none"> • Erosion control from temporary roads and drill pads construction • Management of drilling fluids • Management of camp wastes • Collection of hydrogeological data • Collection of rock samples for environmental geochemical analyses
Resource development	<ul style="list-style-type: none"> • Erosion control from semi-permanent roads and additional drill pads • Management of camp wastes, allowing for increased personnel for longer periods • Commence baseline data collection: <ul style="list-style-type: none"> • Hydrological and hydrogeological • Climate <ul style="list-style-type: none"> ○ Biological ○ Geochemical
Design	<ul style="list-style-type: none"> • Ongoing refinement of data collection • Determine the expected water requirements for the operation – quality and quantity – from the proposed mining and processing methods • Develop an expected mine site water balance • Undertake an audit of potential mine-related contaminants • Quantify the potential pathways of contaminant transport and the expected rate and chemical alterations during transport • Define the physical locations, types and timing of potential environmental impacts • Undertake modeling to assess the reliability of water supply and potential environmental impacts • Undertake a risk assessment • Develop strategies to minimize the risk of water contamination • Design a preliminary water transfer system to meet water supply and environmental contingency needs • Develop a preliminary runoff drainage system to manage high-rainfall events • Develop contingency procedures • Develop a data collection program for design performance validation
Operation and rehabilitation	<ul style="list-style-type: none"> • Validate design predictions and collect data to reduce the uncertainties in design, where necessary • Monitor the environmental and operational performance of the water management system • Develop accountabilities for the maintenance and operation of the physical and mechanical components of the water management system and in implementing contingency procedures • Train operators in these areas • Continue with system investigations, that take account of new technologies, to minimize the risk of environmental impacts and maintain flexibility for the mining operation • Identify and manage risks

	<ul style="list-style-type: none"> • Develop techniques for and implement progressive rehabilitation • Develop a data collection program for rehabilitation performance post-mining
Post mining	<ul style="list-style-type: none"> • Collect data and determine the performance of the post-mining landform activity against the agreed post-mining land use /environmental values • Publish the information so that governments and the mining industry can improve their environmental performance

4.3 Measures to improve raw water quality at the reservoir

The most important aspect in improving the water quality at a reservoir is to understand the reservoir dynamics and chemical behaviour of the pollutant. The lake or a reservoir is usually thermally stratified and can be divided into three layers depending on the change in the temperature at different depths which is due to change in water density with temperature (Lackey, 1972a). These layers include (a) Epilimnion which is the top-most layer in a thermally stratified reservoir. It is warmer and typically has higher pH and high dissolved oxygen concentration (b) Metalimnion or thermocline is the middle layer that may change depth throughout the day and (c) Hypolimnion is the dense bottom layer and typically the coldest layer in summer and warmest during winter. Being at depth, it is isolated from surface wind mixing during summer and usually receives insufficient irradiance for photosynthesis to occur⁷. The presence of the indicator parameters under study i.e. iron and manganese largely depend on the parameters described for different layers.

Iron and manganese exists in water both in insoluble and soluble states. The inorganic soluble iron does not pose a big problem as it can be removed by coagulation, sedimentation and filtration processes. However, the removal of organic soluble iron and manganese pose a serious problem. It may be noted that only total iron and manganese are determined while analysing the water sample due to established procedures.

In reservoirs, manganese and iron build up by a combination of biological and chemical processes working simultaneously. The aqueous chemistry of manganese is complex. Mobilization of manganese is favoured by low redox potential and pH conditions. When reducing conditions are present, iron and manganese are converted from their insoluble higher valence state to their soluble divalent state. This is brought about in reservoirs by decomposition of organic materials in sediment which consume oxygen thereby creating reducing conditions and releasing carbon dioxide gas which in turn lowers the pH. This process is commonly observed in the hypolimnion layer of a reservoir (NEERI, 1993).

From the past data, it was observed that the total manganese in the Salaulim reservoir had increased sporadically. This may be because the water is pumped from the hypolimnion layer which has anoxic conditions that help in dissolution of manganese stored in the sediments that have settled over the years. Another reason could be the sediments coming along with the runoff from the mines in vicinity.

Considering this background some of the potential measures could be:

⁷ For more details: <http://en.wikipedia.org/wiki/Hypolimnion>

- Pumping of raw water from the middle layer instead of lower most (hypolimnion) layer
- Depth integrated sampling and analysis of the water samples at different parts of the reservoir should be done to study the behaviour of the pollutant
- Aeration to increase dissolved oxygen
- Use of activated carbon/adsorbent as a tertiary treatment could be explored and studied

4.4 Institutional and governance measures

1. Source water protection committee comprising of members from different government departments such as WRD, PWD, DoMG and GSPCB should be constituted. The committee should be dedicated to taking action to prevent pollution in the watersheds which contribute to water supply reservoirs of the State including Salaulim
2. Regular monitoring of surface and groundwater quality and levels should be carried out to keep a check. For observing the impact on deeper aquifers, shallow and deep piezometers should be constructed close to the mine area for monitoring the water levels in the shallow and deeper aquifers respectively. The location for these piezometers should be finalized in consultation with Central Ground water Board.
3. The current working mines should strictly implement all the control measures to prevent water pollution and should adhere to proper management plan at the time of closure. New mining activity should not be allowed in the immediate vicinity of the reservoir and especially in the micro-watersheds that have been identified as areas of high erosion potential
4. The rehabilitation of abandoned pits and dumps and de-silting of stream and nallahs due to past mining activities should be taken up on an urgent basis. This activity should be initiated by the government with the involvement of the mining companies
5. Dumps which are stabilized over the years and have established vegetation should not be disturbed. The slopes of these dumps should be checked and maintained below 10%. In future dumping of mining rejects should not be allowed within 500 m from the reservoir
6. Washing of trucks and runoff from haul roads should be curtailed
7. Strict adherence with the national, local environmental standards/laws and EMP's for mining lease areas to minimize water pollution

5 Conclusions and Recommendations

The overall objective of this study was to assess the impact of mining. The catchment of Salaulim reservoir in South Goa was identified as the study area. Field investigations were carried out to delineate the watershed, identify the mining locations, assess the surface water quality including estimation of sediment load, groundwater development and quality. The study spanned over one and half years and three season monitoring was carried out. Based on the findings following conclusions are made. The recommendations for better management are presented in the next section.

5.1 Conclusions

- There are three different sub watersheds that contribute surface as well as groundwater to the Salaulim reservoir covering a total area of 180 km² and a reservoir area of 26 km².
- Nearly 87% of the watershed is covered by forest, agriculture and plantations while around 13% is covered with human settlements, mining leases/dumps and water spread area.
- There are three active working mines in Curpem sub watershed and one in Guleli sub watershed. Therefore total of four active mines have been recorded from field survey and satellite image mapping.
- There are five abandoned mines of which four are located in Curpem sub watershed and one in Guleli sub watershed.
- The minute survey using satellite image has indicated presence of 17 very old and abandoned mine workings of which 15 are located in Curpem and Guleli sub watersheds and two in Kumbhari sub watershed.
- There are five laterite quarries lying in the extreme northern part of the Curpem sub watershed.
- The surface water in the study area was monitored at seven perennial locations and a total annual sediment load of 33993 tonnes was estimated. The highest sediment load was found in Kumbhari followed by Guleli River. The sediment load is a cumulative effect of erosion due to natural topography and silt runoff from the mining dumps.
- The groundwater availability in three watersheds worked out to be 192 hectare meter per annum and the present stage of groundwater development is 38.84% which is classified as 'Safe' according to the CGWB norms.
- The groundwater mainly gets recharge from the forested areas as compared to the low lying plain areas. It gets discharged in the low lying paddy fields, reservoir and rivers.
- Well hydrographs that were plotted using secondary data from CGWB indicate that there is no decrease in groundwater levels in the study area. However, a decreasing trend was observed in a well which lies close to the watershed but not within it. Taking this as an indication, judicious development/withdrawal of groundwater in future is warranted.

- The surface water quality was monitored for three seasons and compared to IS: 2296, Surface water quality standard for Class A. It was observed that the iron and manganese concentrations usually exceed the limit during monsoon and vary on daily basis. Around 54.3% of the total number of samples that were collected exceeded the prescribed limit for iron whereas 11.4% were beyond the permissible limit in case of manganese during early monsoon indicating the first flush effect. This water needs treatment before drinking. The other physico-chemical parameters were within the respective standard limit.
- There was an increase in suspended solid concentration during the monsoon season in the groundwater wells located near the active mines. The TSS, iron and manganese concentrations were within the limit. The groundwater flow net analysis was carried out to understand the potential pathway of contaminant. The preliminary observation was that the iron concentration was more at the wells closer to the mine and decreased with the increase in the distance. However, more data would be required to analyse the trend, expected rate and chemical alterations during transport before drawing any conclusion.
- The groundwater was also monitored for locations in vicinity of abandoned or old working mines. The iron concentration exceeded the standards at two locations during monsoon and the manganese was beyond limit in case of three locations at least in one season. The groundwater flow net analysis revealed that these locations were in the downstream direction of the old/abandoned mines which could be the reason for pollution.
- Past ten years secondary data on raw water quality from the laboratory based at the water treatment plant and the rainfall during that period was used for trend analysis. It was found that both iron and manganese concentration rise beyond the permissible limit mostly during the monsoon season indicating the contribution due to surface runoff during this period. Further, there is an increasing trend in the highest value of iron concentration over the years. The highest recorded value did not surpass the standards in 2004 however has been going beyond the limit in the later/current years. In case of manganese, the increase in concentration is also during monsoon season and has been exceeding the limit since the year 1993 as indicated by NEERI study. This may be attributed to the background level in the reservoir.
- It is anticipated that there could be a collective effect of active mine and approach roads, old and abandoned mines/dumps, and laterite quarries on water quality in the area.

5.2 Recommendations

A holistic approach is essential to control and prevent further adverse impact on the Salaulim reservoir owing to point and non-point sources of pollution. For attaining the desired objective of minimizing the negative impact on water quality and quantity, four strategies are proposed which should be implemented concurrently. These include:

1. Preventive measures for control of soil erosion at sensitive areas in the watershed

The micro-watersheds in the catchment of Salaulim reservoir that are prone to severe erosion have been identified along with the streams that contribute high sediment load. These areas require implementation of soil conservation measures on urgent basis. The state-of-art control measures for sediment management were reviewed. The measures that are

suitable for the area include non-structural and structural measures and have been discussed at length in the previous sections of the report.

2. Control measures at the mining sites/leases and dumps

The key sources within the mining lease area that add to the sediment load are (i) runoff within the mine lease area (ii) dewatering of mine pit water (iii) runoff from the dump. To address these localized issues robust measures entailing the best management plan (BMP) for handling mine site water are presented in the report. These measures should be strictly practiced by all the mine operators. Good practices in terms of dump management have been discussed and needs strict compliance.

