Sushee Chandragupt Coal Mine Pvt. Ltd.

PREPARATION OF DPR FOR DIVERSION OF CHOTKI RIVER AND STRAIGHTENING A NOTCH OF BARKI RIVER OF CHANDRAGUPT MDO PROJECT

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EXECUTIVE SUMMARY

M/s Sushee Chandragupt Coal Mine Pvt. Ltd, is developing the Chandragupt coal mining block in Keredari CD block in the Hazaribagh district in the state of Jharkhand, India. The mining block lies between latitude 23°54'40"N to 23°51'20"N and longitude 85° 1'10"E to 85° 3'20"E.

Barki river flows abutting west side of the mining block while Chotki river originates from outside of the mining area, passes through northern part of the mining block and joins the Barki river from left side at 23°53'28.66"N, 85° 1'35.83"E. The Chotki river has its catchment area beyond the boundary of the mining block towards northern side. Further, there is an acute meander of the Barki river at 23°51'56.62"N, 85° 1'49.67"E and it lies in the mining block. Thus, it is necessary to develop a cut off channel to straighten the Barki river and to divert the Chotki river.

In this regard, Mr. A K Dutta, Vice President, Sushee Chandragupt Coal Mine Pvt. Ltd., Hyderabad, Telangana – 500034 requested the author through an email dated June 02, 2022 to prepare a Detailed Project Report for diversion of Chotki River and straightening of the Barki River.

A reconnaissance survey of the mining area was carried out on 28/6/2022 for examination of site in the respect of existing drainage system, land use land cover, type of soil, morphology of the river, hydraulic structures, etc. Topographical map of the Chandragupt mining block has been developed by carrying out the Drone survey. Digital elevation map, Drainage map, Slope map and Land use Land cover map have been developed using Cartosat data for a) Barki river at its confluence with Chunro river near Tandla and at north-west corner of the mining block, and b) Chotki river at its confluence with Barki river and its entry point to mining block.

Major land use in the catchment of the Barki and Chotki rivers is forest followed by agriculture. Catchment areas of the Barki river at N-W corner of mining block and at confluence of Chunro river are 201.8 km^2 and 231.5 km^2, respectively. While catchment areas of the Chotki river at its entry point to the mining block and at confluence with Barki river are 3.89 km^2 and 7.19 km^2, respectively.

Hydrological rainfall data obtained from CWC-IMD (2015) and CSWRTI Bull No. 3 have been analysed and IDF curves are developed for return periods of 25, 50 and 100 years. The developed IDF curve is used to estimate peak discharge. The estimated peak discharge in Barki river at N-W corner of mining block for 25, 50, and 100 years return period are 358.41, 413.20 and 466.20 m^3/s, respectively. Estimated peak discharge in Chotki river at its entry to the mining block for 25, 50, and 100 years return period are 18.57, 20.35 and 22.28 m^3/s, respectively. While estimated peak discharge in Chotki river at confluence with Barki river for 25, 50, and 100 years return period are 27.75, 30.41 and 33.27 m^3/s, respectively.

A one-dimensional HEC RAS model for the Barki river has been developed from its Chainage 9000 m to 375 m under steady state condition for the existing condition and with diversion of the Chotki river and straightening of the Barki river. Since the lease for mining block is for 25 years, therefore, the developed hydraulic model is run for discharge of 25 years return period. However, for raising the banks of the Barki river, 50 years return period discharge has been taken and for the protection works 100 years return period discharge has been taken.

Initially, the developed 1D HEAC RAS model was run for the existing condition under the steady state condition followed by diversion of Chotki river and diversion of Chotki river along with straightening of the Barki river for 25 years return period discharge.

After examination of the contour map and bed levels of the Barki and Chotki rivers, a diversion channel is aligned from the point 23°54'24.02"N, 85° 2'21.02"E to point 23°54'35.02"N, 85° 1'35.48"E to divert the flow of Chotki river to Barki river. The diversion channel is of trapezoidal shape of bed width of 6.0 m, bed slope of 0.0005 and side slope of 1V:1.5H. The length of the diversion channel is 1380 m. Step falls is provided at the outfall of the diversion channel into Barki river.

Computed water surface profile under diversion of the Chotki river compares well with the existing condition. This reveals that effect of diversion of the Chotki river through diversion channel on the flow parameters in the Barki river is negligible

For straightening of the meander, it is proposed to provide a cut off channel of 100 m long starting from 23°51'59.14"N; 85° 1'50.54"E to 23°51'56.51"N, 85° 1'52.64"E. It is proposed to provide earthen embankment with 1V:2H both sides slope and top width of 6.0 m to block the inlet and outlet channels of the meander.

Since the bed level of the river at Chainage 2000 is 440.36 m and at Chainage 625 is 436.97 m, thus it is proposed to provide two drop impact falls in the cutoff channel. Design of the drop impact is carried out as given in the Chanson (2004). Accordingly, two drop impact falls each of drop 2.5 m are provided.

In the remaining 60 m length, the cut off channel of trapezoidal shape of bed width of 35 m and side slope of 1V:2H is provided. The cutoff channel will reduce the length of the Barki river by 1175 m.

Comparison of computed water level under diversion of the Chotki river and straightening of the Barki river with existing condition reveals that from chainage 2000 m to 2500 m, the water level under moderated condition is lower than the existing condition, however, there is a negligible change in water level upstream of the Chainage 2500 m. There is no difference in the water level between Chainage 375 m to Chainage 625 m. High velocity in the cross-sections at Chainage 500 m and 375 m are due to their narrow sections.

Running the model for 50 years peak discharge reveals that at some locations, computed water level is higher than the left bank. Such locations are near the Chainages 6150 m, 4500 m, 4000 m and 2500 m. It is suggested that in a length of about 100 m at each chainage, earthen levees of height 1.5 m, side slope 1V:2H and top width of 2.5 m be provided to control the ingress of the flood water in the mining block area.

It is proposed to provide an earthen embankment of top width of 4.50 m and side slopes of 1V:2H to block the mouth of the Chotki river at its confluence with Barki river. An earthen embankment for top with 3.0 m and side slopes of 1V:2H shall be provided at entry of the Chotki river to mining block to divert it to Barki river.

It is recommended to execute the proposed diversion channel, cut off channel for straightening of the Barki river and embankments/bunds for the protection works to pass safely flood water through the Barki river.

Diversion of the Chokti river and the straightening of meander of the Barki river would not affect the flow downstream of the Chainage 375 m. Thus, any structure on the Barki river or Chunro river would not be affected with proposed diversion.

Date: 11th April 2023

Place: Roorkee

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1. INTRODUCTION

1.1 Introduction

Jharkhand state is blessed with small hills and rivers due to its varied topography. Major parts of the Jharkhand state lie on the Chhota Nagpur plateau. The river Damodar which is the largest and biggest in Jharkhand has a number of tributaries. Barki river that passes along the west boundary of the Chandragupt mining block is one of its tributaries.

The Chandragupt coal mine is a proposed opencast mine, to be operated by Central Coalfields Limited, a subsidiary of Coal India, producing 15 million tonnes per annum, in Jharkhand state, India. M/s Sushee Chandragupt Coal Mine Pvt. Ltd, is developing the Chndragupta coal mining block in Keredari CD block in the Hazaribagh district in the state of Jharkhand, India. The mining block lies between latitude 23°54'40"N to 23°51'20"N and longitude 85° 1'10"E to 85° 3'20"E.

The Barki river, which is a tributary of the Damodar river flows abutting west side of the mining area of the Chandragupt MDO project. It flows relatively from north to south near the project site. Chotki river originates from outside of the mining area, passes through northern part of the mining area and joins the Barki river from left side at 23°53'28.66"N, 85° 1'35.83"E. Another river originates from the mining area and joins the Barki-Chunro river downstream of the mining area at 23°51'10.88"N, 85° 2'22.19"E. The Barki river joins with Chunro river near the southern part of the mining block at 23°51'37.86"N, 85° 1'47.99"E and then finally outfalls in the Damodhar river.

The Chotki river has its catchment area beyond the boundary of the mining block towards northern side. Further, there is an acute meander (notch) of the Barki river at 23°51'56.62"N, 85° 1'49.67"E and it lies in the mining block. Thus, it is necessary to develop a cut off channel to straighten the Barki river.

In this regard, Mr. A K Dutta, Vice President, Sushee Chandragupt Coal Mine Pvt. Ltd., Hyderabad, Telangana – 500034 requested the author through an email dated June 02, 2022 to prepare a Detailed Project Report for diversion of Chotki River and straightening the meander of Barki River of Chandragupt MDO project with the scope of the work given in section 1.2 of this report.

1.2 Scope of the Work

The scopes of the work are as follow:

a) To conduct reconnaissance survey of the mining area for examination of site in the respect of existing drainage system, land use land cover, type of soil, morphology of the river, hydraulic structures, etc. and also for discussion with the authorities.

b) To study of the present topography of the mining area and existing drainage system.

c) Preparation of maximum intensity-duration-frequency curve of the study area using hourly rainfall data, if the same is not available. Otherwise Isopluvial maps available in the CWC report and/or PMP Atlas for Ganga River Basin including Yamuna of CWC shall also be used.

d) Development of digital elevation model and drainage map of the mining areas using the developed topographical map of the area through land survey.

e) Delineation of the catchment area of the different rivers inside and outside of the mining area. Development of digital elevation model and drainage map of the areas outside of the mining area using satellite images (SRTM/Cartosat/Google engine).

f) Development of the land use and land cover map of the catchment areas of rivers inside and outside of the mining areas.

g) Study of soil map of the catchment areas of the rivers inside and outside of the mining areas.

h) Estimation of peak discharge/flood hydrograph for different return periods like 25, 50 and 100 years in the Chotki and Barki rivers on the basis of hydrological analysis of the catchment area, land use pattern, topography of the area and meteorological data etc. Estimation of peak discharge/hydrograph shall be carried out invoking empirical equations, rational method and unit hydrograph theory.

i) Fixing the alignment of the diversion channel on the basis of the contour map and utility plan of the mining area. Fixing the shape and size including bed slope of the channel on the basis of the peak discharge, L-section of the ground along the channel, etc.

j) Designing the lining of the diversion channel, if necessary. Design of structure/bund/embankment across the rivers to divert the flow in the diversion channel.

k) Design of suitable measures enroute and at the end of the diversion channel to avoid any degradation/aggradation in the existing rivers, if necessary.

l) Development of one-dimensional HEC-RAS model for the Barki river in the vicinity of the mining area under the virgin condition and with diversion channel. The diversion channel shall also be modelled.

m) Running the model for the pre and post diversion scenarios with estimated peak discharge for return periods of 25, 50 and 100 years for to obtain hydraulic parameters like water surface profile, velocity, bed shear stress, aggradation/degradation etc.

n) Discussion on the hydraulic parameters and morphology of the Barki river to examine the pre and post diversion scenarios – impact of the diversion of the rivers on the Barki river.

o) To study the impact of the diversion of the rivers on the existing structures/protection works on the Barki river due to diversion of the rivers and to suggest measure/s to minimize the impact.

p) Examination of water surface profile vis-à-vis bank levels of the Barki river to identify the stretches that require raising of the banks and their design.

q) Preparation of the detailed project report and relevant drawings and their submission.

r) Presentation of the report to the Authority/ies, if required and discussion with the project authorities for finalization of the DPR.