3. Treatment measures to improve raw water quality at the reservoir

The thermal stratification of the reservoir and its effect on the behaviour of pollutants (i.e. iron and manganese) has been addressed in the report. Some of the key recommendations to manage the background pollutant levels to enhance raw water quality are: (i) pumping of raw water from the middle layer instead of lower most (hypolimnion) layer (ii) aeration to increase dissolved oxygen (iii) depth integrated sampling and analysis of the water samples at different parts of the reservoir should be done to study the behaviour of the pollutant

4. Institutional and governance measures

- Source water protection committee comprising of members from different government departments such as WRD, PWD, DoMG and GSPCB should be constituted. The committee should be dedicated to taking action to prevent pollution in the watersheds which contribute to water supply reservoirs of the State including Salaulim
- Regular monitoring of surface and groundwater quality and levels should be carried out to keep a check. For observing the impact on deeper aquifers, shallow and deep piezometers should be constructed close to the mine area for monitoring the water levels in the shallow and deeper aquifers respectively. The location for these piezometers should be finalized in consultation with Central Ground water Board
- The current working mines should strictly implement all the control measures to prevent water pollution and should adhere to proper management plan at the time of closure. New mining activity should not be allowed in the immediate vicinity of the reservoir and especially in the micro-watersheds that have been identified as areas of high erosion potential
- The rehabilitation of abandoned pits and dumps and de-silting of stream and nallahs due to past mining activities should be taken up on an urgent basis. This activity should be initiated by the government with the involvement of the mining companies
- Monitoring of water quality of mine water discharge, local river/nallah and domestic water (dug well/hand pumps) should be conducted as per approved calendar in order to evaluate the performance of the mitigation measures
- Dumps which are stabilized over the years and have established vegetation should not be disturbed. The slopes of these dumps should be checked and maintained below 10%
- Washing of trucks and runoff from haul roads should be curtailed. Strict adherence with the national and local environmental standards/laws including EMP's made for the mining leases to minimize water pollution

Annexure I: Impacts on water bodies due to mining

Village	Mining activities	Water bodies and total stretch (km)	Impacted stretch (km)	Contributing factors
Bicholim	Mine dumps -8 Pits - 4 B Plant -1 T Pond - 2	Bicholim river - 7.25 Lamgao stream - 1.4 Other streams - 9.4	3.15 1.4 Nil	Effluent from 2 tailing ponds and confluence of silted Lamgao stream. Carries silts due to runoffs from mine dumps at Lamgao village
Sirigao	Pits - 5 Mine dumps - 7 Stockyard - 1	Assonara - 7.1	1.82	Stockyard and associated activities and the discharge of pit water. The pit water travels a large distance before joining Assonara river
Mayem	Mine dumps - 33 Pits - 7 T Ponds - 1 B Plant - 2	Other streams - 19.22 Assonara -8.55 Mayem lake - 0	7.3 1.39 Nil	Runoff from 18 mine dumps and seepage water from a tailing pond. Runoffs from 5 mine dumps and a stock yard located in Sirigao village
Piligao	Stockyard - 1 B Plant - 1 Mine dumps - 1 Tailing pond - 2	Sanquelim - 1.84 Mandovi - 2.41 Bicholim - 2.43 Other streams - 6.54	Nil 0.5 Nil 0.5	Stockyard Beneficiation Plant
Carapur	None	Bicholim river stretch is already accounted in Piligao. Sanquelim river is discussed below. Other streams - 3.72	Nil Entire stretch Nil	Mining activities of neighbouring villages
Adwalpale	Pit - 2 Mine dumps - 4	Other streams - 11.7	1.35	One wet pit and one dump
Maulinguem south	Mine dump - 13 Pits - 6 B Plant - 1 T Pond - 3	Cudnem nallah - 2.76 Other streams - 1.59 Sanquelim - 2.16	2.76 1.59 1.23	Runoffs from 6dumps present in adjacent Cudnem village and upstream mining activities 5dumps; 1 wet pit & 2 tailing ponds 1 dump and 2 wet pits
Arvalem	Pits - 4 Mine dumps - 2	Other stream - 3.31 Arvalem river - 4.75 Cudnem river - 2.33 Sonshi nallah - 0.53	1.0 Nil 2.33 0.53	4 mine pits & 1 dump Due to upstream mining activity Upstream mining activity

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Village	Mining activities	Water bodies and total stretch (km)	Impacted stretch (km)	Contributing factors
Onda	Pits – 2 Mine dumps – 3 B Plant – 1	Other streams – 6.91 Sonshi nallah – 1.8	Nil 1.8	Upstream mining activities
Cudnem	Pits – 6 Dumps – 20 B Plant – 1	Other streams joining Cudnem nallah – 2.12	2.12	Runoff from dumps and discharge from 4 pits
Sonshi	Pits – 11 Dumps – 16 B Plant – 1	Sonshi nallah – 3.8 Tributary of Advai – 5.7	3.8 2.31	All mining activities in the village Mine dumps
Pissurlem	Pits – 10 Dumps – 12 B Plant – 1	Pissurlem nallah – 2.6 Advai tributary – 1.15	Nil 0.8	5 dumps, 3 pits
Surla	Pit – 6 Dumps – 18 B Plant – 1 Stockyard - 1	Surla nallah – 8.23 Velguem river – 1.62 Other stream – 1.66 Mandovi – 2.8	1.81 Nil 0.6 1.3	Confluence of silted Surla nallah 2 dumps Stockyard related activities
Velguem	Pits – 3 Dumps - 14	Velguem river – 2.4	0.93	2 dumps of this village and 3 from adjacent village
Pale	Pit – 6 T Pond – 2 B Plant – 1 Dumps - 32	Madei river – 8.5 Other streams – 11.06 Mandovi – 0.87	2.17 3.65 Nil	2 pits & 5 dumps 1 tailing pond & 7 dumps
Cotombi	Dumps – 2 Pit – 1 B Plants – 2 T pond – 1 Stockyard - 5	Mandovi river – 6.45 Other streams – 2.95	6.45 1.37	Stockyards related activities 4 dumps and 1 stockyard
Vantem & Ponocem	Dumps – 7 Pits – 4	Vantem nallah – 4.19 Other streams – 4.09 (meets Advei nallah) Medai – 2 Advei -1.06	1.9 Nil Nil Nil	Mine dumps
Amona	Dumps – 1 Stockyards – 1 B Plant – 2 T Pond - 1	Mandovi river – 3.59 Other streams – 1.78 Surla nallah – 0.8	0.4 1.61 Nil	Stockyard associated activities, dump and beneficiation plant
Navelim	T ponds – 2 B Plant – 1 Stockyards – 2 Pits – 1 Dump - 1	Mandovi – 4.2 Other streams – 6.14	1.53 0.4	Stockyard related activities

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Village	Mining activities	Water bodies and total stretch (km)	Impacted stretch (km)	Contributing factors
Caranguinim	B Plant – 1 T ponds - 3	Other streams – 10.53	0.46	Runoff from one dump and seepage water from 2 tailing ponds
Antoriem	Pits - 2	Other streams – 5.61	0.2	Discharge from pits
Sanvordem	Pits – 1 Dumps - 2	Zuari river – 3.35 Other streams – 10.23	Nil 0.7	Discharge from pits
Camarconda	Pits – 1 Dumps - 1	Other streams – 7.55	0.55	Dump and pit
Bandoli	Dumps – 3 Pits - 4	Other streams – 15.5	1.3	Dumps & pits
Calem	Dumps – 5 Dry pits - 5	Kalay river – 20.2 Other streams – 56.1	0.5 0.3	Discharge from pit 1 dry pit and beneficiation plant
Dudal	Dump – 8 Pits – 6 T ponds - 1	Other streams – 1.56	1.5	Discharge from pits and runoff from dumps
Darbandora	Pits – 24 Dumps - 22	Khandepar river – 10.63 Other stream – 78.19 Ragada nadi – 2.02	10.63 0.99 Nil	Mining activity in this and adjacent village
Codli	Pits – 17 Dumps – 24 B Plants – 2 T Ponds - 6	Khandepar river – 9.34 Other streams – 29.57 Perennial stream - 7	9.34 Nil Nil	Pit water discharge and runoff from mine dumps
Sancordem	Pits – 13 Dumps - 10	Ragada river – 11.3 Other streams – 33.6	0.3 2.8	1 wet pit 3 dry pits and 5 mine dumps
Cormonem	Pits – 2 Dumps – 5 T pond – 7 B Plant - 1	Kalay – 4.34 Other stream – 4.98	1.1	2 wet pits and 3 dumps of which 1 lies in Codli
Sigao	Pits – 10 Dump - 14	Dudhsagar – 9.51 Other stream – 32.2	4.3	Mining activities nearby
Santona	Pits – 14 Dumps – 18 B Plant – 2 T pond - 2	Other streams – 13.39	1.5	4 dry pits and 5 dumps
Tudou	Pits – 16 Dumps - 19	Streams – 27.9	0.94	2 dumps and 1 wet pit
Portem	Pits – 8 Dumps - 2	Streams 73.4	0.3	3 dry pits and 1 dump

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Village	Mining activities	Water bodies and total stretch (km)	Impacted stretch (km)	Contributing factors
Bati	Pits – 39 Dumps - 29	Streams – 36.7	3.5	Mining activities

Source: TERI (1997)

Annexure II: List of working mines in 2010-11

S.No	Name of the lessee	Lease No	Village	Taluka	Water Body(Dam/Lake) (km)	Streams/Nallah (km)	Main River (km)
1	M/s Chowgule & Co. Ltd	005/49	Sirigao	Bicholim		1.28	2.13
2	M/s Chowgule & Co. Ltd	13/49	Maem	Bicholim		0.87	2.88
3	M/s Chowgule & Co. Ltd	31/53	Pale	Bicholim			2.33
4	M/s Dempo Mining Corp. Pvt Ltd.	011/41	Langao, Maem	Bicholim	0.83		
5	M/s Sesa Goa Ltd	010/49	Maulinguem	Bicholim	2.5	0.72	
6	M/s Soc. Timblo Irmaos Ltda (S.F.I)	45/52	Cudnem	Bicholim	3.12	1.2	
7	M/s Soc. Timblo Irmaos Ltda (T.P.L)	92/52	Cudnem	Bicholim	3.5		3.9
8	M/s V.M.Salgaocar & Bro. Pvt Ltd	83/52	Surla	Bicholim			2.5
9	M/s V.M.Salgaocar & Bro. Pvt Ltd	29/54	Sonus-Volvoliem	Bicholim			1.8
10	M/s V.S. Dempo & Co. Pvt. Ltd	21/54	Surla	Bicholim	3.3	0.25	
11	M/s Soc. Timblo Irmaos Ltda (P.T.I)	35/55	Pale	Bicholim			1.12
12	M/s Rajaram Bandekar (s) mines Pvt Ltd	004/49	Sirigao	Bicholim		0.71	2.36
13	Smt. Sunanda D Bandodkar (Late)	62A/52	Velguem	Bicholim			2.93
14	M/s Bandekar Bros. Pvt Ltd.	84/52	Pale	Bicholim			0.88

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.No	Name of the lessee	Lease No	Village	Taluka	Water Body(Dam/Lake) (km)	Streams/Nallah (km)	Main River (km)
15	M/s Lithoferro	89/52	Advalpale	Bicholim		2.6	2.6
16	V.M. Salgaocar & Bro. (Sallitho)	86/53	Pale	Bicholim			0.73
17	Smt Kunda Gharse	51/52	Cudnem	Bicholim	3.65	0.32	
18	Shri Lekhraj Nathurmal (Late)	39/53	Arvalem	Bicholim	5	1.68	
19	M/s Chowgule & Co. Ltd	31/55	Ambelim, Xelpo Curado, Gavanem	Sattari			0.54
20	M/s Chowgule & Co. Ltd	98/52	Onda, Cudnem	Sattari		0.44	6
21	M/s Chowgule & Co. Ltd	41/56	Velguem, Poncem	Sattari			1.38
22	M/s Sesa Goa Ltd	28/51	Pissurlem	Sattari			5.42
23	M/s V.S. Dempo & Co. Pvt. Ltd	005/54	Cudne, Sonshi	Sattari		3.17	4.48
24	Smt. Geetabai M Parulekar	55/51	Pissurlem	Sattari			6.16
25	M/s R.S. Shetye & Bros	70/51	Pissurlem	Sattari			5.62
26	M/s Cosme Costa & Sons	110/53	Pissurlem	Sattari			4.93
27	Shri. V.G. Quenim (Late)	16/55	Sonus, Vonvoilem	Sattari		1.31	4.68
28	M/s Sesa Goa Ltd	006/55	Honda	Sattari			4.74
29	M/s Chowgule & Co. Ltd	22/50	Costi	Sanguem			0.7
30	M/s Sesa Goa Ltd	70/52	Codli	Sanguem			0.25
31	M/s Sesa Goa	126/53	Codli	Sanguem			0.35

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.No	Name of the lessee	Lease No	Village	Taluka	Water Body(Dam/Lake) (km)	Streams/Nallah (km)	Main River (km)
	Ltd						
32	M/s Soc. Timblo Irmaos Ltda (P.T.I)	61/53	Codlim, Dharbandora	Sanguem			1.2
33	M/s Soc. Timblo Irmaos Ltda (P.T.I)	87/53	Sigao	Sanguem	2.6	0.7	
34	M/s Soc. Timblo Irmaos Ltda (P.T.I)	143/53	Sangod	Sanguem	6	1.84	4.87
35	M/s Soc. Timblo Irmaos Ltda (S.F.I)	88/52	Sigao	Sanguem			1.1
36	M/s V.M.Salgaocar & Bro. Pvt Ltd	13/55	Sigao	Sanguem			0.16
37	M/s V.M.Salgaocar & Bro. Pvt Ltd	50/53	Sigao	Sanguem			1.8
38	M/s V.S. Dempo & Co. Pvt. Ltd	35/52	Colomba	Sanguem		0.1	
39	M/s V.S. Dempo & Co. Pvt. Ltd	003/51	Curpem	Sanguem	2		
40	M/s Soc. Timblo Irmaos Ltda (T.P.L)	14/58	Codli	Sanguem			2.36
41	M/s Emco Goa Pvt Ltd	007/41	Mollem, Collem	Sanguem			0.34
42	M/s Emco Goa Pvt Ltd	23/53	Sigao	Sanguem			0.15
43	Shri V. D. Chowgule (Late)	16/51	Santona, Dudal	Sanguem			0.85
44	Shri V. D. Chowgule (Late)	40/50	Calem	Sanguem			0.44
45	M/s M.S. Talaulikar	002/51	Sancordem	Sanguem		0.62	