1.3 Available Data

Following data were made available by the project authority:

a) Topographical map of the mining area marked with the salient features including land use along with existing rivers in the mining area (Drg. 1)

b) L-section and cross-section of the existing Barki and Chotki rivers (Drg. 2 & 3)

c) Soil samples of river bed material from Barki and Chotki rivers

d) L-section and cross-section of the ground along the alignment of the proposed diversion channel.

e) L-section along the cut off channel at the meander

1.4 Methodology for the River Diversion

Following methodologies shall be adopted for the river diversion:

a) A reconnaissance survey of the mining area shall be carried out for examination of the site in the respect of existing drainage system, land use land cover, type of soil, morphology of the river, hydraulic structures, etc. and also for discussion with the authorities.

b) Digital elevation model, drainage map, land use and land cover map, Slope map of the catchment of the Chotki river at its confluence with Barki river and and its entry point to the mining block shall be developed using Cartosat data.

c) Digital elevation model, drainage map, land use and land cover map, Slope map of the catchment of the Barki river at north-western corner of the mining block and at its confluence with the Chunro river shall be developed using Cartosat data.

d) Unit hydrograph shall be developed for the catchment of the Barki river at north-western corner of the mining block and at its confluence with the Chunro river. Procedure laid in the CWC report for Lower Ganga plains (sub Zone -1g) Report No. LG-1(g)/R-1/94 shall be used to develop the unit hydrograph and storm hydrograph of the river for return period of 25, 50 and 100 years.

e) Having area of the catchment of the Chotki river at its outfall into Barki river and at its entry to the mining area less than 50 km^2, rational method shall be used to estimate the peak discharge for return period of 25, 50 and 100 years.

f) Soil map of the catchment areas of the rivers shall be procured from Jharkhand Space Application Centre and shall be analysed to derive characteristics of soil in the catchment areas.

g) Contour map of the mining block shall be examined and alignment of the diversion channel of the Chotki river from its entry point to the north-west corner of the mining area into the Barki river shall be fixed. The shape, size and slope of the diversion channel shall be fixed on the basis of the discharge from the catchment of Chotki river outside the mining block.

h) At the meander of the Barki river, a cut off channel shall be provided of suitable shape and size to straighten the barki river.

i) A one-dimensional HEC-RAS model for the Barki river from north and western corner of the mining block to its confluence with Chunro river shall be developed. The model shall be run under the virgin condition for the estimated peak discharge for return periods of 25, 50 and 100 years in the Barki river and Chotki river. The hydraulic parameters like water surface profile, velocity, bed shear stress, aggradation/degradation etc. shall be studied.

j) The model shall be re-run for the post diversion scenarios (i.e., diversion of Chotki river and straightening of the Barki river) with estimated peak discharge for return periods of 25, 50 and 100 years to obtain various hydraulic parameters.

k) Hydraulic parameters and morphology of the Barki river under pre and post diversion scenarios shall be examined to study impact of the diversion of the rivers on the Barki river and existing structures and to suggest measure/s to minimize the impact.

l) The lining of the diversion and cut off channels, if necessary shall be designed along width design of structure/bund/embankment across the rivers to divert the flow in the channels.

m) A detailed project report comprising the above points shall be prepared along with relevant drawings and to be submitted to the sponsor.

2. STUDY AREA

M/s Sushee Chandragupt Coal Mine Pvt. Ltd, is developing the Chndragupt coal mining block in Keredari CD block in the Hazaribagh district in the state of Jharkhand, India. The mining block lies between latitude 23°54'40"N to 23°51'20"N and longitude 85° 1'10"E to 85° 3'20"E as shown in Fig. 1.

The area of the mining block is about 3700 acres. Barki river flows abutting west side of the mining area of the Chandragupt MDO project. It flows relatively from north to south near the project site. Chotki river originates from outside of the mining area, passes through northern part of the mining area and joins the Barki river from left side at 23°53'28.66"N, 85° 1'35.83"E. Another river originates from the mining area and joins the Barki-Chunro river downstream of the mining area at 23°51'10.88"N, 85° 2'22.19"E. The Barki river joins with Chunro river near the southern part of the mining block at 23°51'37.86"N, 85° 1'47.99"E and then finally outfalls in the Damodhar river. A Barrage is constructed across the Barki-Chunro rivers at about 900 m downstream of the confluence of the Barki and Chunro river,

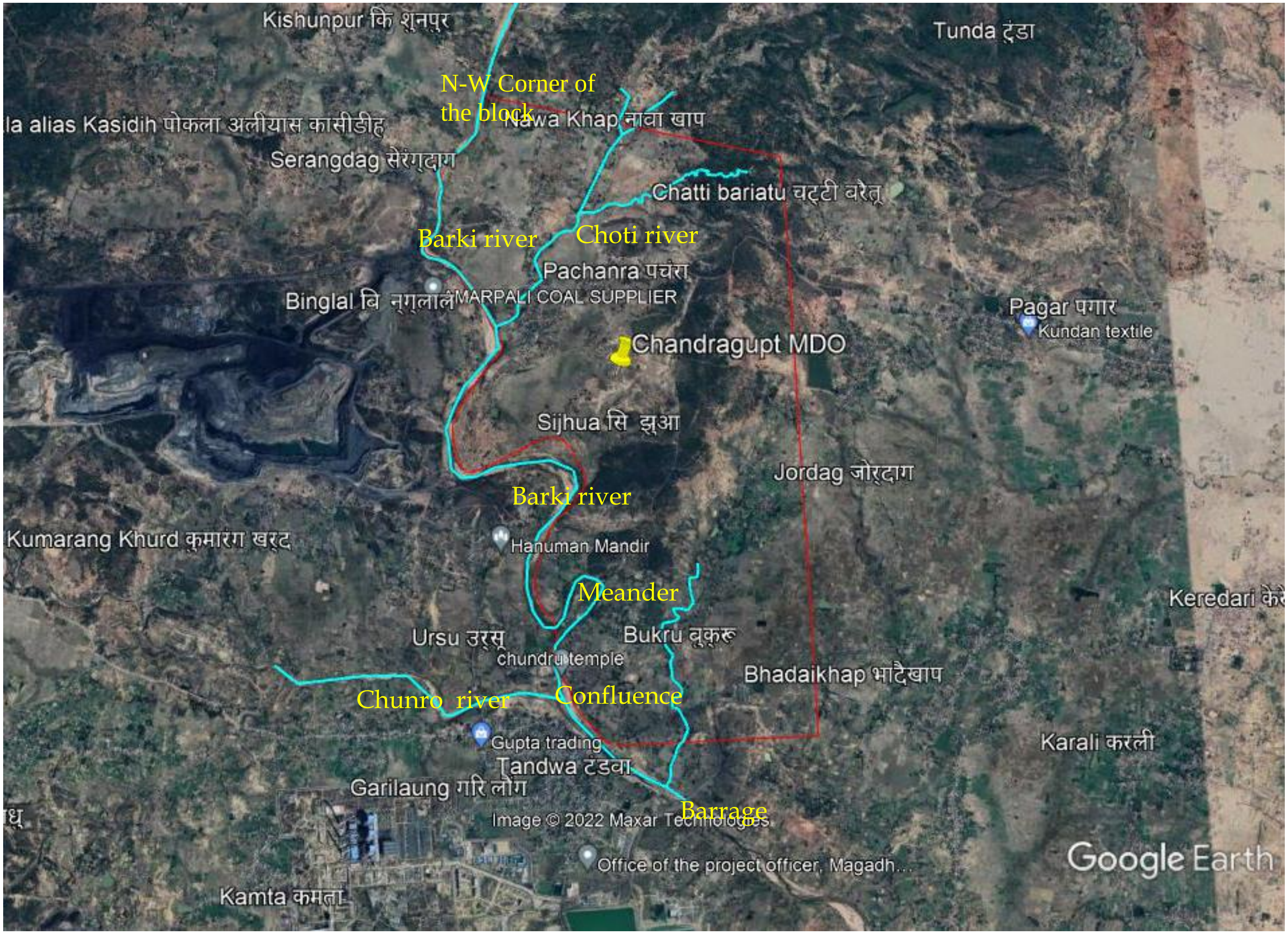


Figure 1 Chandragupt mining block and drainage system

2.1 Topographical map

Topographical map of the Chandragupt mining block has been developed by carrying out the Drone survey. Contours are drawn at an interval of 1.0 m. The developed topographical map is attached with this report (see Drg. 1).

2.2 Digital Elevation Model

Digital elevation map for the following catchment area have been developed using Cartosat data.

a) Catchment of Barki river at its confluence with Chunro river near Tandla (Figure 2)

b) Catchment of Barki river at north-west corner of the mining block (Figure 3)

c) Catchment of Chotki river at its confluence with Barki river (Figure 4)

d) Catchment of Chotki river at its entry point to mining block (Figure 5)

Digital elevation models of the Barki and Chotki rivers at their different locations along with drainage pattern are developed and shown in Figures 2-5.

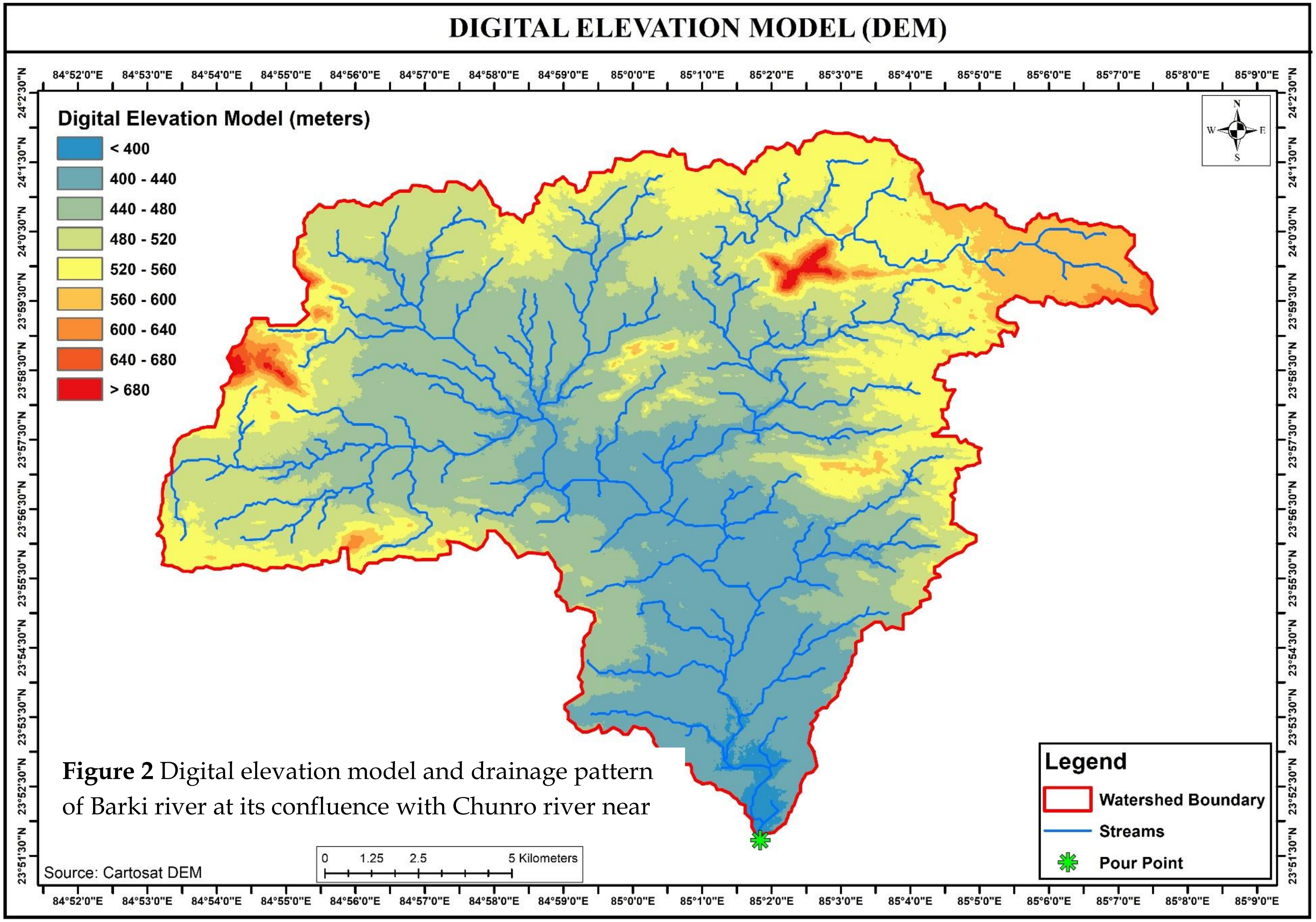


Figure 2 Digital elevation model and drainage pattern of Barki river at its confluence with Chunro river near