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.No	Name of the lessee	Lease No	Village	Taluka	Water Body(Dam/Lake) (km)	Streams/Nallah (km)	Main River (km)
	&Sons Pvt Ltd						
46	M/s Mineira National Ltd	62/51	Santona/Quir	Sanguem			1.36
47	M/s Shantilal Kushaldas & Bros. Pvt Ltd	28/52	Rivona	Sanguem			0.45
48	Sova (Balkrishna Avde)	45/54	Sangod	Sanguem			0.1
49	M/s Marzook & Cadar Ltd	004/55	Dharbandora	Sanguem			0.11
50	M/s Zarapcar & Parcar	34/55	Dabal	Sanguem			0.07
51	Shri Cipriano D'Souza (Late)	007/58	Colem/Sangod	Sanguem			0.53
52	Shri G.N. Agrawal	008/41	Sigao/Colem	Sanguem		0.54	
53	Shri Hiralal Khodidas (Late)	006/49	Colomba	Sanguem		2	5.47
54	Shri A.X. Palondicar (Late)	17/49	Colomba	Sanguem	4.9		
55	Shri Chandrakant F. Naik (Late)	63/51	Curpem	Sanguem	0.56		
56	Smt Amalia Rodrigues Fiquereido (Late)	65/51	Curpem	Sanguem	1.66		
57	Shri. N.S. Narvekar (Late)	40/51	Santona	Sanguem			0.69
58	Shri. N.S. Narvekar (Late)	012/52	Quirlapale	Sanguem	5		0.7
59	M/s Badruddin Hussainbhai Mavani	14/52	Rivona	Sanguem			0.8

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.No	Name of the lessee	Lease No	Village	Taluka	Water Body(Dam/Lake) (km)	Streams/Nallah (km)	Main River (km)
60	Shri Alexio Manuel Da Costa	005/53	Tudou/Patiem	Sanguem	2.6		0.75
61	Smt Kunda Gharse	19/54	Tudou	Sanguem	3.5		0.84
62	Smt Kunda Gharse	33/57	Patiem	Sanguem	3.5		0.84
63	Smt Kunda Gharse	003/57	Tudou	Sanguem	3.5		0.84
64	Smt. Ahiliabai Sardessai (Late)	41/54	Cormonem, Bandoli	Sanguem			1.3
65	Shri Ramchandra Velingkar	24/57	Dharbandora	Sanguem		0.09	
66	Shri Gangadhar Narsingdas Agrawal	006/61	Sigao/Colem	Sanguem			0.55
67	Shri Voicunta Canecar (Kadnekar) (Late)	75/52	Colomba	Sanguem			0.45
68	Shri Prafulla Hede	30/50	Collem	Sanguem	5.18		0.8
69	M/s Shantilal Kushaldas & Bros. Pvt Ltd	44/51	Maina	Quepem		0.81	
70	Shri Haider Kassim Khan (Late)	010/51	Sulcorna, Vichundrem	Quepem		1.71	2.83
71	Shri Zoiram Neogui (Late)	59/51	Cavorem	Quepem		1.04	
72	Shri Voicunta Canecar (Kadnekar) (Late)	012/53	Maina	Quepem		2	
73	Smt Kunda Gharse	42/56	Undorna	Quepem	2.44		0.07
74	Shri Pravin	004/68	Naquerim	Quepem			

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.No	Name of the lessee	Lease No	Village	Taluka	Water Body(Dam/Lake) (km)	Streams/Nallah (km)	Main River (km)
	Kumar S Gosalia						
75	Shri Mahabaleshwar Garco (Late)	002/57	Muguli/Costi	Sanguem	4.4		0.7
76	Shri Shaikh Mohamad Issac (late)	001/51	Cavrem	Quepem	3	3	
77	Shri X.A.X.A. Aziz S A Gofur (late)	53/51	Curpem	Sanguem	2.22	2.7	
78	M/S Soc. Timblo Irmaos Ltda (SFI)	14/53	Cudnem	Bicholim			5.37
79	M/S Damodar Mangalji & Co. Ltd	001/55	Surla	Bicholim			4.85
80	M/S Damodar Mangalji & Co. Ltd	33/53	Surla	Bicholim			0.95
81	M/S Damodar Mangalji & Co. Ltd	95/52	Pissurlem	Sattari			3.8
82	M/s Dempo Mining Corp. Pvt Ltd.	012/41	Mayem, Lamgao	Bicholim	1.36		4.6
83	M/s Dempo Mining Corp. Pvt Ltd.	13/41	Bordem, Mayem, Lamgao	Bicholim			4.2
84	M/s Dempo Mining Corp. Pvt Ltd.	14/41	Mulgao	Bicholim	0.75		3
85	M/s Dempo Mining Corp. Pvt Ltd.	15/41	Mulgao, Sirigao, Mayem	Bicholim	4.5	1.58	2.3
86	Shri Gajanan Podiyar	001/78	Molcornem	Quepem	3.3		
87	M/s V.M. Salgaocar & Bro. Ltd (SMI)	41/55	Tivim / Pirna	Bardez			3.3

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.No	Name of the lessee	Lease No	Village	Taluka	Water Body(Dam/Lake) (km)	Streams/Nallah (km)	Main River (km)
88	M/s Madachem Bat Mines Pvt Ltd	008/61	Pale	Bicholim			1.8
89	M/s Sesa Goa Ltd	76/52	Advalpale	Bicholim	3.9		3.4

Annexure III: Details of barge loading points

Company	Loading Point	Village	Capacity (MT/annum)	River	Mines served	Distance from mines (km)
Dempo	Sarmanos	Piligao	1.85	Madei	Bicholim	5
R Bandekar	Sirsaim	Adwallpale	0.57	Assnora	Sirigoa	5
Chowgule	Kalvi	Sirigoa	0.27	Mapusa	Sirigao	5
Chowgule	Khazan	Cotombi	0.99	Madei	Pale, Bimbol, Vanguriem, Onda	7,33,12,17 respectively
Sesa Goa	Amone	Amone	0.87	Madei	Sonshi, Cudnem, Xelpi,	9, 8, 20 respectively
Bandekar	Kotambi	Cotombi	1.33	Madei	Mollo, Madachem Bhat	7 each
D Mangalji	Kotambi	Cotombi	1.33	Madei	Ceavan dongor	14
D Mangalji	Navelim	Navelim	1.03	Madei	Band dhonkol, Deulem	8 each
V S Dempo	Sinori	Surla	0.86	Madei	Surla, Sonshi	6.5, 4 respectively
V M Salgaokar	Vaguriem	Cotombi	2	Madei	Velguem/Surla, Sigao, Sancordem, Cudnem	11,27,29,15 respectively
Sallitho	Vaguriem	Cotombi	2	Madei	Purmar	7
V G Quenim	Vaguriem	Cotombi	2	Madei	Sonshi	11
Timblo	Maina	Cotombi	2	Madei	Dignem	6
Sesa Goa	Sanvordem	Sanvordem	2.77	Zuari	Codli	12
R S Gharse	Sanvordem	Sanvordem	2.77	Zuari	Molia dongor	54
Dempo	Sanvordem	Sanvordem	2.77	Zuari	Kirlapale	12
Chowgules	Xelvona	Sanvordem	1.31	Zuari	Tudou, Costi, Kalay	30,16,13 respectively
Chowgules	Capxem	Sanvordem	1.33	Zuari	Emco	38
Fomentos	Capxem	Sanvordem	1.33	Zuari	Chiraband, Sigao	23, 22 respectively

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Timblo	Capxem	Sanvordem	1.33	Zuari	Nassarmordi	51
R S Gharse	Capxem	Sanvordem	1.33	Zuari	Tollem	55
Mineira Nacional	Digashi	Sanvordem	1.33	Zuari	Cuddegalivoril	11
S Kantilal	Digashi	Sanvordem	1.33	Zuari	Shanti Group	23

Source: TERI.1997. Area wide environmental quality management (AEQM) plan for the mining belt of Goa state, Report published by Directorate of Planning, Statistics & Evaluation, Govt of Goa, pg 56-57.

Annexure IV: List of seasonal streams in the catchment area

S.No.	Name	Village/Location
1.	Toliam bandzor	Salgini Verlem
2.	Milemzor	Neturlim
3.	Ondolizor	Neturlim
4.	Bandwadazor	Neturlim/Bandoda
5.	Tulezor	Kurpem
6.	Kolezor	Kurpem
7.	Satarkarzor	Kurpem/Satarkarwada
8.	Nagzar	Vichundrem
9.	Kolezor	Vichundrem/Velipwada
10.	Mesrazor	Vichundrem/Velipwada
11.	Pordzor	Vichundrem
12.	Gaonkerwadozar	Naikinim/Velxem
13.	Sotiamzor	Naikinim/Velxem
14.	Pangoriazor	Bhati
15.	Paikazor	Bhati
16.	Siddhazor	Bhati/Pattem

Source: Water Resources Department, Government of Goa

Annexure V: Existing mining leases in three watersheds

List of all mine concessions falling in Curpem watershed area

S.no	Name of lessee	T.C.no	Map no.	Area (ha)	Village	Status
1	Romano Maria R Soares of Aldona	61/51	120-R	91.4250	Curpem	
2	Vassantram G Mehta of Vasco da Gama	33/52	214	56.800	Curpem	
3	Maria Seani Raphael of Curchorim	5/41	115-R	87.200	Curpem	
4	Polo Dongor mine of Xec Abdul Gofur	53/51	107	30.22	Curpem	working
5	Vassudev M Salgaocar of Vasco da Gama	41/58	641-R	71.8800	Curpem	
6	Haji Jan Mohamed of Goa	57/51	116-R	40.6240	Curpem	
7	Shantilal Kushaldas & Bros Ltd of Margao	1/61	777	32.4315	Curpem	
8	Mrs Maria De Lourdes Filomena Figueredo De Albuquerque (operated by Sri Imran Khan) Pola Dongor	65/51	106	58.27	Curpem	working
9	Balcrisna Bahirji Patil of Margao	97/52	236	58.5100	Curpem	
10	Mussa Usman Ali of Goa	85/52	237	75.4030	Curpem	
11	Firna Mineira Nacional Ltd., of Margao	4/63	788-R	57.2990	Curdi	
12	Ramachandra Thaker of Goa	14/60	775	75.840	Curdi	
13	Noor mohammad Abdul Karim(late)	43/53	296	34.22	Curpem	abandoned
14	Sociedade Timblo Irmao Ltd., of Margao	134/53	387	51.950	Curpem	
15	Sri Salvado Fernandes (late)	48/54	440		Curpem	
16	Rajesh Timblo	63/51	195	69.4745	Curpem	working
17	M/s. Kantilal & Co Pvt Ltd (Operated by A Salgaonkar)	60/52	194	43.63	Curdi	
18	Firma Metha & Cia Ltd., of Vasco da Gama	14/50	104	33.7878	Curdi	abandoned
19	M/s. Shantilal Khushaldas & Bro Pvt Ltd	55/52	193	91.7400	Curdi	
20	Mucunda Sazu S Salelcar of Sanguem	36/59	707	96.5300	Curdi	
21	M/s. Sova	13/54	410	29.8500	Curdi	
22	Esvonta Visnum P Raiturcar of Margao	37/53	246	32.00	Curdi	
23	N.S. Narvekar (late)	32/53	247	68	Curdi	
24	Xantarama V Curdicar of Curdi	33/50	77	23.3240	Curdi	
25	Narahari Siurama X Narvecar of Goa	44/59	713	73.4870	Curdi	

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.no	Name of lessee	T.C.no	Map no.	Area (ha)	Village	Status
26	Xembu Zoidev X Moratto of Sanguem	45/51	78	93.1000	Undorna	
27	Gopinath S Garco (late)	11/56	498	93.95	Undorna	abandoned
28	Gopinath Sinai Garco of Agacaim	34/59	705	20.0000	Curdi	
29	Xec Ayub of Sanguem	49/59	718	21.5100	Curdi	
30	Firma Kantilal & Cia Ltd., of Margao	62/59	729	87.2000	Salaulim	
31	M/s. Shantilal Khushaldas & Bro Pvt Ltd	60/53	313	96.28	Undorna	
32	Data not available, Lease in Reservoir		331	Not available		
33	S Kantilal & Cia Ltd., of margao	5/60	764	94.5200	Salaulim	
34	Babol Sanvlo N Tari of Sanguem	91/52	248	94.5000	Cotarli & Xelpem	abandoned
35	Abdul Aziz Mahomed Jalal of Goa	7/57	545	89.6000	Xelpem	
36	Pundolica P Xete Narvecar of Sanguem	128/53	381	44.7750	Salaulim	
37	Quessova Sinai Cundo of Margao	30/55	479	49.7000	Xelpem	
38	Firma S Kantilal & Cia Ltd., of Margao	3/49	68	99.7319	Salaulim	

R- These concessions are common in adjacent watersheds of Guleli and Kumbhari Rivers. Therefore total of **38 mining concessions** including 5 common concessions fall in Curpem watershed covering mainly Curpem and Curdi villages.