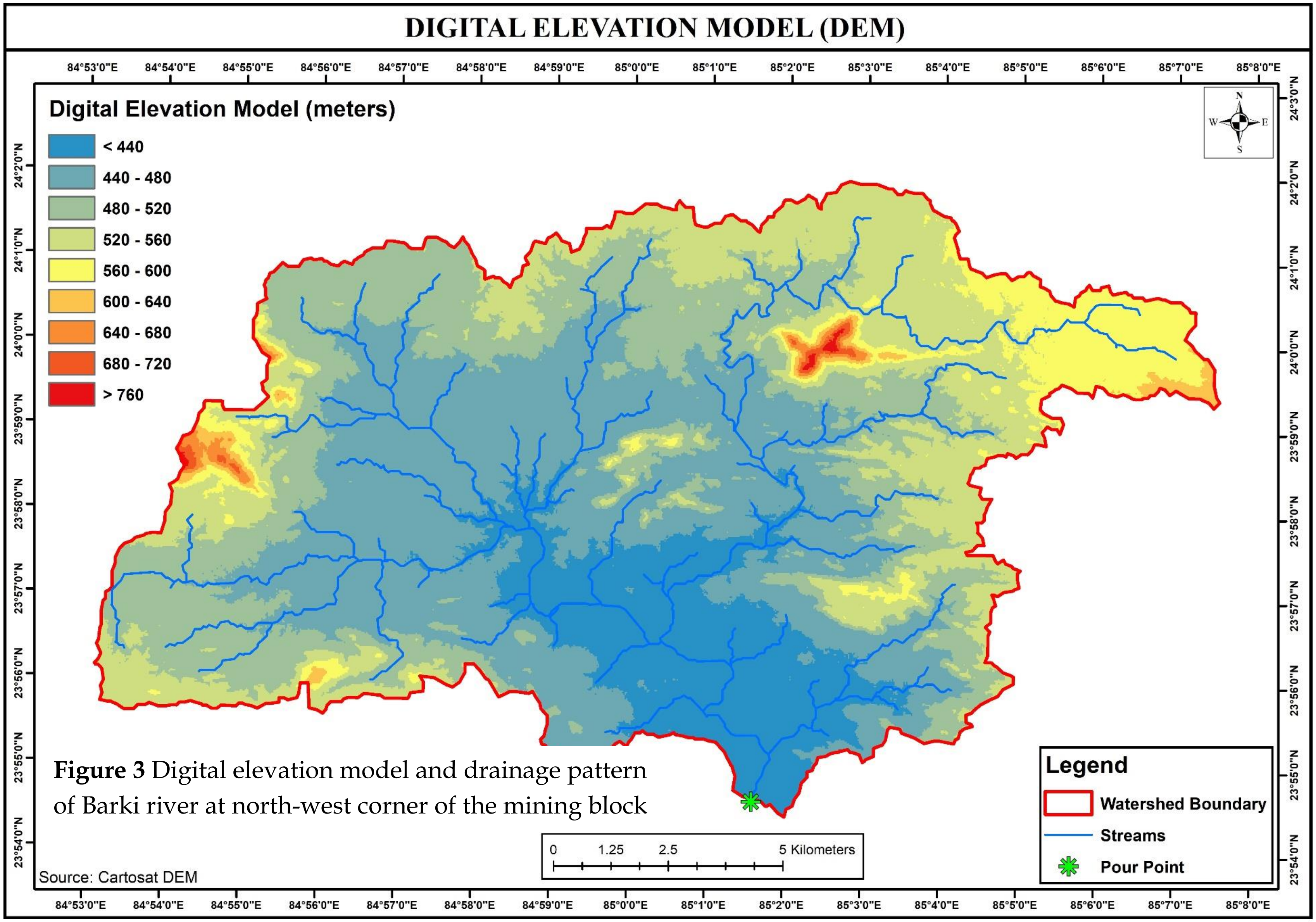


Figure 3 Digital elevation model and drainage pattern of Barki river at north-west corner of the mining block

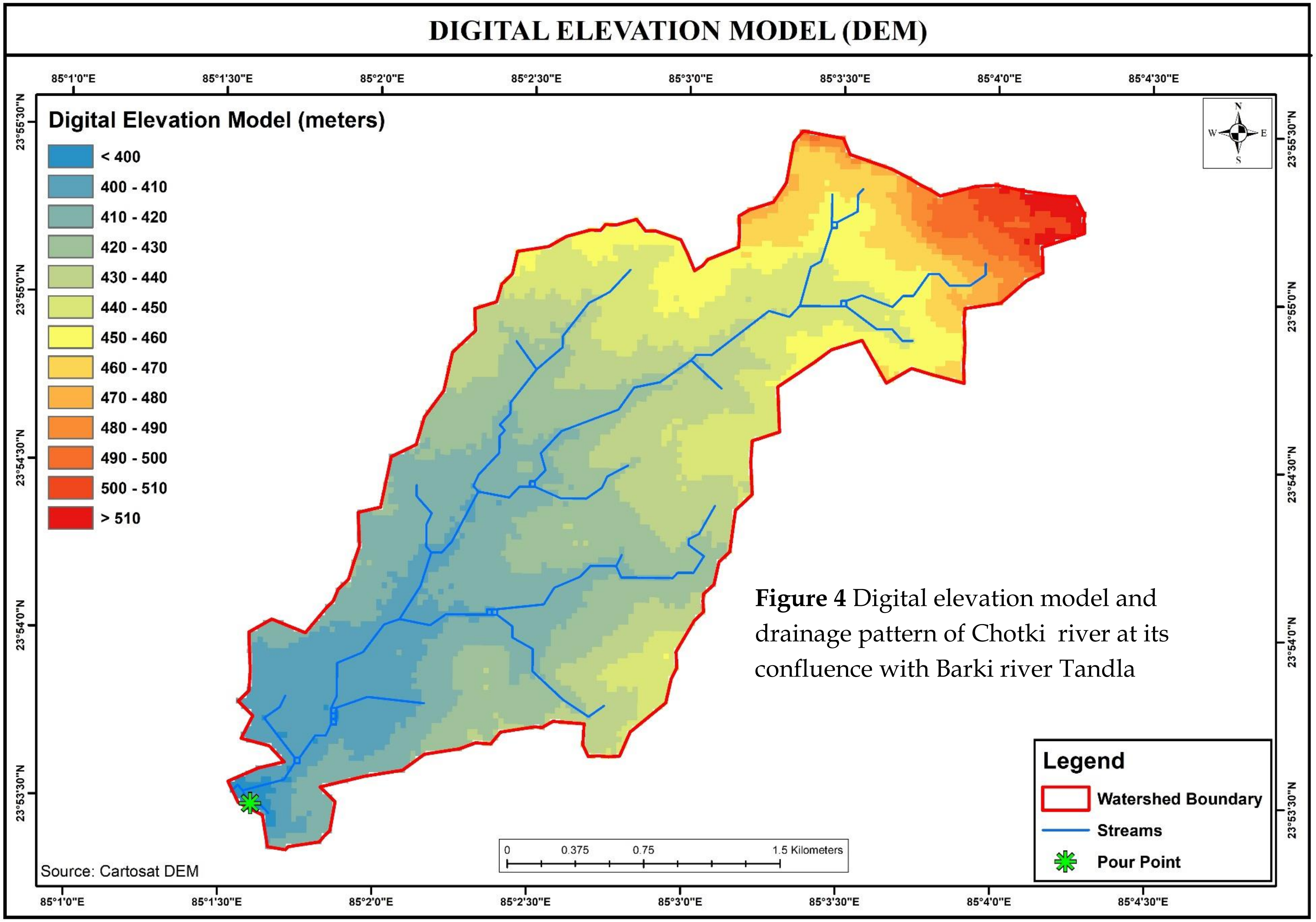


Figure 4 Digital elevation model and drainage pattern of Chotki river at its confluence with Barki river Tandla

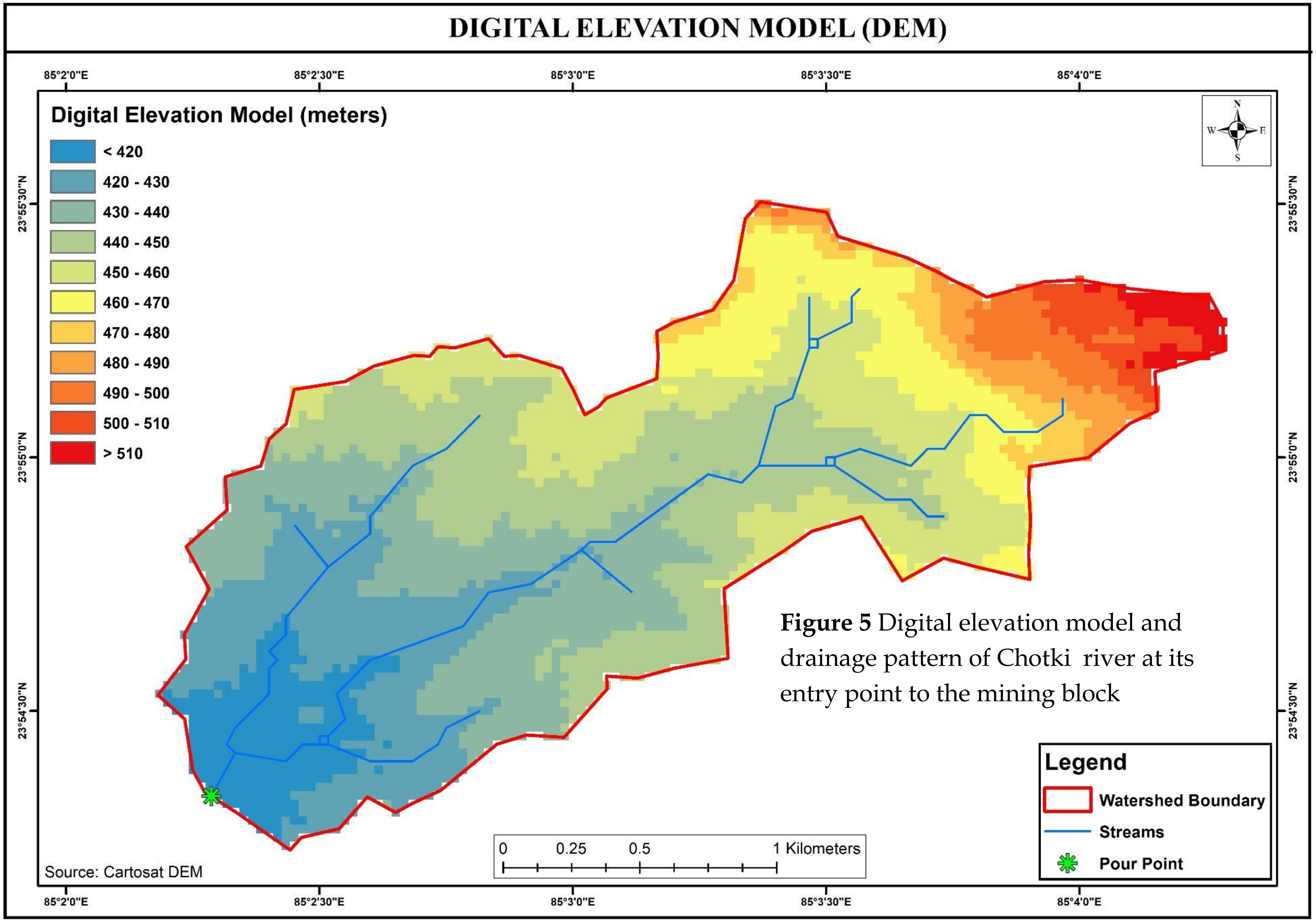


Figure 5 Digital elevation model and drainage pattern of Chotki river at its entry point to the mining block

2.3 Soil Map

The soil map of the Hazarinagh district has been taken from Jharkhand Space Application Centre (JSAC). The soils occurring in different landforms were characterised at the time of soil resource mapping of the state on 1:250,000 scale and three soil orders namely Entisols, Inceptisols and Alfisols were observed in Hazaribagh district as shown in Fig.6 and mentioned in Table 1. Alfisols were the dominant soils covering 71.9 percent of TGA followed by Entisols (18.1%) and Inceptisols (7.8%) in the Hazaribagh district.

National Bureau of Soil Survey and Land Use Planning (ICAR) Regional Centre, Kolkata carried out a study on "Assessment and Mapping of Some Important Soil Parameters including Soil Acidity for the State of Jharkhand (1:50,000 Scale) towards Rational Land Use Plan- Hazaribagh District" and concluded the following:

The soil pH ranges from 4.5 to 7.8. Majority of soils (88.2 % of total area) of the area are acidic in reaction. The organic carbon content in the soils ranges from 0.08 to 5.54 percent. Soils of 64.5 percent area have high surface organic carbon content. Medium and low organic carbon content constitute 17.4 and 15.9 percent area, respectively.

Available nitrogen content in the surface soils of the district ranges between 68 and 710 kg/ha. Soils of majority area (69.4 % of total area) of the district have medium availability status of available nitrogen (280-560 kg/ha) and 17.9 percent area have low available nitrogen content (20 mg/kg) in available sulphur content, respectively.