List of all mine concessions falling in Guleli River watershed area

S.no	Name of lessee	T.C.no	Map no.	Area (ha)	Village	Status
1	Sociedade Nacional Agency of Ponda	2/49	154	93.7677	salaulim	
2	Roguvir Naraina Lotlecar of Margao	16/50	150	56.5812	Verlem	
3	Roguvir Naraina Lotlecar of Margao	15/50	149	70.2890	Verlem	
4	Xec Alub of Sanguem	19/53	148	80.2600	Tudou of Verlem	
5	Gurudas Timblo of Margao	51/51	153	67.4820	Verlem	
6	Vincente Joao Filomeno Figueiredo of Loutuli	44/53	297	46.6580	Verlem	
7	Govonda Poi Cano of Margao	9/57	547	62.3600	Verlem	
8	Shashikant R S Moraskar of Sanguem	15/56	502	76.8000	Verlem	
9	Jose Azavedo Duarte of Sanguem	54/51	152	36.1590	Verlem	
10	Timblo Irmaos Ltd., of Margao	1/41	151	64.5000	Verlem	
11	Xec Hussein of Margao	22/52	222	31.1450	Tudou	
12	Hajijan Mahomed of Goa	34/54	430	67.2200	Sulcorna	
13	Xec Issac X Jaffar of Vaco da Gama	23/52	221	62.7200	Cunguem	
14	Raia Sinai Quirtonim of Goa	25/60	772	66.3100	Netorlim	
15	Datatraia R Porobo Dessai of Netorlim	63/53	316	91.6980	Neturlim	
16	Gangadhar Narsingdas Agrawal of Margao	35/50	145	99.1760	Neturlim	
17	Gangadhar Narsingdas Agrawal of Margao	36/50	144	87.8000	Neturlim	
18	Sociedade N.B. Kamat % Sons Ltd., of Margoa	25/51	146	20.1600	Neturlim	
19	Xec Ismail C/o Smt Apizambi of Margao	63/52	220	97.4200	Neturlim	
20	Gurudas Timblo of Margao	23/51	147	69.3524	Tudou of Verlem	
21	Abdul Satar Abdul Kadar Soudagar of Margao	20/53	241	52.3200	Neturlim	
22	Vassudev Naraina Sarmalcar of Margao	6/51	142	35.3130	Neturlim	
23	Vincente J.F. Figueiredo of Lotlim	48/51	143	100.000	Neturlim	
24	Firma Oriente Ltd., of Margao	15/53	239	58.3500	Neturlim	
25	Rajaram naraina X Bandekar & Co Pvt Ltd of Vasco da Gama	10/41	140	98.8264	Nundem	
26	Firma S Kantilal & Cia Ltd., of Margao	70/53	323	22.2000	Neturlim	
27	S Kantilal & Cia Ltd., of Margao	17/51	141	44.0750	Neturlim	

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.no	Name of lessee	T.C.no	Map no.	Area (ha)	Village	Status
28	Sociedade Timblo Irmaos Ltd., of Margao	81/52	229	36.1000	Neturlim	
29	Mineira Prometedora Ltd., of Neturlim	32/51	138	37.2600	Neturlim	
30	Roguvira N Lotlecar of Margao	103/52	238	49.6920	Neturlim	
31	Vassanta Balcrisna Camotim of Margao	18/51	137	39.6000	Neturlim	
32	Firma S Kantilal & Cia Ltd., of Margao	67/51	139	34.0000	Rumade of Neturlim	
33	Esvonta Visnum P Raiturcar of Margao	36/53	245	44.0310	Neturlim	
34	Raia Porobo Batcar of Sanguem	8/54	405	43.2000	Mangal	
35	Vassudev Guiri Quenim of Goa	3/63	787	77.8940	Bali	
36	Crisna Mucunda Camotim of Assolna	6/53	240	58.6400	Jaqui of Neturlim	
37	Data not available	27/50	135			
38	Firma Shantilal Kushaldas & Bros., of Margao	42/51	136	63.0480	Neturlim	
39	Ramanta N Corpo of Sanguem	30/51	127	25.5000	Neturlim	
40	Damodar Ananta Sinai Bobo of Nerul	85/53	338	36.0500	Neturlim	
41	Vichundrem Iron ore mine of Sri Velingkar	67/52	217	59.8180	Netorlim	
42	Atchuta Vishnu S Velingcar of Velinga	7/52	218	59.8180	Vichundre of Neturli	
43	Harichondra S.N. Tari of Sanguem	21/52	219	60.6502	Vichundre	
44	Atchutta Panduronga P Dessai of Neturlim	26/53	244	75.1345	Vichundre	
45	Firma Chowgule & Cia Ltd., of Marmagao	21/50	134	51.3287	Vichundre	
46	Sociedade Timblo Irmao Ltd., of Margao	132/53	385	94.6400	Vichundre	
47	Hiru Bombo Gaunco of Margao	38/52	215	100.000	Vichundre	Abandoned
48	Xeque Hussen of Margao	34/53	243	98.8200	Vichundre	
49	Xec Ali Xec Abdul Sharan of Sanguem	12/50	125	100.000	Neturlim	
50	Francisca Sequeira of Nuvem	12/51	126	46.5280	Neturlim	
51	Sociedade Timblo Irmaos Ltd., of Margao	30/53	242	30.8625	Neturlim	
52	Domingos Jose Fernandes of Aldona	1/31	124	97.3000	Netrulim	
53	Abdul Karim Noor Mohamed of Panajim	24/52	192	38.3250	Vadem	
54	Xec Cadar Xec Usman of Goa	120/53	373	38.0400	Vichundre	
55	Marga Fondcul or Chicolmolo mine of M/s. Compania Minerira Progresso Ltda	6/63	790	80.600	Vichundre & Curpem	

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.no	Name of lessee	T.C.no	Map no.	Area (ha)	Village	Status
	operated by Sri Velingkar					
56	Sri Muhamad Usman Muhamad Hassan	10/50	119		Curpem	
57	Canvorizoritembo Motatembo Bandoli Dongor mine of Sri Bhanudas B.S. Kossambe operated by....	9/51	121	98.9684	Curpem & Vichundre	
58	Romano Maria R Soares of Aldona	61/51	120-R	91.4250	Curpem	
59	Maria Severina Fernandes ora Camilo Agostinho Elias Fernandes of Aldona	1/29	123	100.000	Vadem	
60	Vangi Bindi Advona iron ore mine M/s. Haidar kasim Khan operated by Sri Dinar Tarcar	10/51	128	83.0666	Sulcorna & Vichundre	
61	Firma Chowgule & Cia Ltd., of Vasco da Gama	57/53	310	99.3320	Sulcorna & Curpem	
62	Sri Xec Abdul Gofur Xec Abdul Aziz (late)	37/51	117	36.9435	Curpem	
63	M/s. V.S.Dempo & Co. Pvt Ltd	03/51	118	97.6775	Curpem Sulcorna	working
64	Hiru Bombo Gaunco of Margao	1/47	129	20.0000	Vichundre	
65	Prabacar Datarama S Curchorcar of Curchozem	8/53	251	46.7450	Vichundre	
66	Firma V.S. Dempo & Cia Ltd., of Goa	40/54	457	51.0500	Curpem	
67	Maria Seani Raphael of Curchozem	5/41	115-R	87.2000	Curpem	
68	Vassudeva M Salgaocar of Vasco da Gama	41/58	641-R	71.8800	Curpem	
69	Haji Jan Mohamed of Goa	57/51	116-R	40.6240	Curpem	

R- These concessions are common in adjacent watersheds of Curpem and Kumbhari River. Therefore total of 69 mining concessions fall in Guleli River watershed covering mainly Sulcornem and Vichundrem villages.

List of all mine concessions falling in Kumbhari River watershed area

S.no	Name of lessee	T.C.no	Map no.	Area (ha)	Village	Status
1	Narandas Poptlal of Goa	5/55	444	60.9638	Sigonem	
2	Agostinho Franscisco de Braganca of Goa	36/54	432(a)	72.6183	Cumbari	
3	Raugi Chondru S Cuvelcar of Margao	66/52	227	31.84	Sigonem	
4	S Kantilal Cia & Co Ltd., of Margao	43/54	458	60.1920	Cumbari	
5	Hirabai Hegde of Margao	20/56	507	52.8200	Cumbari	
6	Tamhempton Peshottom Dawar of Belgao represented by his Attorney Venkatraman P.S. Suquercar of Margao	4/41	71	76.2600	Cumbari	
7	Firma Metha & Cia Ltd., of Vasco da Gama	79/52	228	27.5400	Cumbari of Bati	
8	Panduronga Timblo Industries Ltd., of Margao	37/50	183	69.8630	Batie Cumbari	
9	S Kantilal & Cia Ltd., Margao	31/57	570	98.3600	Cumbari	
10	Firma S Kantilal & Cia Ltd., of Margao	61/52	185	50.8200	Bati & Cumbari	
11	Firma Damodar Mangalji & Cia Ltd., of Goa	71/52	186	30.0000	Villien	
12	Quexova Sinai Cundo of Margao	65/52	184	21.7000	Villien	
13	Firma S Kantilal & Cia Ltd., of Margao	17/52	187	94.9000	Villien	
14	Firma S Kantilal & Cia Ltd., of Margao	96/52	250	32.0000	Villien of Bati	
15	Prabacar Fottu Dessai of Margao	118/53	371	41.2125	Vargurbe	
16	Xec Aiub of Sanguem	20/52	188	32.2000	Villien of Bati	
17	Firma S Kantilal & Cia Ltd., of Margao	5/50	74	72.2313	Villien	
18	Sripad Voicunta Naique of Bicholim	64/53	318	76.7500	Cotorem	
19	Firma S Kantilal & Cia of Margao	18/52	189	46.8900	Villien of Bati	
20	Gurudas Timblo of Margao	7/51	75	92.6600	Dongor	
21	Govinda S. Q. Agxicar of Goa	36/51	76	85.50	Dongor Naiquini	
22	S Kantilal & Cia Ltd., of Margao	35/53	249	30.5840	Vadem & Sigonem	
23	Firma S Kantilal & Cia Ltd., Margao	50/52	190	48.2000	Naiquini	
24	S Kantilal & Cia Ltd., of Margao	5/56	491	99.9900	Bati	

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S.no	Name of lessee	T.C.no	Map no.	Area (ha)	Village	Status
					Valcem	
25	Adolfo Patrocinio E Gomes of Margao	28/58	628	85.9920	Bati	
26	Tisa Morais Mining Industries of Cuncolim	61/57	595-R	99.6900	Curdi	
27	Sri Shantilal Khushaldas & Bro Pvt Ltd	12/56	499-R		Naiquini	
28	Sociedade S Kantilal & Cia Ltd., of Margao	65/59	732-R	97.3000	Curdi	
29	Firma Mineira Nacional Ltd., of Margao	4/63	788-R	57.2990	Curdi	
30	Firma Mineira Nacional Ltd., of Margao	5/63	789-R	66.3050	Curdi	
31	Tucarama P. X. Parcar of Colem	41/52	191	72.7970	Vadem	
32	Maria Severina Fernandes ora Camilo Agostinho Elias Fernandes of Aldona	1/29	123-R	100.000	Vadem	
33	Horichondra Saunlo N Tari of Sanguem	26/51	72	83.3000	Cumbari	
34	Details not available		122			
35	S Kantilal & Cia Ltd., of Margao	36/56	524	97.9400	Talauli, Bati, Cumbari	
36	Firma S Kantilal & Cia of Margao	68/59	735	23.0200	Cumbari	
37	Details not available		70			
38	Companhia de Sri Naguexa Mineira Ltd., of Bati	31/51	73	30.8592	Bati	

R- These concessions are common in adjacent watersheds of Curpem and Guleli River. Therefore total of 38 mining concessions fall in Kumbhari River watershed.