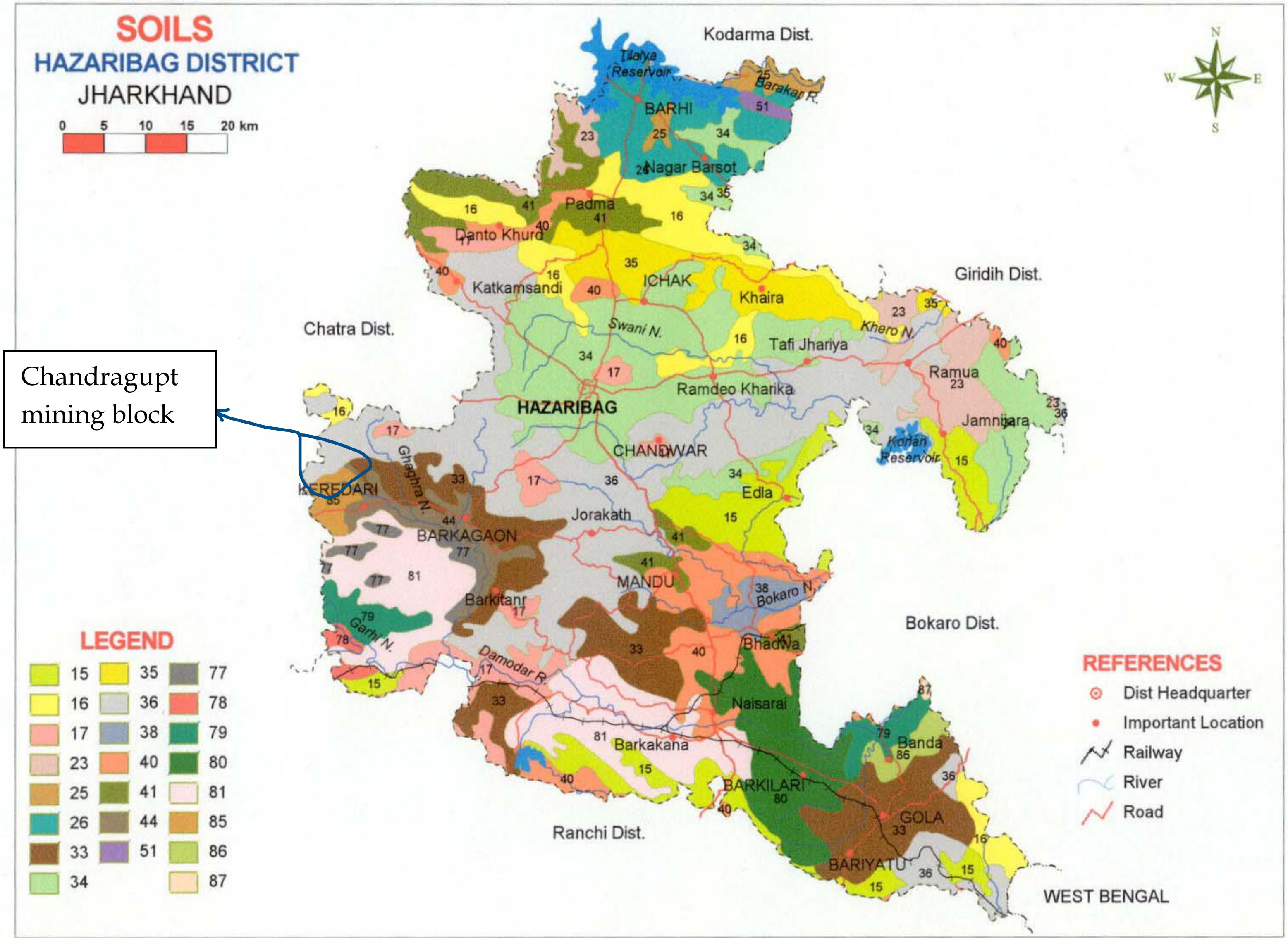


Figure 6 Soil map

Table 1 Soils in Hazaribagh district and their extent (JSAC)

Map unit	Taxonomy	Area ('00ha)	% of TGA
15	Loamy-skeletal, mixed, hyperthermic Lithic Ustorthents Fine loamy, mixed, hyperthermic Ultic Haplustalfs	319	6.32
16	Fine, mixed, hyperthermic Typic Haplustalfs Loamy, mixed, hyperthermic Lithic Ustorthents	280	5.55
17	Loamy, mixed, hyperthermic Lithic Ustorthents Fine, mixed, hyperthermic Typic Rhodustalfs	175	3.47
23	Fine-loamy, mixed, hyperthermic Typic Haplustepts Fine-loamy, mixed, hyperthermic Typic Haplustalfs	176	3.49
25	Fine, mixed, hyperthermic Typic Paleustalfs Fine, mixed, hyperthermic Rhodic Paleustalfs	39	0.77
26	Fine, mixed, hyperthermic Typic Haplustalfs Fine, mixed, hyperthermic Typic Paleustalfs	171	3.39
33	Fine, mixed, hyperthermic Typic Paleustalfs Fine, mixed, hyperthermic Typic Rhodustalfs	466	9.23
34	Fine loamy, mixed, hyperthermic Typic Paleustalfs Fine-loamy, mixed, hyperthermic Typic Rhodustalfs	670	13.27
35	Loamy-skeletal, mixed, hyperthermic Lithic Ustorthents Fine-loamy, mixed, hyperthermic Typic Haplustalfs	185	3.66
36	Fine, mixed, hyperthermic Typic Paleustalfs Fine loamy, mixed, hyperthermic Typic Rhodustalfs	993	19.67
38	Fine loamy, mixed, hyperthermic Typic Paleustalfs Fine loamy, mixed, hyperthermic Typic Haplustepts	52	1.03
40	Fine loamy, mixed, hyperthermic Typic Haplustepts Fine loamy, mixed, hyperthermic Typic Haplustalfs	290	5.74
41	Coarse loamy, mixed, hyperthermic Typic Ustorthents Fine loamy, mixed, hyperthermic Typic Paleustalfs	182	3.60
44	Fine, mixed, hyperthermic Aeric Endoaquepts Fine, mixed, hyperthermic Typic Haplustepts	85	1.68
51	Fine loamy, mixed, hyperthermic Typic Haplustepts Loamy, mixed, hyperthermic Lithic Ustorthents	12	0.24
77	Fine loamy, mixed, hyperthermic Typic Rhodustalfs Loamy, mixed, hyperthermic Lithic Ustorthents	36	0.71
78	Fine, mixed, hyperthermic Typic Paleustalfs Fine loamy, mixed, hyperthermic Ultic Haplustalfs	18	0.36
79	Fine, mixed, hyperthermic Typic Haplustalfs Fine, mixed, hyperthermic Ultic Paleustalfs	90	1.78
80	Fine loamy, mixed, hyperthermic Typic Haplustalfs Loamy, mixed, hyperthermic Lithic Ustorthents	216	4.28
81	Fine, mixed, hyperthermic Typic Rhodustalfs Loamy, mixed, hyperthermic Lithic Ustorthents	410	8.12
85	Fine-loamy, mixed, hyperthermic Typic Haplustalfs Fine, mixed, hyperthermic Typic Paleustalfs	33	0.65
86	Fine, mixed, hyperthermic Typic Rhodustalfs Coarse loamy, mixed, hyperthermic Typic Ustorthents	36	0.71
87	Fine silty, mixed, hyperthermic Typic Haplustepts Fine loamy, mixed, hyperthermic Aeric Endoaquepts	3	0.06
Miscellaneous		112	2.22
Total		5049	100.00

All the soils are sufficient in available iron and manganese whereas soils of 4.2 and 5.5 percent area are deficient in available zinc and copper respectively. Soils of 38.9 percent area of district are deficient (0.50 mg/kg) in available boron content.

Examination of soil type in the Chandragupt mining block as shown in Fig. 1 indicates that, the block area soil is primarily fine loamy.

2.4 Land use and land cover

National Bureau of Soil Survey and Land Use Planning (ICAR), Regional Centre, Kolkata reported the following land use in Hazaribagh district:

Land Use in Hazaribag District (1997-98)

		Hazaribag	**Jharkhand**
1.	Forest	43.94 %	29.2 %
2.	Net sown area	16.20 %	22.7 %
3.	Barren and unculturable waste	8.96 %	7.2 %
4.	Non agricultural use	7.90 %	9.9 %
5.	Orchards	1.01 %	2.5 % (Orchards and Pasture combined)
6.	Pasture	0.65 %	
7.	Culturable wasteland	1.34 %	3.5 %
8.	Current and other fallow	20.00 %	25.0 %

Source: Fertilizer and Agriculture Statistics, Eastern Region (2003-2004)

It is apparent that in the Hazaribagh district, the major land use is forest followed by agriculture.

Land use Land cover of the following catchments have been developed using the Cartosat data

a) Catchment of Barki river at its confluence with Chunro river near Tandla (Fig. 7)
b) Catchment of Barki river at north-west corner of the mining block (Fig. 8)
c) Catchment of Chotki river at its confluence with Barki river (Fig. 9)
d) Catchment of Chotki river at its entry point to mining block. (Fig. 10)

Such land use land cover maps are shown in Figures 7 to 10.

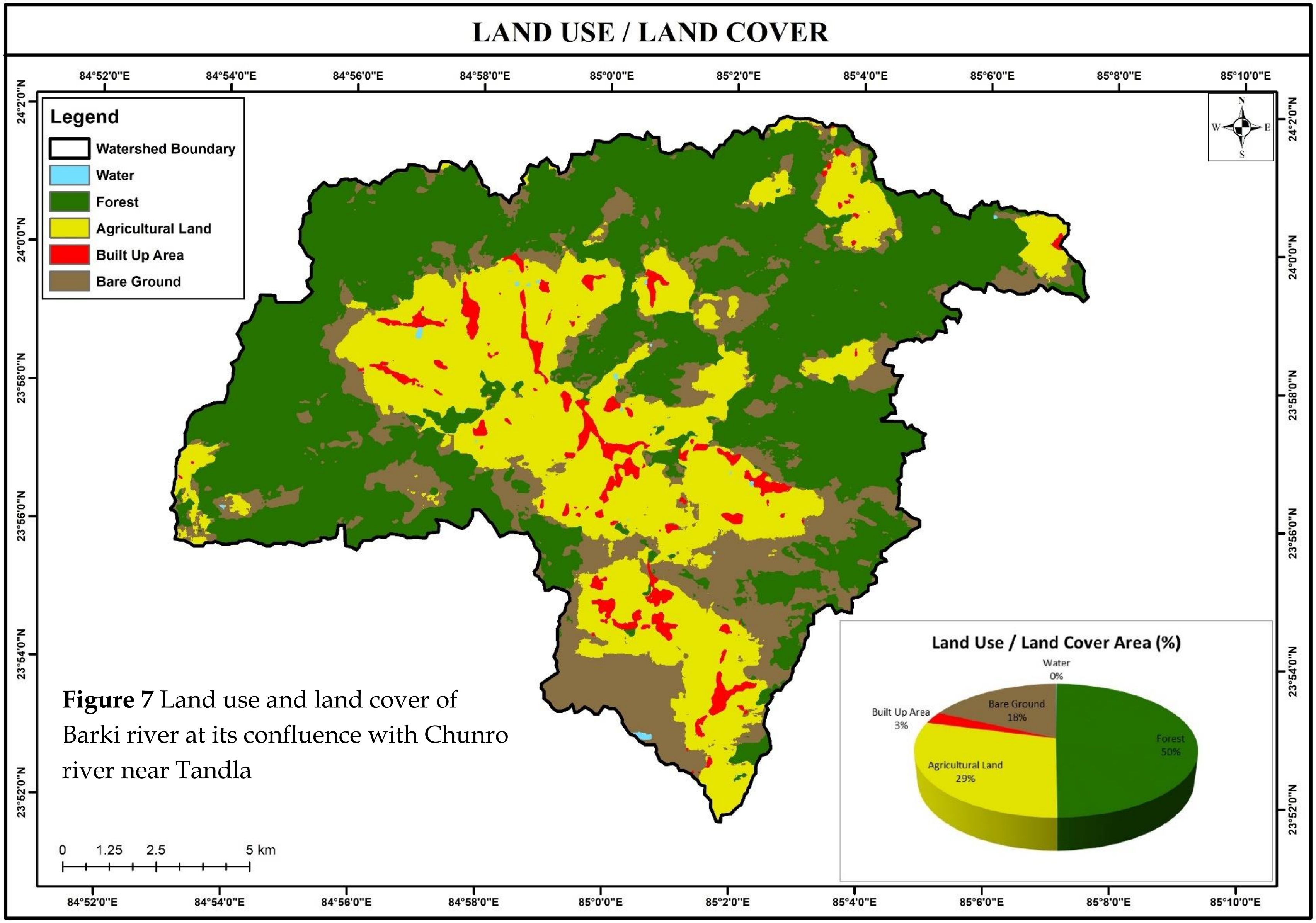


Figure 7 Land use and land cover of Barki river at its confluence with Chunro river near Tandla

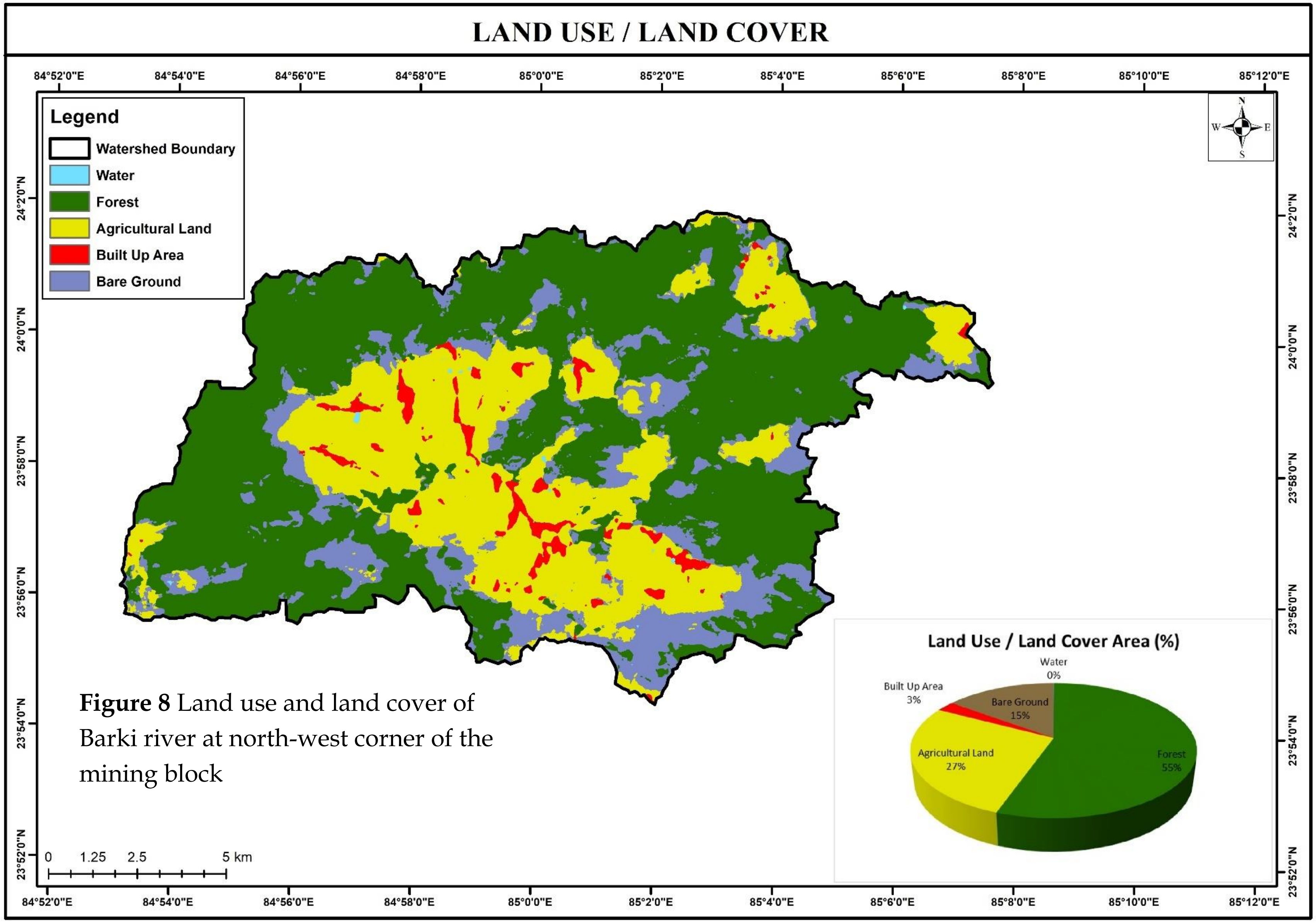


Figure 8 Land use and land cover of Barki river at north-west corner of the mining block

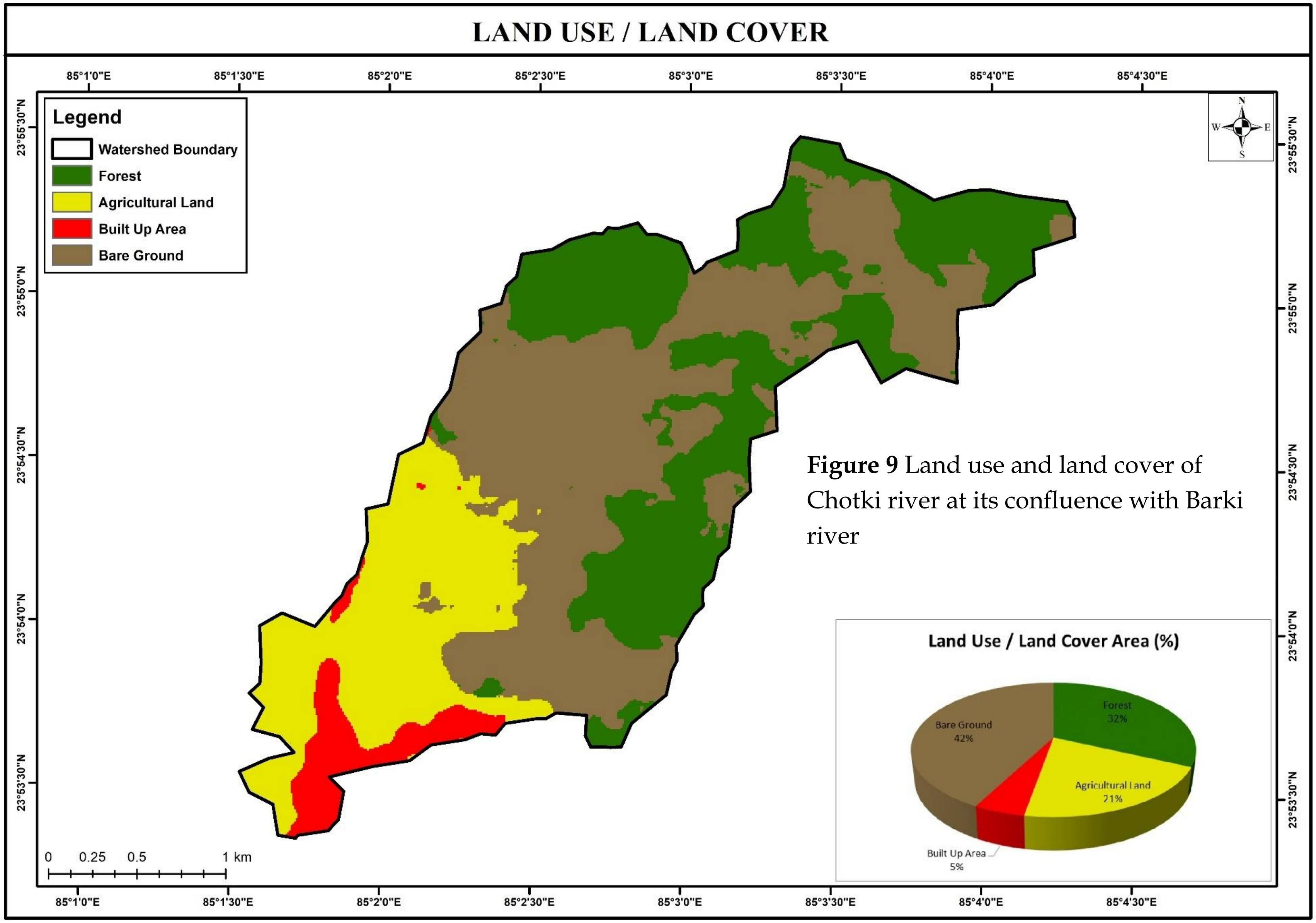


Figure 9 Land use and land cover of Chotki river at its confluence with Barki river

LAND USE / LAND COVER

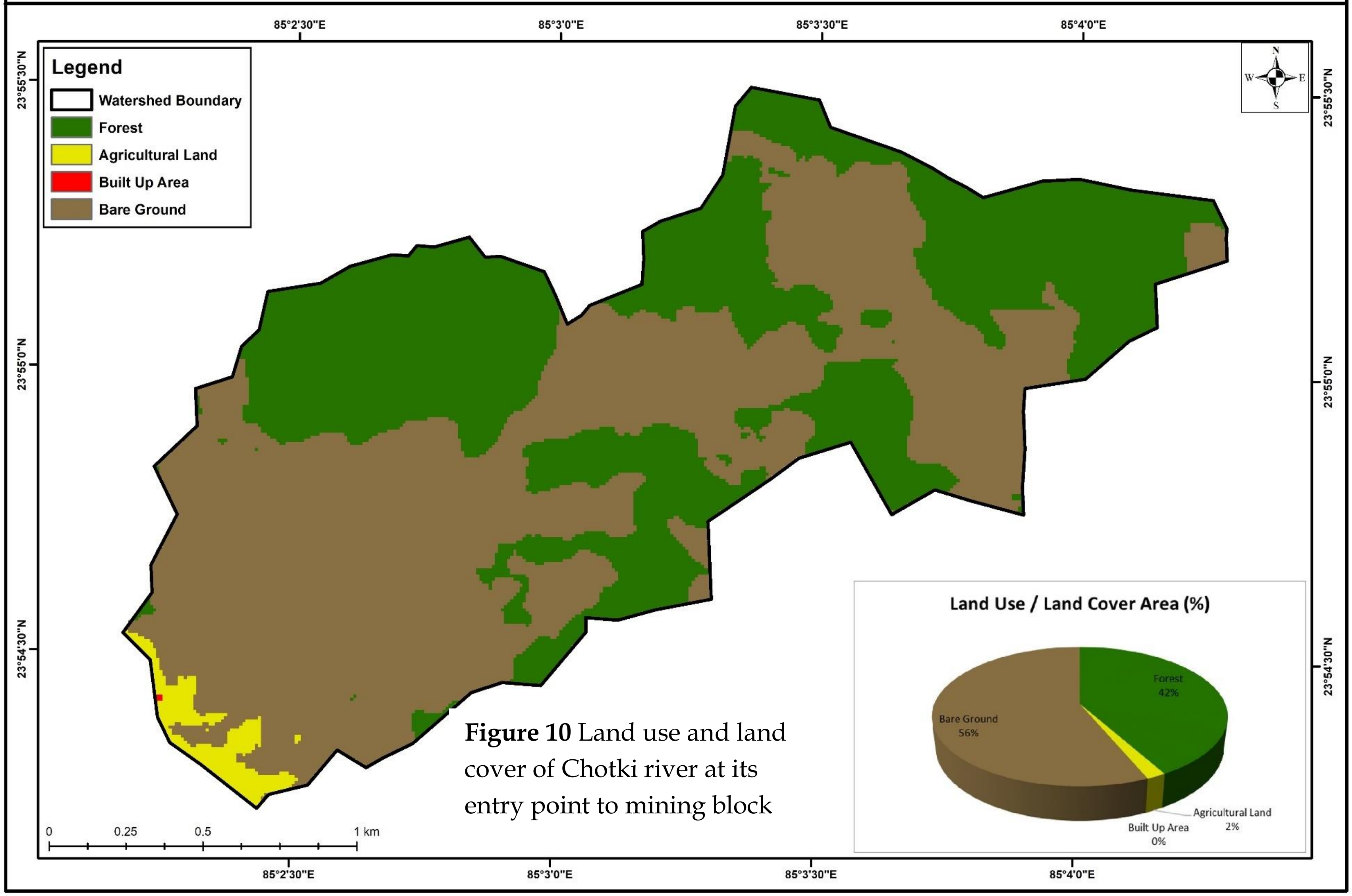


Figure 10 Land use and land cover of Chotki river at its entry point to mining block

2.5 Drainage map

Drainage map has been developed using Cartosat images and shown in Figs. 2 to 5. The developed slope map using Cartosat data are given below:

a) Slope map of Catchment of Barki river at its confluence with Chunro river near Tandla (Fig. 11)
b) Slope map of Catchment of Barki river at north-west corner of the mining block (Fig. 12)
c) Slope map of Catchment of Chotki river at its confluence with Barki river (Fig. 13)
d) Slope map of Catchment of Chotki river at its entry point to mining block. (Fig. 14)