Annexure VI: Co-ordinates of all mines

Latitude and longitude of the four active working mines in the Salaulim Watershed (Source-Google Earth image dated March 2011 and ground check data)

S.No.	Longitude	Latitude	Mine map no	Lease Area(ha)	Distance from nearest reservoir point (m)
1	74.167	15.135	106	58.2700	1750
2	74.176	15.142	195	67.4745	800
3	74.164	15.131	107	30.2200	2200
4	74.173	15.114	118	97.6775	1770

Total lease area of the 4 mines is 255.6450 hectares

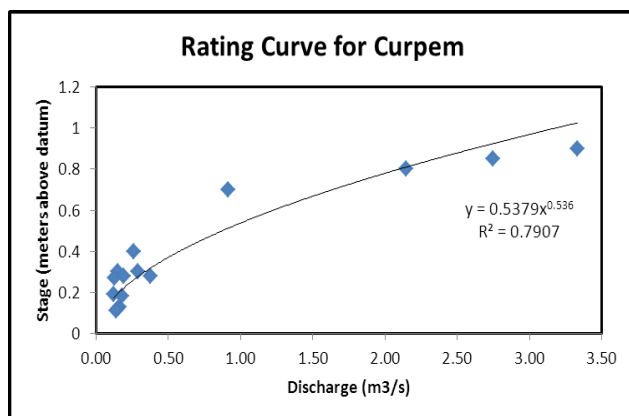
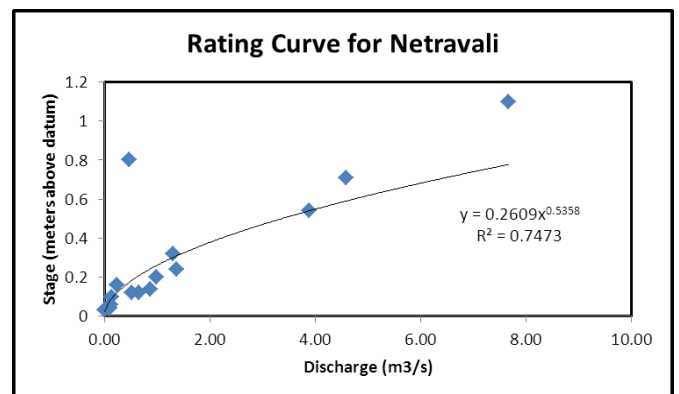
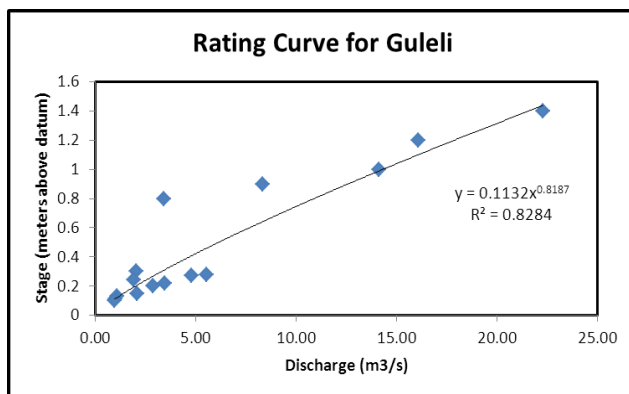
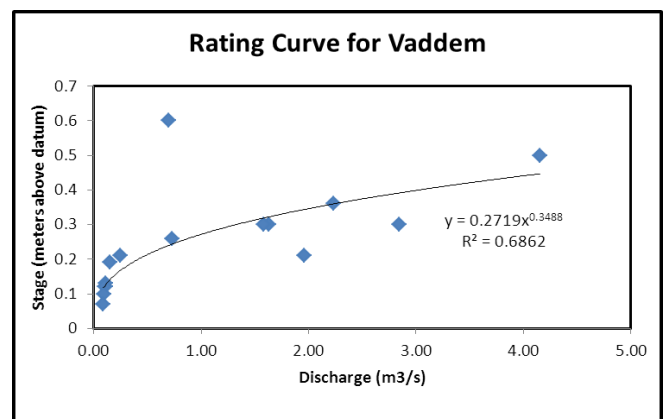
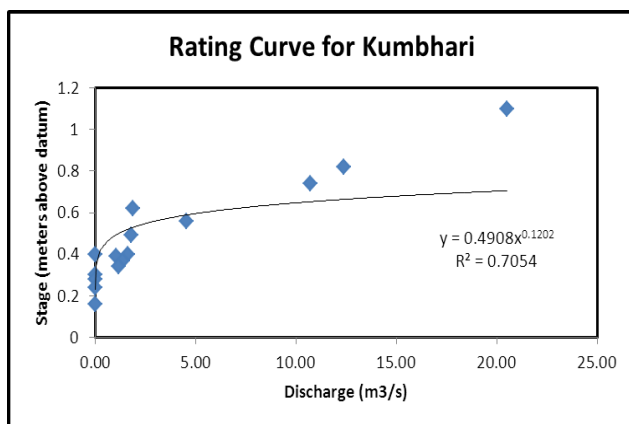
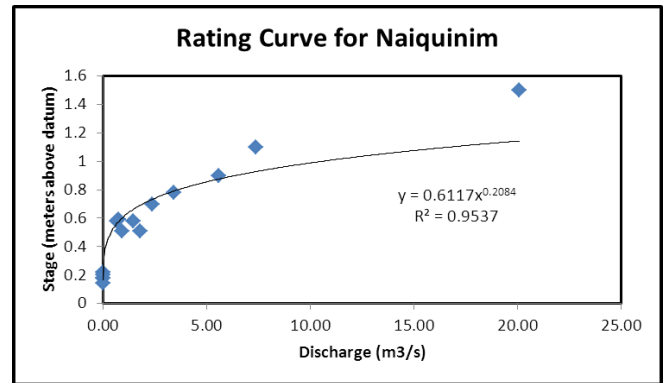
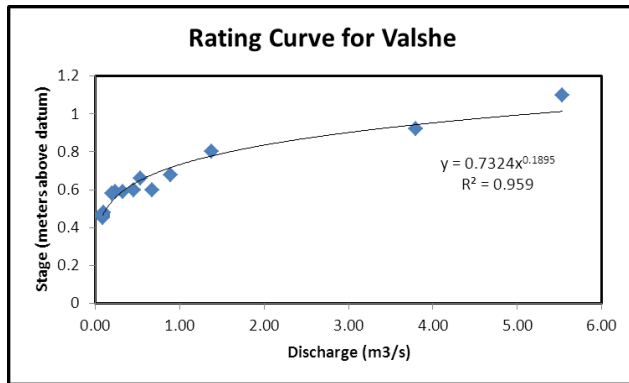
Latitude and longitude of all the five abandoned mines in the Salaulim Watershed (Source-Google Earth image dated March 2011 and ground check data)

S.No.	Longitude	Latitude	Mine map no	Lease area(ha)
1	74.15867	15.18918	248	94.50
2	74.16860	15.18734	498	93.95
3	74.16236	15.14856	104	33.78
4	74.17716	15.14239	296	34.22
5	74.18700	15.10700	215	100.00

Latitude and longitude of very old non-working mines in the Salaulim Watershed (Source-Google Earth image dated March 2011)

S.No.	Longitude	Latitude	Ground elevation(m) amsl	Mine Status
1	74.15885	15.13112	105	Very old
2	74.1587	15.13511	127	Very old
3	74.16237	15.1484	144	Very old
4	74.1634	15.12996	103	Very old
5	74.16465	15.128	154	Very old
6	74.1971	15.08585	116	Very old
7	74.19465	15.07358	145	Very old
8	74.201599	15.067887	294	Very old
9	74.211856	15.074205	182	Very old
10	74.2131	15.068212	242	Very old
11	74.245446	15.05338	598	Very old
12	74.247277	15.051067	630	Very old
13	74.248926	15.054105	539	Very old
14	74.27605	15.180916	181	Very old
15	74.24205	15.161762	128	Very old
16	74.184891	15.211304	48	Very old
17	74.186323	15.209121	52	Very old

Annexure VII: Rating Curves



Annexure VIII: Computation of sediment load

The steps used to calculate the sediment load are as follows:

STEP 1: Discharge (m^3/s) computation using following equation:

$$\text{Discharge (m}^3\text{/s)} = \text{velocity of flow (m/s)} * \text{cross-sectional area (m}^2\text{)}$$

The velocity was measured using float method and pygmy current meter. To improve accuracy, average value of the velocity measured by two methods was used. The cross-sectional area was measured for all the three seasons.

STEP 2: Calculation of Total Suspended Solids (TSS) (mg/l):

Daily samples were collected at all locations for the three seasons during the following period. The samples were taken to the laboratory and TSS was determined using standard filtration method (APHA 2005).

Post-Monsoon: Oct 20 to Nov 20, 2011

Summer: April 23 to May 23, 2012

Monsoon: July 1 to July 31, 2012

STEP 3: Conversion of discharge from (m^3/s) to (litres/day) was done as follows:

$$\text{Discharge (litres/day)} = \text{Discharge (m}^3\text{/s)} * 1000 * 86400$$

STEP 4: Conversion of TSS from (mg/l) to (kg/day) was done as follows:

$$\text{TSS (kg/day)} = \text{TSS (mg/l)} * 1000000$$

STEP 5: Calculation of sediment load (kg/day) using following equation:

$$\text{Sediment load (kg/day)} = \text{Discharge (litres/day)} * \text{TSS (kg/day)}$$

STEP 6: Conversion of sediment load from (kg/day) to (tonnes/day) was done as follows:

$$\text{Sediment load (tonnes/day)} = \text{Sediment load (kg/day)} / 1000$$

The calculations done using Steps 1 to 6 for three seasons are presented in the following tables:

Post-Monsoon (Oct-Nov 2011)							
Location	Average Discharge (m ³ /s)	Average Discharge (litres/day)	Average TSS (mg/l)	Average TSS (kg/day)	Average Sediment load (kg/day)	Average sediment load (tonne/day)	Total Sediment load (tonne)
Valshe	0.27	23328000	4.64	0.0000046	54.18	0.11	3.46
Naiquinim	0.930	80352000	4.28	0.0000043	172.18	0.34	11.01
Kumbhari	1.000	86400000	5.20	0.0000052	225.00	0.450	14.39
Vaddem	0.68	58752000	4.45	0.0000045	130.95	0.26	8.37
Guleli	4.58	395712000	4.52	0.0000045	894.34	1.79	57.18
Netravali	4.15	358560000	5.48	0.0000055	984.22	1.97	62.93
Curpem	0.30	25920000	4.27	0.0000043	55.34	0.11	3.54

Summer (May 2012)							
Location	Average Discharge (m ³ /s)	Average Discharge (litres/day)	Average TSS (mg/l)	Average TSS (kg/day)	Average Sediment load (kg/day)	Average sediment load (tonne/day)	Total Sediment load (tonne)
Valshe	0.09	7901230	12.10	0.00001210	95.65	0.0957	2.97
Naiquinim	0.003	259200	21.61	0.00002161	5.60	0.0056	0.17
Kumbhari	0.003	259200	18.548	0.00001855	4.81	0.0048	0.149
Vaddem	0.22	19008000	41.29	0.0000413	784.85	0.7848	24.33
Guleli	1.41	121824000	13.55	0.0000135	1650.52	1.6505	1.65
Netravali	0.11	9504000	15.48	0.0000155	147.16	0.1472	4.56
Curpem	0.16	14169600	13.87	0.0000139	196.55	0.1965	6.09

Monsoon (July 2012)							
Location	Average Discharge (m ³ /s)	Average Discharge (litres/day)	Average TSS (mg/l)	Average TSS (kg/day)	Average Sediment load (kg/day)	Average sediment load (tonne)	Total Sediment load (tonne)
Valshe	3.83	331263273	25.16	0.000025	8232.5	8.23	255.21
Naiquinim	2.32	200326359	53.55	0.000054	32445.2	32.45	1005.80
Kumbhari	7.70	665267014	88.61	0.000089	126329.9	126.33	3916.23
Vaddem	5.43	469161290	24.52	0.000025	13877.8	13.88	430.21
Guleli	20.08	1734772385	45.00	0.000045	66851.3	66.85	2072.39
Netravali	5.11	268627452	33.55	0.000034	13862.2	13.86	429.73
Curpem	1.93	167061176	29.68	0.000030	6062.5	6.06	187.94

STEP 7: Calculation of total sediment load

The sediment load per season (4 months) = 4 * sediment load (from Step 6)