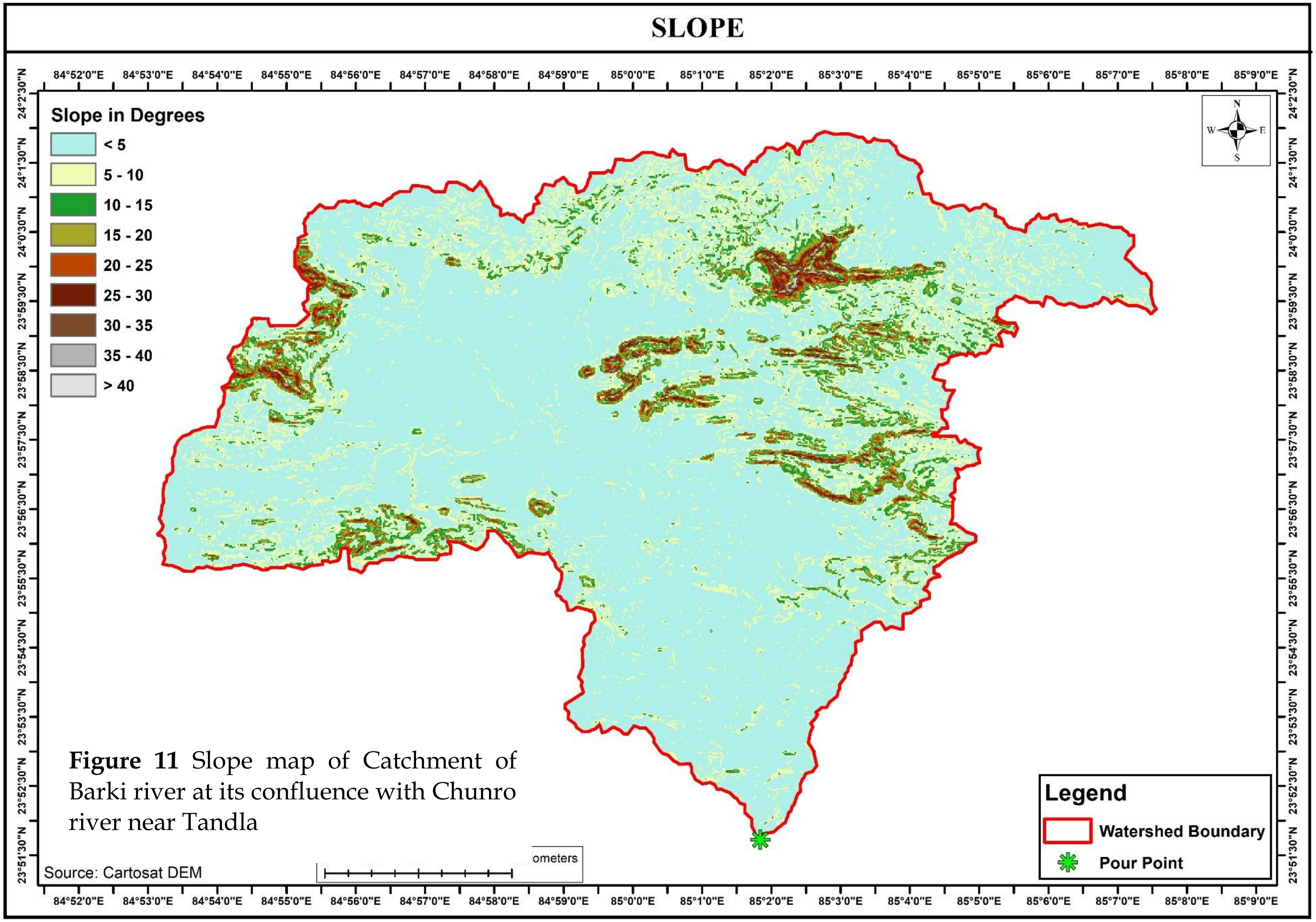


Figure 11 Slope map of Catchment of Barki river at its confluence with Chunro river near Tandla

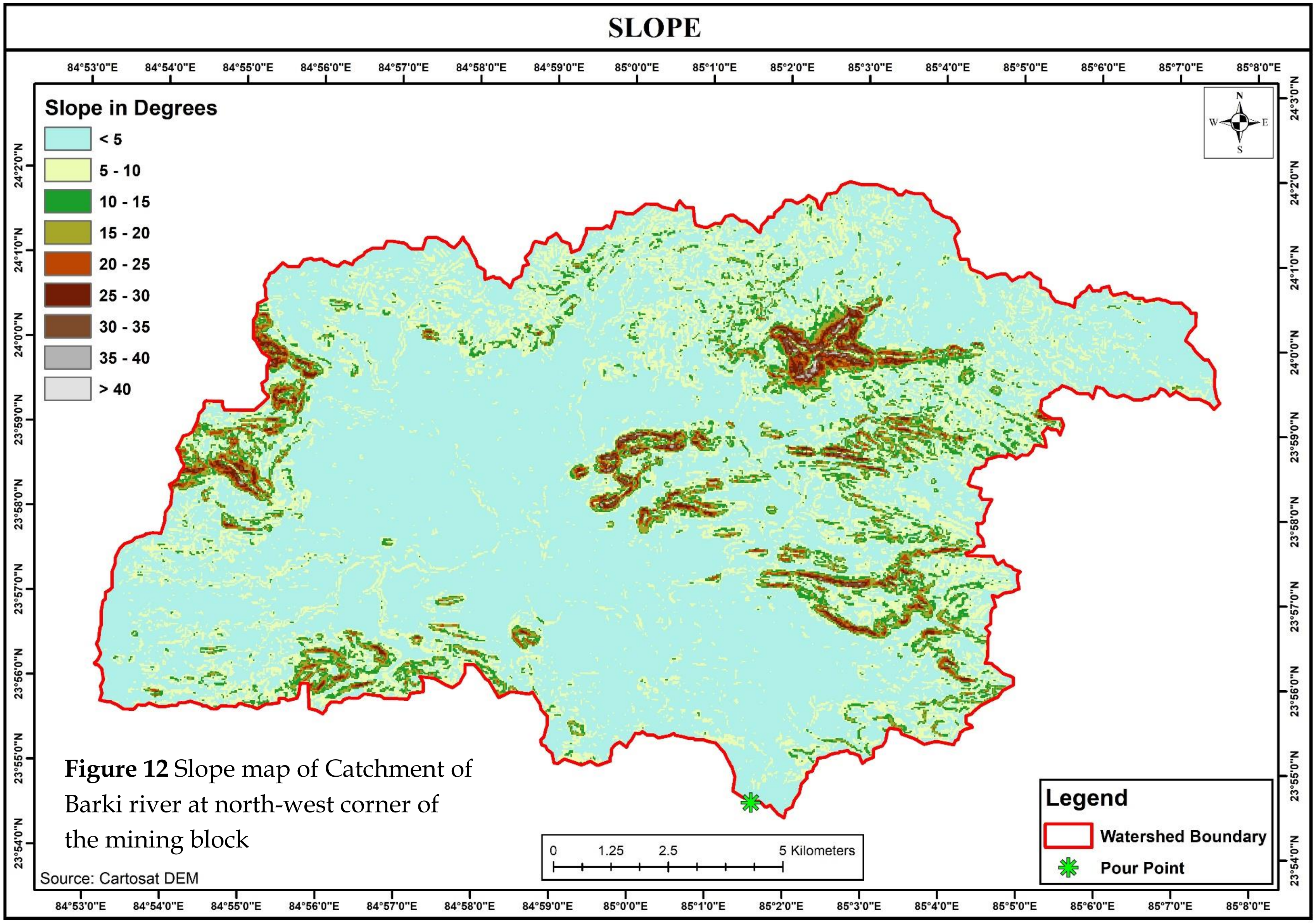


Figure 12 Slope map of Catchment of Barki river at north-west corner of the mining block

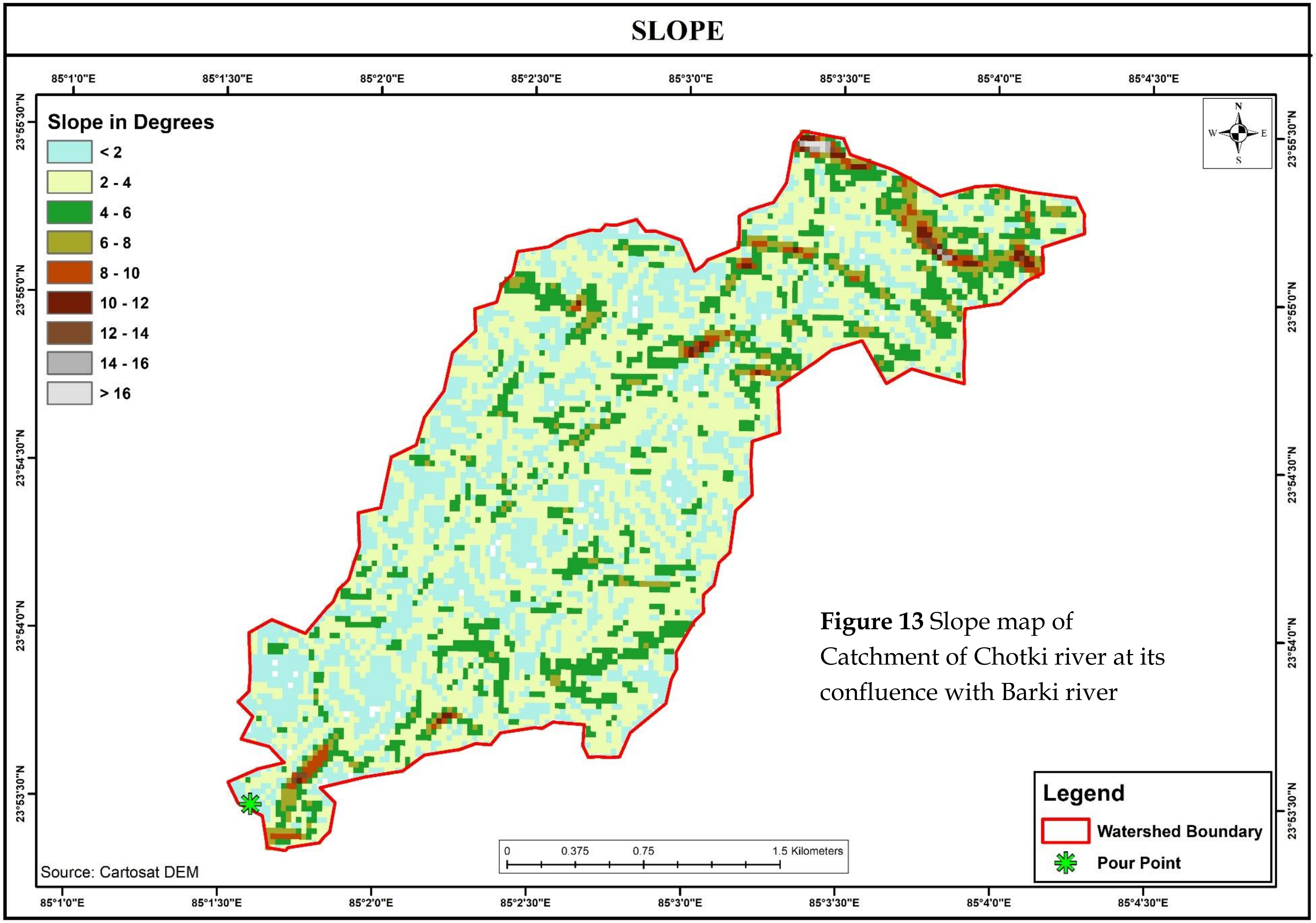


Figure 13 Slope map of Catchment of Chotki river at its confluence with Barki river

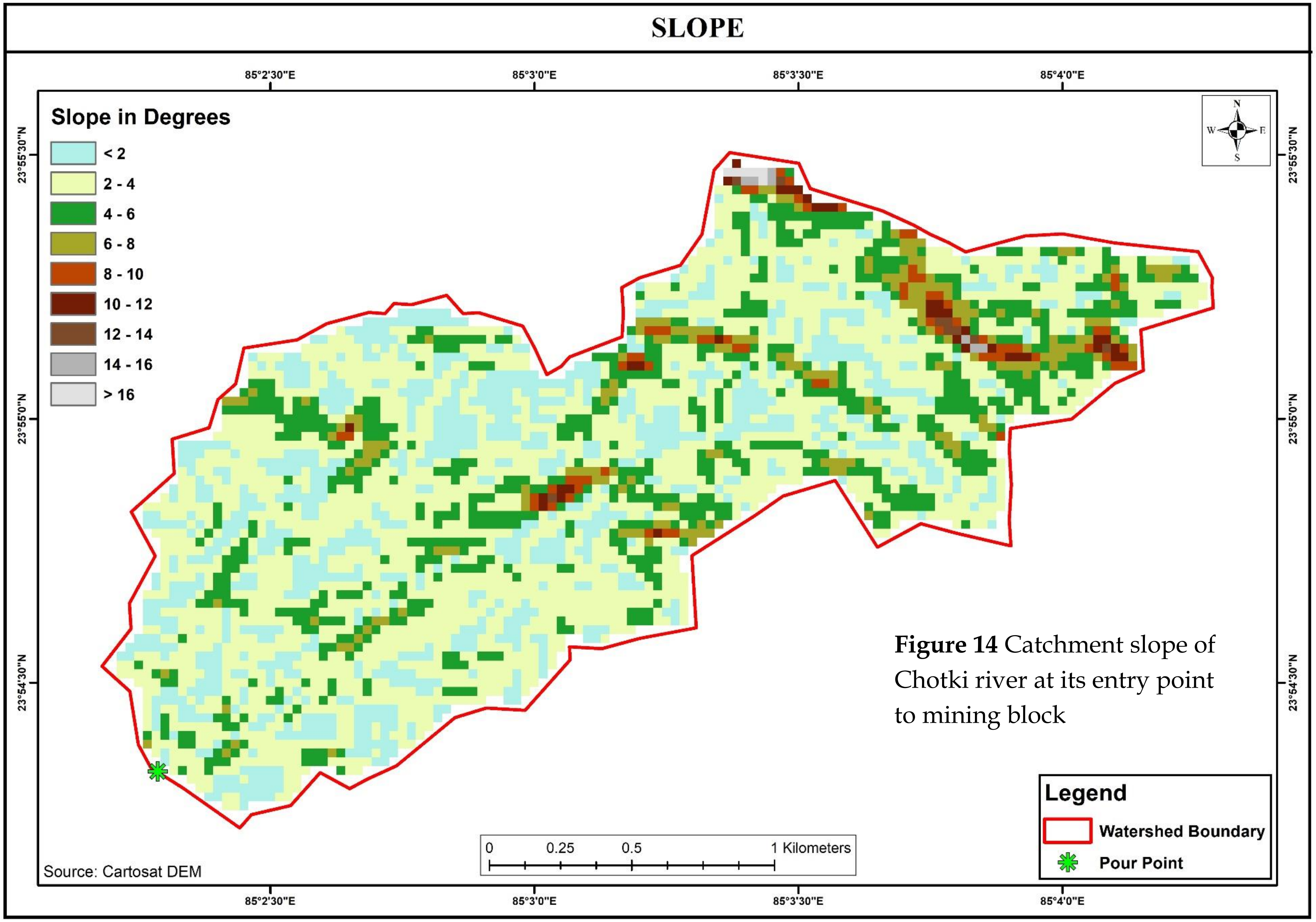


Figure 14 Catchment slope of Chotki river at its entry point to mining block

2.6 Catchment characteristics

a) Characteristics of the catchment Barki river at confluence with Chunro river are as follows:

Area of the catchment A = 231.5 km^2
Length of the longest stream L= 43.13 km
Distance of pour point from centroid = 11.57 km
Catchment perimeter = 97.53 km
Drop in the elevation H = 236 m
Slope S= H/L=236/43.13 = 5.47 m/km
Equivalent stream slope = 3.65 m/km

Bed elevations along the longest stream are as follow (also shown in Fig. 15)

Distance in km	Elevation in m	Distance in km	Elevation in m
0	383	22	440
1	395	23	448
2	387	24	452
3	390	25	464
4	394	26	466
5	397	27	475
6	397	28	483
7	401	29	489
8	404	30	495
9	404	31	501
10	406	32	512
11	407	33	529
12	410	34	529
13	412	35	536
14	413	36	546
15	416	37	548
16	419	38	559
17	424	39	565
18	427	40	573
19	429	41	575
20	439	42	588
21	435	43	619

Drainage map marked with longest stream is shown in Fig. 16.

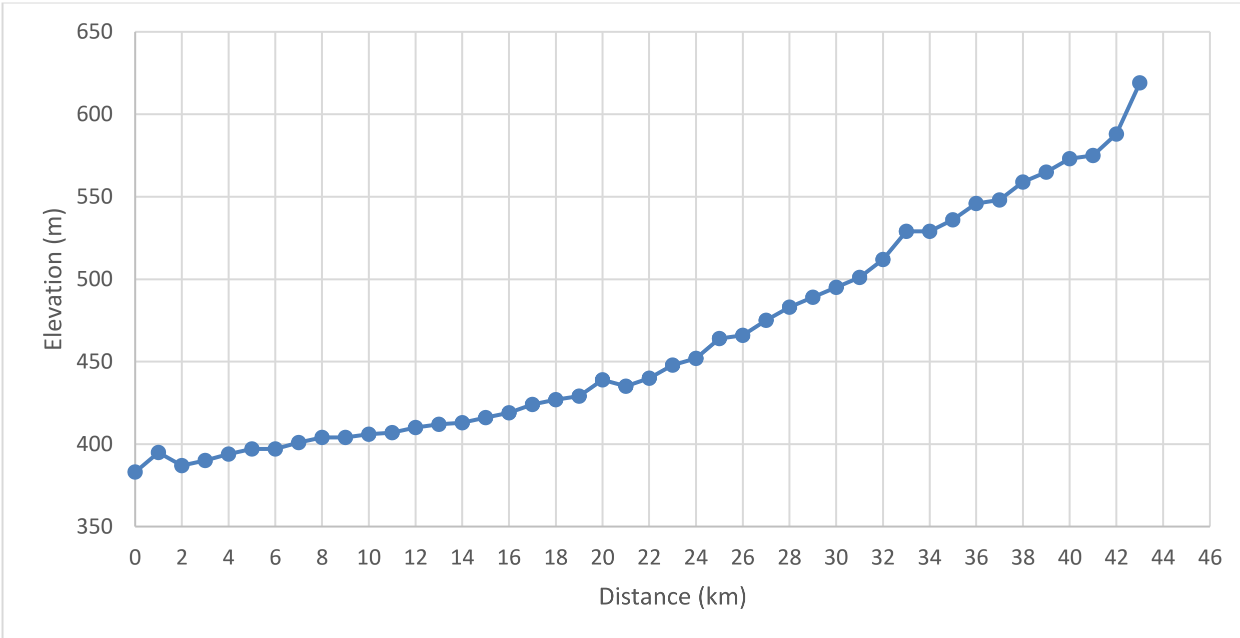


Figure 15 Bed elevation along the longest stream for Barki river at confluence

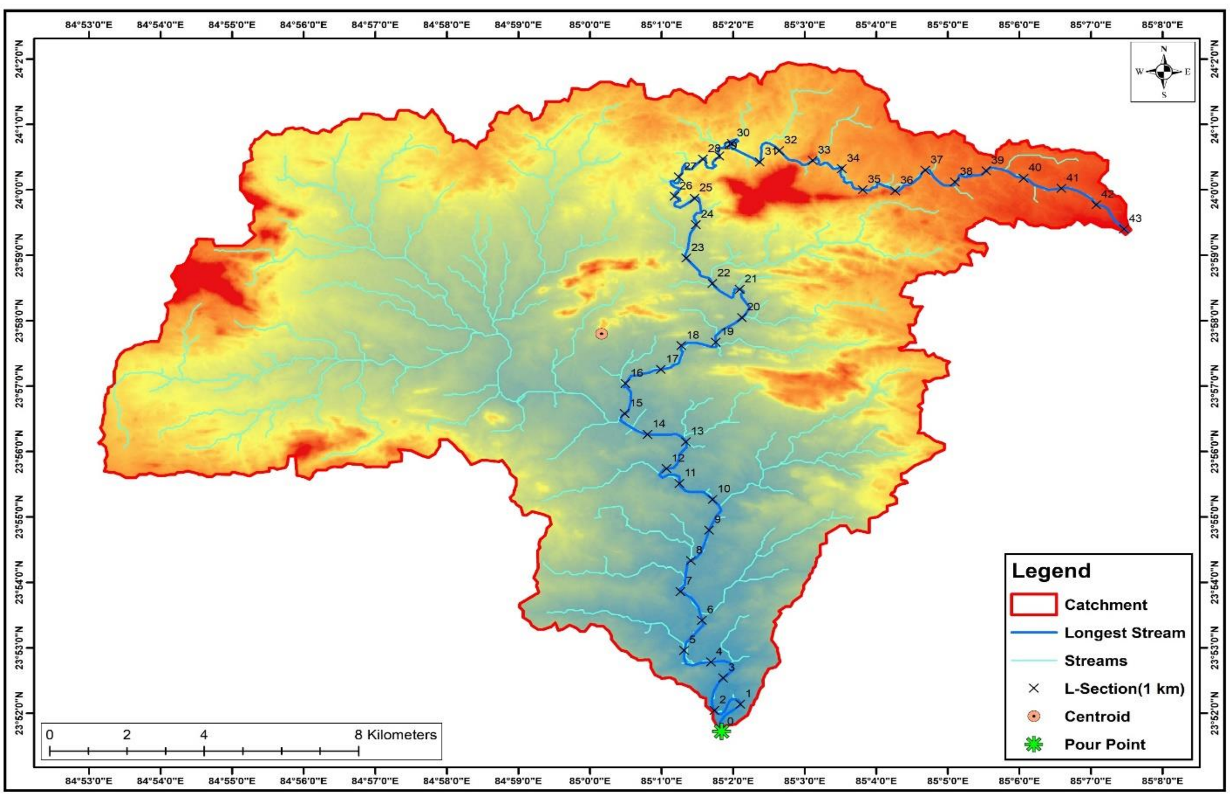


Figure 16 Drainage map marked with longest stream for Barki river at confluence

b) Characteristics of the catchment Barki river at north-west corner of mining block are as follows:

Area of the catchment A = 201.8 km^2

Length of the longest stream L= 33.23 km

Distance of pour point from centroid = 7.11 km

Catchment perimeter = 87.64 km

Drop in the elevation H = 212 m

Slope S=H/L= 212/32.33 = 6.56 m/km

Equivalent stream slope = 4.58 m/km

Bed elevations along the longest stream are as follow (also shown in Fig. 17)

Distance in km	Elevation in m	Distance in km	Elevation in m
0	404	17	470
1	406	18	477
2	408	19	487
3	410	20	497
4	413	21	502
5	414	22	512
6	415	23	529
7	420	24	534
8	424	25	539
9	427	26	543
10	431	27	544
11	434	28	559
12	438	29	569
13	444	30	570
14	448	31	579
15	456	32	588
16	463	33	616

Drainage map marked with longest stream is shown in Fig. 18.

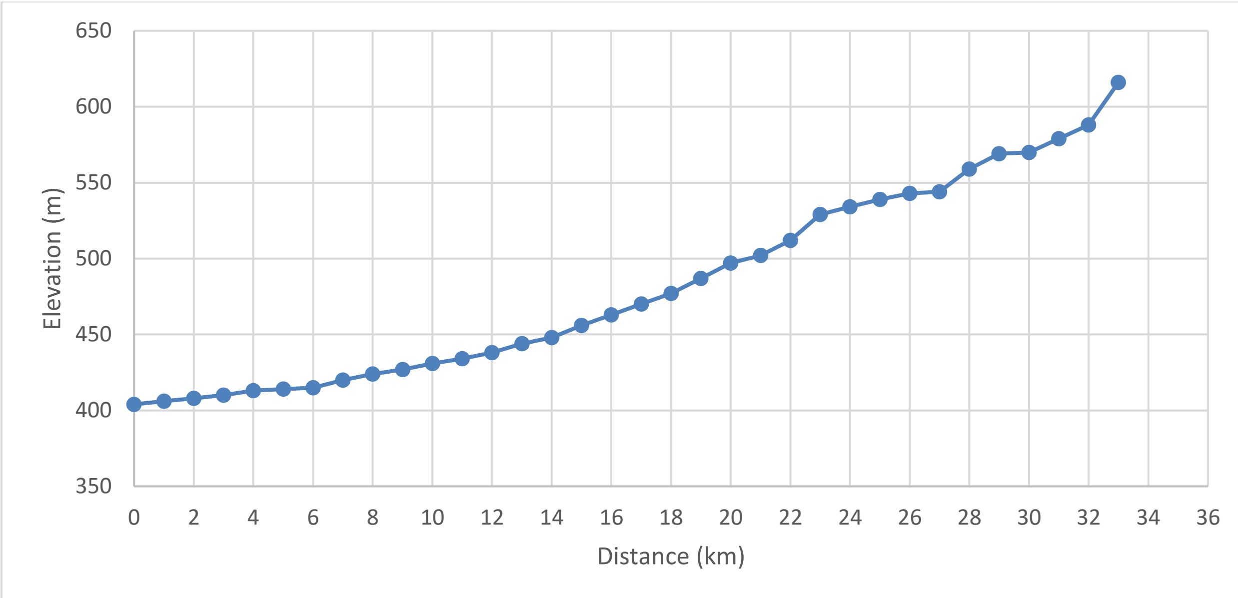


Figure 17 Bed elevation along the longest stream of Barki river at N-W corner of the mining block