Total Annual sediment load = Sediment load from summer + Monsoon + Post-Monsoon

Location	Sediment load (tonnes)			Annual load (tonnes) I+II+III
	Summer (Feb, March, Apr, May) (I)	Monsoon (June, July, Aug, Sept) (II)	Post-Monsoon (Oct, Nov, Dec, Jan) (III)	
Valshe	11.86	1021	13.86	1047
Naiquinim	0.69	4023	44.03	4068
Kumbhari	0.596	15665	57.54	15723
Vaddem	97.32	1721	33.49	1852
Guleli	6.60	8290	228.72	8525
Netravali	18.25	1719	251.71	1989
Curpem	24.37	752	14.15	790
Total Annual load at all locations (tonnes)		33993		

Annexure IX: Details of monitoring wells

Details of the groundwater level monitoring wells in the study area

Well no.	Village	DTWL bmp(m)*, monsoon	Total depth bmp(m)	MP ht agl*(m)	DTWL bgl ^s (m)	Shape of well	Well dia(m)	Well use	Pump fitted?
1	Curpem pornawada	0.36	0.86	0	0.36	Rectangular	3.5 x 12	Domestic	Yes
2	Curpem	2.45	6.26	0.78	1.67	Circular	3	Domestic	Yes
3	Curpem	3.5	4.5	0	3.5	Rectangular	4.25 x 2	Irrigation	Yes
4	Curpem	0.78	3.13	0	0.78	Rectangular	?	Domestic	No
5	Curpem devabhat	3.78	7.78	0.86	2.92	Circular	2.3	Domestic	No
6	Curpem chimotwada	1.17	3	0.77	0.4	Rectangular	3.05 x 6	Domestic	Yes
7	Vichundrem gollowado	0.25	0.94	0	0.25	Square	4 x 4	Irrigation	Yes
8	Vichundrem maddiwada	2.55	3.7	0.24	2.31	Circular	2	Domestic	No
9	Vichundrem	6.32	7.55	0.5	5.82	Circular	2.28	Not used	No
10	Vichundrem	3.33	7.14	0.74	2.59	Square	2.1 x 2.1	Domestic	Yes
11	Vichundrem	1.96	9.57	0.72	1.24	Circular	2.1	Domestic	Yes
12	Jaqui	5.74	8.74	0.85	4.89	Rectangular	3 x 3.38	Domestic	yes
13	Jaqui netravali	4.92	8.4	0.72	4.2	Circular	2.45	Domestic	yes
14	Jaqui	2.61	4.01	0	2.61	Rectangular	2.5 x 3.5	Irrigation	No
15	Jaqui	1.98	6.59	0.55	1.43	Rectangular	8 x 4	Domestic	yes
16	Taliwada netravali	11	12	0.35	10.65	Circular	2.4	Domestic	yes
17	Netravali vakudkamba	7.54	9.36	0.77	6.77	Circular	1.33	Domestic	yes
18	Vichundrem jamgar	10.9	14.05	0.67	10.23	Circular	2.6	Domestic	No
19	Sauri	4.1	6.51	0.85	3.25	Circular	2.4	Not used	No
20	Sauri	2.1	4	0.3	1.8	Rectangular	4 x 6	Domestic	Yes
21	Netravali talirwada	4.7	5.3	0.7	4	Circular	2.9	Domestic	Yes

Continued

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Well no.	Village	DTWL bmp(m), monsoon	Total depth bmp(m)	MP ht agl(m)	DTWL bgl(m)	Shape of well	Well dia(m)	Well use	Pump fitted?
22	Netravali	0.85	1.8	0.67	0.18	Rectangular	4.5 x 2.7	Domestic	No
23	Netravali	10.2	11.7	0.75	9.45	Circular	2.72	Domestic	No
24	Opposite temple	1.9	5.65	0.62	1.28	Circular	4.85	Domestic	No
25	Netravali	1.68	4	0	1.68	Rectangular	9 x 7	Domestic	No
26	Netravali	2.15	4.65	0.5	1.65	Circular	2.65	Domestic	No
27	Bandawada	4.35	6.6	0.8	3.55	Circular	3.7	Domestic	No
28	Bandawada	3.3	7.5	0	3.3	Rectangular	5 x 3	Domestic	No
29	Bandawada	0.1	1.8	0	0.1	Circular	6	Domestic	No
30	Bandawada	0.65	5	0.1	0.55	Circular	6.5	Domestic	No
31	Bandawada	0.2	3.75	0.1	0.1	Rectangular	3.5 x 7.8	Domestic	No
32	Bandawada	2.2	5.37	0.8	1.4	Circular	2.4	Domestic	No
33	Bandawada	2.7	5.75	0.7	2	Circular	2.3	Domestic	No
34	Netravali	1.97	3.45	0	1.97	Rectangular	6.10 x 4	Domestic	Yes
35	Netravali	5.23	7.78	0.68	4.55	Circular	2.43	Domestic	No
36	Netravali	2	9.54	0.86	1.14	Circular	2.86	Domestic	No
37	Gouliwada	6.5	7.9	0.75	5.75	Circular	2	Domestic	No
38	Neturlim	7.75	9	0.75	7	Circular	3.5	Domestic	No
39	Neturlim	9.48	10.27	0.6	8.88	Circular	2	Domestic	No
40	Neturlim	0.9	2.65	0	0.9	Circular	5.75	Domestic	No
41	Neturlim	0.87	1.4	0	0.87	Rectangular	7.1 x 8.3	Domestic	No
w1	Bhati bhilwada	2	7.68	0.68	1.32	Rectangular	1.7 x 2.1	Domestic	Yes
w2	Bhati bhilwada	0.55	2.2	0	0.55	others	3	Irrigation	No

Continued

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

Well no.	Village	DTWL bmp(m), monsoon	Total depth bmp(m)	MP ht agl(m)	DTWL bgl(m)	Shape of well	Well dia(m)	Well use	Pump fitted?
w3	Bhati	1.9	4	0	1.9	Rectangular	1.5 x 2.3	Irrigation	No
w4	Bhati bamawada	3.34	4.52	0.59	2.75	Circular	2.73	Irrigation	yes
w5	dhapadi	1.57	4.3	0	1.57	Rectangular	5 x 4	Irrigation	yes
w6	dhapadi	2.2	5.7	0.75	1.45	Circular	2.75	Domestic	No
w7	dhapadi	2.1	4.6	0.64	1.46	Rectangular	4.7 x 6	Domestic	No
w8	Bhatimal	0.44	5	0	0.44	Circular	4.7	Domestic	Yes
w9	Bhati jambowada	4.88	11.87	0.67	4.21	Circular	4.8	domestic	yes
w10	Vilyan gaudewada	4.65	8.2	0	4.65	Rectangular	8 x 6.5	Domestic	No
w11	Vilyan gaudewada	2.88	5.2	0.75	2.13	Rectangular	4.80 x 3.90	Irrigation	yes
w12	Vilyan	8	10.9	0	8	Rectangular	4.5 x 3.8	Not used	No
w13	Vilyan voilomal	2.8	5.1	0.55	2.25	Circular	1.15	Domestic	Yes
w14	Kumari	2.55	3.75	0	2.55	Rectangular	4.50 x 3.13	Irrigation	No
w15	Kumari	1.74	3.2	0	1.74	Rectangular	2.45 x 2.20	Domestic	No
w16	Vilyan	0	2.3	0	0	Circular	5.6	Irrigation	No
w17	Wadde colony1	5.54	10.24	0	5.54	Square	4.8 x 4.8	Irrigation	yes
w18	Wadde colony1	0.7	4.3	0	0.7	Rectangular	7 x 4	Irrigation	yes
w19	Wadde	2.35	5.2	0.65	1.7	Circular	4.5	Irrigation	Yes
c1	Damal savdimal	11.35	13	0.65	10.7	Square	2.85 x 2.85	Domestic	No
c2	Wade	1.15	4.1	0	1.15	Rectangular	11 x 6	Irrigation	Yes
c3	Xelpem	12.59	14.65	0.6	11.99	Circular	2.3	Not used	No
c4	Malkapan	4.26	5.85	0	4.26	Circular	5	Irrigation	No
c5	Malkapan	10.13	11.4	0.74	9.39	Circular	3.66	Domestic	No
c6	Udana	12	17.58	0	12	Square	5	Not used	No

End of Table

*DTWL- Depth to water level, BMP- Below measuring point

+ AGL - Above ground level, BGL - Below ground level, MP - Measuring Point

Annexure X: Computation of groundwater balance and state of groundwater development in the study area

1. General Introduction

Groundwater balance is a book keeping of the total inflows and out-flows in a given watershed during a given hydrological calendar year. Groundwater balance is an important activity of any hydrogeological survey. The estimation of groundwater balance of a given watershed is useful for planning for the number of pumping wells to be installed and managing of the groundwater resources for sustainable supplies. The estimation also provides information about the groundwater stress or availability status of a watershed.

2 Ground Water Estimation Methodology (1997) Format

Type of Ground Water Assessment Unit And Characteristics of Ground Water Year

1. Name of State / Union Territory: **GOA**; 2. Ground Water Assessment Year: **2011-12**

No.	Description of item	Quantity
1	Predominant type of terrain (Alluvial / Hardrock)	Hard Rock
2	Predominant monsoon (South-West / North-East)	South-West
3	If predominant monsoon is, 'South -West', the time when it usually commences (late May or early June / late June or early July)	Early June
4	Type of Ground Water Assessment Unit (Block / Taluka / Mandal / Watershed)	Watershed
5	Ground Water Year (June to May / July to June / October to September)	June to May
6	Monsoon Season (June to September / July to October / October to December)	June to September
7	Non-Monsoon Season (October to May / November to June / January to September)	October to May
8	Pre-monsoon Interval (May / June / September)	May
9	Post-monsoon Interval (October / November / January)	November

Location Details and Area of Each Ground Water Assessment Unit and Sub-Units within It

1. Name of Ground Water Assessment Unit: Salaulim Watershed

2. Index Number of Ground Water Assessment Unit: CGA-X

3. Ground Water Assessment Year: 2011-12

No.	Description of item	Quantity
1	Reference number(s) of Survey of India Toposheet(s) of 1 in 50000 scale in which the Ground Water Assessment Unit is located	48/4
2	Latitudes within which the Ground Water Assessment Unit is located; (1)Starting (2)Ending	N 15.04 N 15.22
3	Longitudes within which the Ground Water Assessment Unit is located; (1)Starting (2)Ending	E 74.14 E 74.30
4	Total area in hectares of the 'Ground Water Assessment Unit'	18000
5	Area in hectares of the 'Hilly Area'	12600
6	Area in hectares of the portion of the Ground water Assessment Unit which ground water recharge is possible [(4) – (5)]	5400

No.	Description of item	Quantity
7	Area in hectares of the 'Poor Ground Water Quality Area'	Nil
8	Area in hectares of the 'Command Area'	Nil
9	Area in hectares of the 'Non- command Area'	5400

Summary of Current Gross Ground Water Draft Components in Non- command Area

S No	Description of item(in non-command area)	Quantity
1	Current gross ground water draft for 'Irrigation' in non-command area in hectare metres (1) during monsoon season (2) during non-monsoon season	0.0 53.37
2	Current annual gross ground water draft for 'Irrigation' in non-monsoon area in hectare metres	53.37
3	Current annual gross ground water draft for 'All Uses' in non-command area in hectare metres	59.94
4	Current gross ground water draft for 'All Uses' in non-command area during monsoon season in hectare metres	6.57
5	Area in hectares of non-command area [From Table 2.1]	5400
6	Current annual gross ground water draft for 'Irrigation' in non-command area per unit area in mm [(2) / (5) * 1000]	9.88
7	Current annual gross ground water draft for 'All Uses' in non-command area per unit area in mm [(3) / (5) * 1000]	11.10

Irrigation Water Applied by Ground Water irrigation In Non-command Area

S.No (1)	Description of item (in non-command area) (2)	Quantity (3)
1	Irrigation water applied by ground water irrigation in non-command area during monsoon season in hectare metres [From Table 3.2]	0.0
2	Irrigation water applied by ground water irrigation in non-command area during non-monsoon season in hectare meters [From Table 3.2]	53.37

Water Table Data during Monsoon and Non-monsoon Seasons in Non-command Area

S. No. (1)	Name of observation well (in non-command area) (2)	Depth to water table below ground level in meters		
		In ground water assessment year during		In ground water year immediately following the ground water assessment year during
		Pre-monsoon interval (4)	Post-monsoon interval (5)	Pre-monsoon interval (6)
1	54 open wells	5.358	4.003	Not available
For the Non-command area as a whole (Av. of all wells considered)		Y1= 5.358	Y2= 4.003	Y3= not available

Return Flow Factor for computing Recharge from Irrigation Water Applied by Ground water Irrigation in Non-command Area

Sl. No. (1)	Description of item(in non-command area and underground water irrigation) (2)	Monsoon season (3)	Non-monsoon season (4)
1	Irrigated area under Paddy	Nil	1800
2	Irrigated area under Non-paddy [From Table 6.3] plantations??	Nil	Nil
3	Range of depth to water table below ground level (<10 m/10-25 m/>25 m) [From Table 6.2]	<10	<10
4	Is return flow factor for Paddy based on results from documented field studies(Yes/No)	No	No
5	Is return flow factor for Non-paddy based on results from documented field studies(yes/No)	No	No
6	Return flow factor for Paddy as a fraction [From Appendix 6.1]	0.45	0.45
7	Return flow factor for Non-paddy as a fraction [Appendix 6.1]	-	-
8	Return flow factor for the non-command area as a whole as a fraction $[(6)*(1)+(7)*(2)] / (1)+(2)$	0.0	0.45

Recharge from Irrigation Water Applied by Ground Water Irrigation in Non-command Area

Sl. No. (1)	Description of item (in non-command area) (2)	Monsoon season (3)	Non-monsoon (4)
1	Irrigation water applied by ground water irrigation in non-command area in hectare meters [From Table 6.1]	Nil	53.37
2	Return flow factor for computing recharge from irrigation water applied by ground water irrigation in non-command area as a fraction [From Table 6.4]	Nil	0.45
3	Recharge from irrigation water applied by ground water irrigation in non-command area in hectare meters $[(1)*(2)]$	0.0	24.02

Recharge from 'Other Sources' in Non-command Area

Sl. No. (1)	Type of source (in non-command area) (2)	Monsoon season (3)	Non-monsoon season (4)
1	Recharge from irrigation water applied by ground water irrigation in hectare metres [From Table 6.5]	0.0	24.02
2	Recharge from tanks and ponds in hectare metres[From Table 7.4]	Nil	Nil
3	Recharge from water conservation structures in hectare metres[From Table 8.4]	Nil	Nil
4	Recharge from 'Other sources' (a)in hectare meters(1+2+3) (b)per unit area in mm [(4a/TA')x1000]	Nil	24.02 13.34

TA=watershed area in ha.

Normal rainfall During Monsoon and non-monsoon Seasons on Non-command Area

Sl. No. (1)	Names of rain gauges applicable for non-command area (2)	Normal rainfall in mm obtained for the rain gauge during	
		Monsoon season (3)	Non-monsoon (4)
1	Sanguem	3435.42	380.54
Average of all rain gauges considered		3435.42	380.54

Rainfall Infiltration factor in Non-command Area

Sl. No.	Description of items (in non-command area)	Quantity
1	Type of predominant terrain (Alluvial/ Hardrock)	Hardrock
2	If terrain is 'Alluvial', the geographic location (Indo-Gangetic and Inland Areas/ East Coast/ West Coast)	West Coast
3	If terrain is 'Hardrock', the rock type (from list given in Appendix 10.1)	Laterite
4	Are watershed development programs with associated soil and water conservation measures carried out in the sub-unit(Yes/No)	No
5	Are results from documented field studies available for rainfall infiltration factor in the sub-unit(Yes/No)	YES
6	If response to (5) above is 'Yes' (a) rainfall infiltration factor from field studies as a fraction (b) is the value given in '6a' above less than the minimum or greater than the maximum as specified in the norms given in Appendix 10.1(Yes/No)	0.06 YES
7	Rainfall Infiltration Factor in 'Non-command Area' as a fraction	0.06

Rainfall recharge in Non-command Area by Rainfall Infiltration Factor Method

SNo. (1)	Description of item(in command area) (2)	Quantity (3)
1	Area in hectares [From Table 2.1]	5400
2	Normal rainfall during (a) Monsoon season in mm (b) Non-monsoon season in mm (c) Is non-monsoon season rainfall as a percentage of normal annual rainfall greater than 10 percent (Yes/No) [From Table 10.6]	3435.42 380.54 No
3	Rainfall infiltration factor as a fraction [From Table 10.7]	0.06
4	Rainfall recharge in non-command area by rainfall infiltration factor method in hectare metres during (a) Monsoon season $[(1)*[(2a)/1000]*(3)]$ (b) Non-monsoon season [=0 if (2c) is 'No' = $(1)*[(2b)/1000]*(3)$ if (2c) is 'Yes']	1113 0.0

Rainfall during Monsoon Season of the Current Ground Water Assessment Year in Non-command Area

Sl. No. (1)	Rain gauges applicable for non-command area	
	Name (2)	Rainfall in mm during monsoon season of current ground water assessment year as recorded in the rain gauge (3)
1	Sanguem	3800.46
2		
Monsoon season rainfall in mm during current ground water assessment year in non-command area (average of all rain gauges considered)		3800.46

Water Table fluctuations During Monsoon Season of Current Ground Water Assessment Year in Non-Command Area

Sl. No. (1)	Observation wells in non-command area		
	Name (2)	Depth to water table below ground level in metres in the observation well as recorded in current ground water assessment year	
		Pre-monsoon (3)	Post-monsoon (4)
1	54 open wells	5.067	3.998
Average of all wells considered		Y ₁ =5.067	Y ₂ =3.998

Specific Yield in non-Command Area

S.No. (1)	Description of items (in command area) (2)	Quantity (3)
1	Type of terrain (alluvial/ Hardrock)	Hard rock
2	If terrain is 'Alluvial', the soil type (Sandy/ Silty/ Clayey)	-
3	If terrain is 'Hardrock', the rock type (From list in Appendix 11.1)	Laterite
4	Are results of specific yield available from pump tests (Yes/No)	No
5	If (4) is 'yes', (a) Specific yield from pump tests as a fraction (b) Is the value in '5a' less than the minimum or greater than the maximum as specified in Appendix 11.1(Yes/No)	No
6	Is the 'Dry Season Ground Balance Method' used for computing specific yield value (Yes/No)	No
7	If (6) is 'Yes', Specific yield as a fraction from "Dry Season Ground Water Balance Method" [From Table 11.12a]	No
8	Specific Yield in Non-command Area as a Fraction [From Appendix 11.1 or from (7)]	0.03

Ground Water Balance Computations during Monsoon Season of Current Ground Water Assessment year in Non-command Area

S.No. (1)	Description of items (in non-command area) (2)	Quantity (3)
1	Area in hectares [From Table 2.1]	5400
2	Recharge from 'Other Sources' in hectare metres during monsoon season [From Table 9.2]	0.0
3	Gross ground water draft in hectare metres for 'All Uses' during monsoon season [From Table 3.2]	6.57
4	Water table fluctuation in metres during monsoon season [Table 11.11]	1.063
5	Specific yield as a fraction [From Table 11.12]	0.03
6	Change in ground water storage in hectare metres during monsoon season [(1)*(4)*(5)]	172
7	Rainfall recharge in hectare metres during monsoon season in non-command area by ground water balance approach [(6)+(3)-(2)]	178.57
8	Rainfall in mm during monsoon season in non-command area for which the rainfall recharge in (7) above corresponds to [From Table 11.10]	3800.46

Complete Set of Data on Monsoon Season Rainfall And Corresponding Rainfall Recharge in Non-command Area as Obtained by Ground water Balance Approach

Sl. No.	[From Table 11.13 of this Ground Water Assessment Report and Table 11.14 of the Previous Assessment Report]		
(1)	Ground water year (2)	Monsoon season rainfall in millimeters (3)	Rainfall recharge during monsoon season in hectare metres (4)
1	2011-12	3800.46	178.57

Valid Set of Data on Monsoon Season Rainfall and Corresponding Rainfall Recharge in Non-command Area

1. Normal Monsoon season Rainfall in Non-command Area in mm, 'NMR' =[From Table 10.6]

Sl. No.	[From Table 11.14]			Deviation of monsoon season rainfall from normal monsoon season rainfall value as a percentage (5) (3)-'NMR' [(------)*100] 'NMR'
	Ground Water year (2)	Monsoon season rainfall in mm (3)	Rainfall recharge during monsoon season in ha.m (4)	
1	2011-12	3800.46	178.57	10.62

Only those groundwater years in Table 11.14 are considered for which rainfall recharge values during monsoon season are neither negative nor nearly zero

Rainfall recharge During Monsoon Season in Non-command Area By Water Table Fluctuation Method (Using Normalization Procedure No.1)

1. Normal Monsoon Season Rainfall in Non-command Area in mm, 'NMR' =[From Table 10.6]

Sl. No.	[From Table 11.15]		Recharge corresponding to normal monsoon season rainfall in hectare metres [('NMR'*(3))/ (2)] (4)
	Rainfall during monsoon season in mm (2)	Corresponding rainfall recharge in hectare metres (3)	
1	3800.46	178.57	161.42
Rainfall recharge during monsoon season in hectare metres in non-command area by 'Water table Fluctuation Method' [Average of recharge values in Col.(4)]		178.57	161.42

Rainfall Recharge During Monsoon Season in Non-command Area After Comparing Results From Water-Table Fluctuations Method and Rainfall Infiltration Factor method

S.No.	Description of item (in non-command area)	Quantity
1	Is the water table fluctuation method used for computing rainfall recharge during monsoon season(Yes/No)	Yes
2	If response to (1) is 'No' *Rainfall recharge during monsoon season in hectare metres in non-command area (same as by rainfall infiltration factor method) [From table 10.8]	-
3	If response to (1) is 'Yes' *Rainfall recharge during monsoon season in hectare metres in non-command area (a)By Water Table Fluctuation Method [From Table 11.16 or 11.17] (b)By Rainfall Infiltration Factor Method [From Table 10.8] *Difference between (3a) and (3b) expressed as a percentage of (3b), 'PD' = $[(3a)-(3b))/(3b)]*100$ *Rainfall recharge during monsoon season in hectare metres in non-command area [= (3a if 'PD' is between -20 and +20% = 0.8*(3b) if 'PD' is less than -20% = 1.2* (3b) if 'PD' is greater than +20%]	178.57 1113.00 -83.96 890.40

Summary of Recharge from Rainfall in Non-command Area

S.No.	Description of item (in non-command area)	Quantity
1	Area in hectares [From Table 2.1]	5400
2	Is recharge from rainfall during monsoon season computed by 'water Table Fluctuation Method'(Yes/No)	Yes
3	Recharge from rainfall during monsoon season (By 'water table fluctuation method' if(2) is 'Yes', or by rainfall infiltration method if (2) is 'No') (a)in hectares meters [From Table 11.18] (b)per unit area in mm $[(3a)/(1))*1000]$	178.57 33.07

S.No.	Description of item (in non-command area)	Quantity
4	Recharge from rainfall during non-monsoon season (By rainfall infiltration factor method) (a)in hectares meters [From Table 10.8] (b)per unit area in mm [(4a)/(1))*1000]	Nil Nil
5	Annual recharge from rainfall in non-command area (a)in hectares meters [(3a)+(4a)] (b)per unit area in mm [(3b)+(4b)]	178.57 33.07

Net Annual ground Water Availability in Non-command Area

S.No.	Description of item (in non-command area)	Quantity
1	Area in hectares [From Table 2.1]	5400
2	Annual recharge from rainfall in hectare metres [From Table 11.20]	178.57
3	Annual recharge from 'Other Sources' in hectare metres [From Table 9.2]	24.02
4	Total annual ground water recharge (a)in hectares meters [(2)+(3)] (b)per unit area in mm [(4a)/(1))*1000]	202.59 37.52
5	Is rainfall recharge during monsoon season computed by 'Water table Fluctuation Method' (Yes/No) [From Table 11.20]	Yes
6	Unaccounted annual natural discharge (a)in hectares metres [0.40*(3) if responses to (5) is 'Yes' or, 0.1*(3) if response to (5) is No'] (b)per unit area in mm [(6a)/(1))*1000]	9.61 1.78
7	Net annual ground water availability in command area (a)in hectares meters [(4a)-(6a)] (b)per unit area in mm [((7a)/ (1))*1000]	192.98 35.74

Stage of Ground Water Development in Command and Non-command Area

S.No. (1)	Description (2)	Command area (3)	Non-command area (4)
1	Net annual ground water availability in hectare metres [From table 12.1/12.2]	Not applicable	192.98
2	Current annual gross ground water draft for all uses in hectare metres [From Table 3.1/3.2]	Not applicable	15+59.94=74.94
3	Stage of Ground Water Development as a percentage [(2)/(1)*100]	Not applicable	38.83%

No falling trends in groundwater levels in either of the seasons

Note: The estimated groundwater draft component from working mine pit discharges in the present groundwater basin to the tune of 15-hectare meter per year has been added to the draft component for computing the stage of groundwater development.

Categorization of Command and Non-command Area

Sl. No. (1)	Description of item (2)	Command area (3)	Non-command area (4)
1	Stage of ground water development as a percentage [From Table 13.1]	Not Applicable	38.83%
2	Does the water table during pre-monsoon interval show a falling trend(Yes/No) [from Table 14.4/ 14.9]	Not Applicable	No
3	Does the water table during Post-monsoon interval show a falling trend(Yes/No) [From Table 14.5/ 14.10]	Not Applicable	No
4	Categorization of the sub-unit(Safe/ Semi-critical/ Critical/ over Exploited)	Not Applicable	Safe

Unit Gross Ground Water Draft Per Well for Different Types of Wells

Sl. No (1)	Type of well (2)	Estimated draft per well per day (M ³ /day) (3)	Estimated number of days the wells are operated during		Estimated gross ground water draft per well in hectare metres during		
			Monsoon season (4)	Non-monsoon season (5)	Monsoon season [(3)*(4)/10 ⁴] (6)	Non-monsoon season [(3)*(5)/10 ⁴] (7)	Annual [(6)+(7)] (8)
1	Irrigation B/W	51.84	0.00	105	0.00	0.54	0.54
2	Irrigation D/W	36.90	0.00	75	0.00	0.27	0.27
2	Domestic	2.0	122	243	0.0244	0.0486	0.073
3	Industrial	16	122	243	0.488	0.972	1.46

Note:

1) On an average irrigation bore wells are pumped at a rate of 2.4 lps or 207m³/day for 6 hours for 105 days on non-monsoon season. Thus the unit draft for bore wells works out to be 0.54 ham per annum (CGWB, 2011).

2) On an average the dug wells are pumped @ 2.5 hours daily with an average discharge of 34.56m³/day (4 lps) for 75 days of non-monsoon season. Thus the unit discharge for dug wells works out to be 0.27 ham per annum (CGWB, 2011).

3) Each of the domestic well is assumed to draw about 2m³ of water per day and therefore the unit draft adopted for the study area is 0.073 ha.m. per year (or 0.0002 ha.m per day). The domestic wells are normally used throughout the year.

4) Industrial bore wells operating for about 8 hours a day are assumed to have an average draft rate of 120 m³/day (1.46 ham per annum) throughout the year.

Reference: Report on “dynamic groundwater resources of Goa-March 2009”, Department of Water Resources, Govt., of Goa and CGWB, SW Region, Bangalore, published in February 2011, 35p.

Current Gross Ground Water Draft for Irrigation in Non-command Area

Sl. No.	Type of well (in non-command area, and used for irrigation)	Estimated number of wells currently in use	Estimated gross ground water draft per well for irrigation in hectare metres [From Table 3.4]		Estimated gross ground water draft for irrigation from all wells of a given type in hectare metres during		
			Monsoon season	Non-monsoon season	Monsoon season [(3)*(4)]	Non-monsoon season [(3)*(5)]	Annual [(6)+(7)]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Open well	22	0.00	0.27 75days	0.00	5.94	5.94
2	Bore well	88	0.00	0.54 105 days	0.00	47.43	47.43
Current gross ground water draft for irrigation in non-command area (Total of all types of wells considered)					0.00	53.37	53.37

Note: In Sanguem Taluka there are 106 Irrigation dug wells and 426 bore wells spread over an area of 87375 hectares area of the taluka (CGWB, 2011). Thus the number of units per hectare of area works out to be 0.0012/ha and 0.00488/ha respectively of dug wells and bore wells.

Current Gross Ground Water Draft for Domestic Water Supply in Non-command Area

Sl. No.	Type of well (in non-command area, and used for domestic water supply)	Estimated number of wells currently in actual use	Estimated gross ground water draft per well for domestic water supply in hectare metres [From Table 3.4]		Estimated gross ground water draft for domestic water supply from all wells of a given type in hectare metres during		
			Monsoon season	Non-monsoon season	Monsoon season [(3)*(4)]	Non-monsoon season [(3)*(5)]	Annual [(6)+(7)]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Open well	90*	0.0244 (122 days)	0.0486 (243days)	2.196	4.374	6.57
2	Bore well	Nil	Nil	Nil	Nil	Nil	Nil
Current gross ground water draft for domestic water supply in non-command area (Total of all the types of wells considered)					2.196	4.374	6.57

*The density of domestic wells is estimated to be 10per km² of the of settlement area which is about 5% of the total catchment area.

Current Gross Ground Water Draft for Industrial Water Supply in Non-Command Area

Sl. No.	Type of well (in non-command area, and used for industrial water supply)	Estimated number of wells currently in actual use	Estimated gross ground water draft per well for industrial water supply in hectare metres [From Table 3.4]		Estimated gross ground water draft for industrial water supply from all wells of a given type in hectare metres during		
			Monsoon season	Non-monsoon season	Monsoon season [(3)*(4)]	Non-monsoon season [(3)*(5)]	Annual [(6)+(7)]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Bore well	Nil	0.488 122days	0.972 243 days	0.00	0.00	0.00
2	Open well	Nil			0.00	0.00	0.00
Current gross ground water draft for industrial water supply in non-command area,(Total of all the types of wells considered)					0.00	0.00	0.00

Current Gross Ground Water Draft for 'All Uses' In Non-Command Area

Sl. No.	Description of items (in non-command area)	Monsoon season	Non-monsoon season
(1)	(2)	(3)	(4)
1	Gross ground water draft in non-command area during current ground water assessment year in hectare metres for		
	(a) Irrigation [From Table 3.9]	0.0	53.37
	(b) Domestic Water Supply [From Table 3.10]	2.196	4.374
	(c) Industrial Water Supply	0.00	0.00

Sl. No.	Description of items (in non-command area)	Monsoon season	Non-monsoon season
(1)	(2)	(3)	(4)
	[From Table 3.11]		
	(d)' All Uses' [(1a)+(1b)+(1c)]	2.196	57.744

Summary Report in Respect of each Ground Water Assessment Unit

1. Name of State/ Union Territory: **GOA (South Goa)**
2. Name of Ground water Assessment Unit: **Salaulim watershed**
3. Index Number of Ground water Assessment Unit: **CGA-X**
4. Type of Water Assessment Unit: **Watershed**
5. Predominant Type of Rock Formation: **Hard rock terrain with laterite covered surface**
6. Area in hectares of
 - (a) Ground Water Assessment Unit: **18000**; (b) Command Area: **0.0**
 - (c) Non Command Area: **5400**; (d) Poor Ground Water Quality Area [Table 2.1]: **0.0**
7. Ground Water Assessment Year: **2011-12**

Command and Non-command Areas

Sl. No.	Description of item	Non-command area	
		ha.m.	mm
1	Recharge from 'Rainfall' during [From Table 11.19/ 11.20] (a) monsoon season (b) non-monsoon season	178.57 0.0	33.070.0
2	Recharge from 'Other Sources' during [From Table 9.1/ 9.2] (a) monsoon season (b) non-monsoon season	0.0 24.02	0.0 4.45
3	Annual ground water recharge [Form Table 12.1/ 12.2]	202.59	37.52
4	Unaccounted annual natural discharge [From Table 12.1/ 12.2]	9.61	1.78

Sl.	Description of item	Non-command area	
5	Net annual ground water availability [From Table 12.1/ 12.2]	192.98	35.74
6	Current annual gross ground water draft for 'All Uses' [Tble 3.12/ 3.2]	59.94	11.10
7	Current annual gross ground water draft for 'Irrigation' [Table 3.2]	53.37	9.88
8	Annual ground water allocation for domestic and industrial water supply up to next 25 years [From Table 16.1]	3.29	6.09
h9	Net annual ground water availability for 'Future Irrigation Use' [17.1]	136.32	25.24
10	Was the rainfall recharge during monsoon season obtained by using the water table fluctuation method (Yes/No)	YES	
11	If response to sl. No. 10 is 'Yes', How was specific yield value obtained	CGWB NORMS	
12	Stage of ground water development as a percentage [Table 13.1]	38.83%	
13	Does the water table during pre-monsoon interval show a falling trend(Yes/ No) [From Table 14.4/ 14.9]	No	
14	Does the water table during post-monsoon interval show a falling trend(Yes/ No) [From Table 14.5/ 14.10]	No	
15	Categorisation for future ground water development(Safe/ Semi-critical/ Critical/ Over exploited) [From Table 15.1]	Safe	

Summary of Annual Ground Water Allocation for Domestic and Industrial Water Supply in Command and Non-command Area

1. Name of Ground Water Assessment Unit: **Salaulim watershed, Goa**
2. Index Number of Ground Water Assessment Unit: **CGA - IX**
3. Ground Water Assessment Year: **2011-12**

S. no. (1)	Description of item (2)	Command area (3)	Non-command area (4)
1	Annual allocation of ground water for domestic and industrial water supply in hectare metres	0.00	3.29
2	Area in hectares [From table 2.1]	0.00	5400

Assessing the impact of mining activities on water body: Case study of Salaulim Reservoir, Goa

S. no. (1)	Description of item (2)	Command area (3)	Non-command area (4)
3	Annual allocation of ground water for domestic and industrial water supply per unit area in millimeters [[$(1)/(2)$] * 1000]	0.00	0.61

Note: Annual increase of 2% of the present drafts for domestic (6.57ham) and industrial (0.00ham) demands is assumed over next 25 years in computing annual allocation.

Net Annual Ground Water Availability for Future irrigation Use in Command and Non-command Areas

1. Name of Ground Water Assessment Unit: **Salaulim watershed, Goa**
2. Index Number of Ground Water Assessment Unit: **CGA - IX**
3. Ground Water Assessment Year: **2011-12**

S. no. (1)	Description of item (2)	Command area (3)	Non-command area (4)
1	Area in hectares [From Table 2.1]	0.00	5400
2	Net annual ground water availability in hectare meters [Table 12.1/ 12.2]	0.00	192.98
3	Current annual gross ground water draft for Irrigation in hectare meters [Table 3.11/ 3.12]	0.00	53.37
4	Annual allocation of ground water for domestic and industrial water supply in hectare meters [from Table 16.1]	0.00	3.29
5	Net annual ground water availability for 'Future irrigation use' in hectare meters [(2)-((3)-(4))]	0.00	136.32
6	Net annual ground water availability for 'Future Use' per unit area in millimeters [((5)/(1))*1000]	0.00	25.24

Annexure XI: Water Quality Standards

Indian Standard Specifications for Drinking Water IS: 10500

Parameter	Unit	Desirable Limit
pH	-	5.5 -9.0
Total Alkalinity	(mg/l) as CaCO ₃	200
Conductivity	(mS/cm)	-
Total Dissolved Solids	(mg/l)	500
Nitrates	(mg/l)	45
Total Hardness	(mg/l) as CaCO ₃	300
Chlorides	(mg/l)	250
Dissolved Oxygen	(mg/l)	4 – 6
Sodium	(mg/l)	-
Potassium	(mg/l)	-
Iron	(mg/l)	0.3
Manganese as Mn	(mg/l)	0.1

Surface Water Quality Standards IS: 2296

Class A - Drinking water without conventional treatment but after disinfection. Class B - Water for outdoor bathing. Class C - Drinking water with conventional treatment followed by disinfection. Class D - Water for fish culture and wild life propagation. Class E - Water for irrigation, industrial cooling and controlled waste disposal

Parameter	A	B	C	D	E
pH	6.5 – 8.5	8.5	8.5	8.5	8.5
Conductivity (µS/cm)at 250 C	-	-	-	1000	2250
Total Dissolved Solids (mg/l)	500	-	1500	-	2100
Nitrates (mg/l)	20	-	50	-	-
Total Hardness (mg/l) as CaCO ₃	300	-	-	-	-
Chlorides (mg/l)	250	-	600	-	600
Dissolved Oxygen (mg/l)	6	5	4	4	-
BOD (mg/l), 3 days 270C	3	3	3	-	-
Iron (mg/l)	0.3	-	50	-	-
Manganese as Mn (mg/l)	0.5	-	-	-	-

CPCB: Proposed Effluent Discharge Standards for iron and manganese ore mines in India

Parameter	Unit	Standard Limit
pH	-	6.0 -9.0
Total Suspended Solids	(mg/l)	50 200 – during monsoon
Dissolved Iron as Fe	(mg/l)	2
Manganese as Mn	(mg/l)	2

Source: Central Pollution Control Board 2007. Comprehensive Industry Document on Iron Ore Mining

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