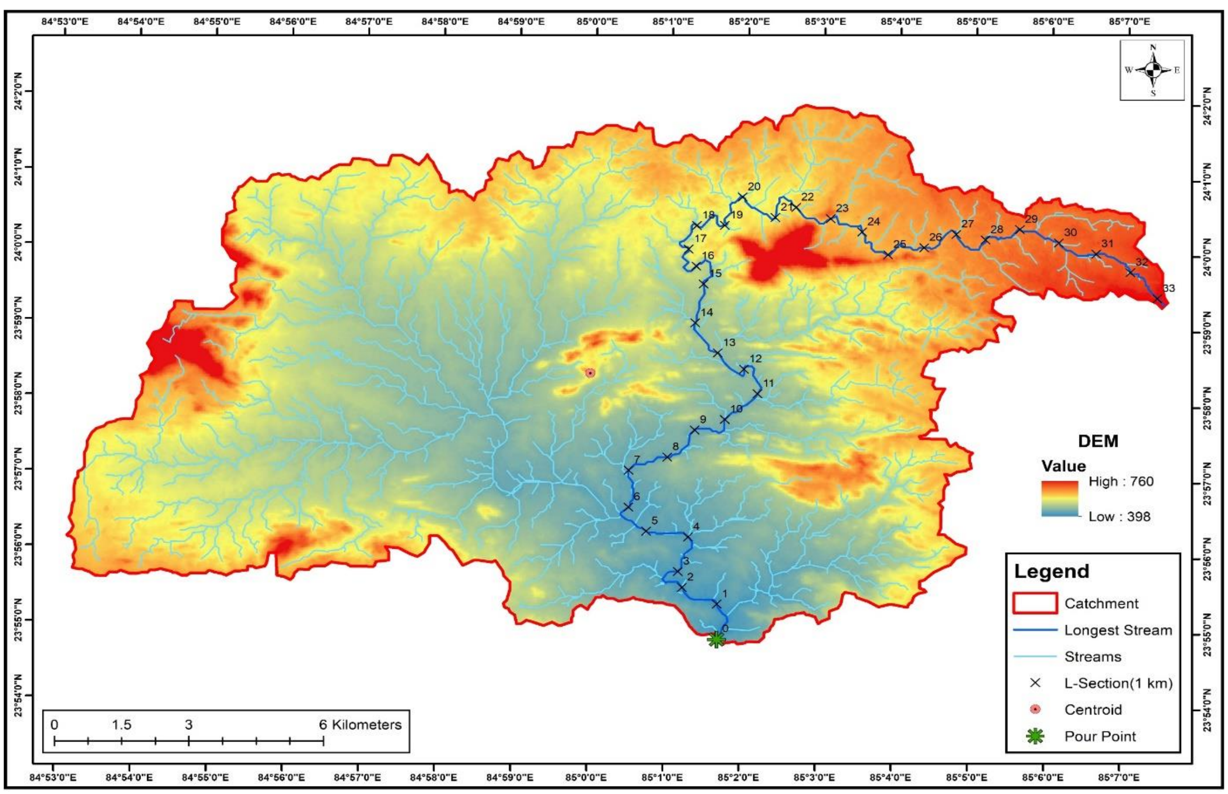


Figure 18 Drainage map marked with longest stream of Barki river at N-W corner of the mining block

c) Characteristics of the catchment at confluence of Chotki river with Barki river are as follows:

Area of the catchment A = 7.19 km^2

Length of the longest stream L = 6.5 km

Distance of pour point from centroid = 2.7 km

Catchment perimeter = 16.28 km

Drop in the elevation H = 117 m

Slope S= H/L = 18 m/km = 0.018

Bed elevations along the longest stream are as follows (also shown in Fig. 19)

Distance in km	Elevation in m	Distance in km	Elevation in m
0	399	3.5	424
0.25	400	3.75	430
0.5	401	4	431
0.75	401	4.25	432
1	401	4.5	440
1.25	403	4.75	441
1.5	405	5	443
1.75	408	5.25	451
2	408	5.5	459
2.25	409	5.75	483
2.5	411	6	498
2.75	415	6.25	507
3	418	6.5	516
3.25	421		

Drainage map marked with longest stream is shown in Fig. 20.

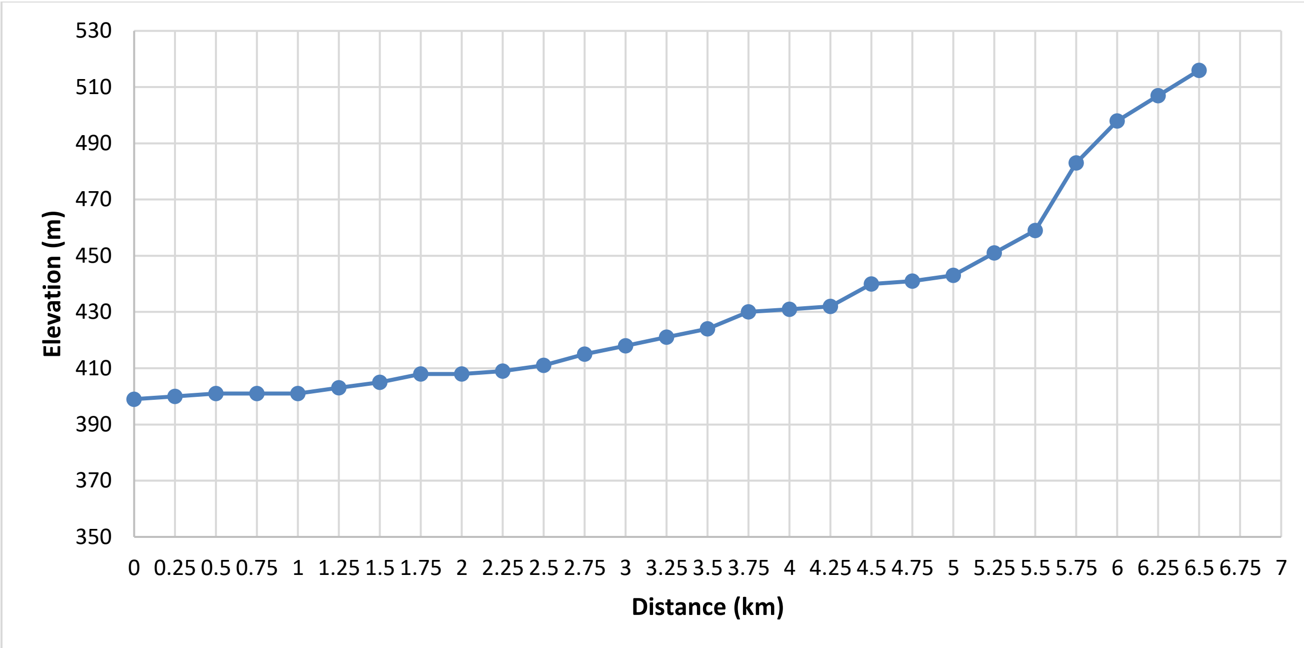


Figure 19 Bed elevation along the longest stream of Chotki river at confluence

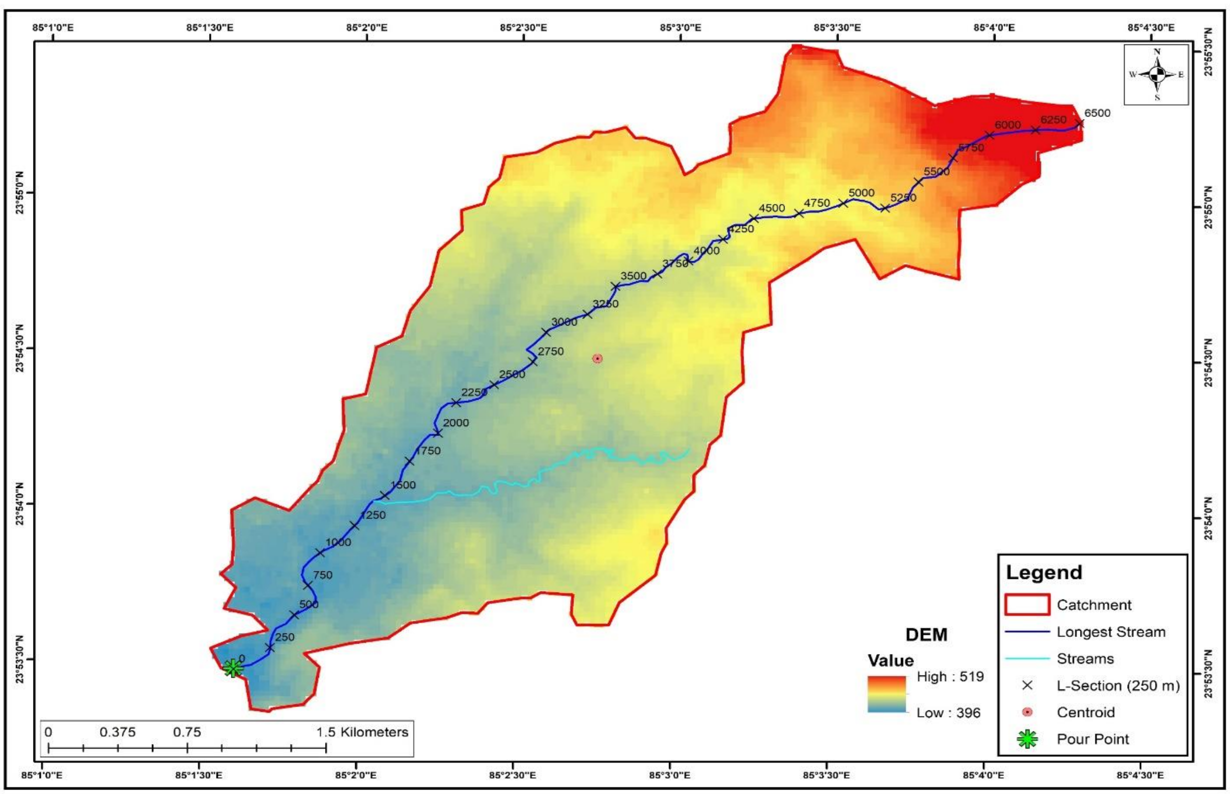


Figure 20 Drainage map marked with longest stream of Chotki river at confluence

d) Characteristics of the catchment at entry of Chotki river in the mining block are as follows:

Area of the catchment A = 3.89 km^2

Length of the longest stream L = 4.31 km

Distance of pour point from centroid = 1.73 km

Catchment perimeter = 10.81 km

Drop in the elevation H = 103 m

Slope S= H/L = 23.90 m/km = 0.024

Bed elevation along the longest stream are as follow (also shown in Fig. 21). Drainage map marked with longest stream is shown in Fig. 22.

Distance in km	Elevation in m
0	411
0.25	410
0.5	415
0.75	418
1	421
1.25	424
1.5	429
1.75	431
2	432
2.25	439
2.5	443
2.75	444
3	447
3.25	456
3.5	472
3.75	498
4	505
4.25	514

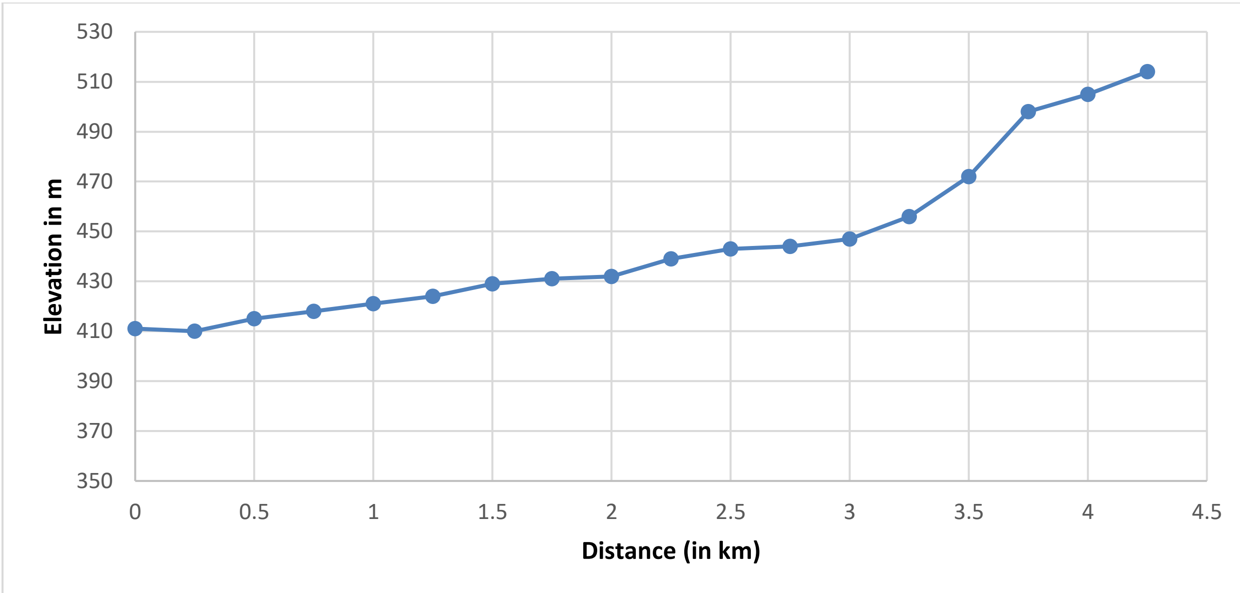


Figure 21 Bed elevation along the longest stream of Chotki river at entry point

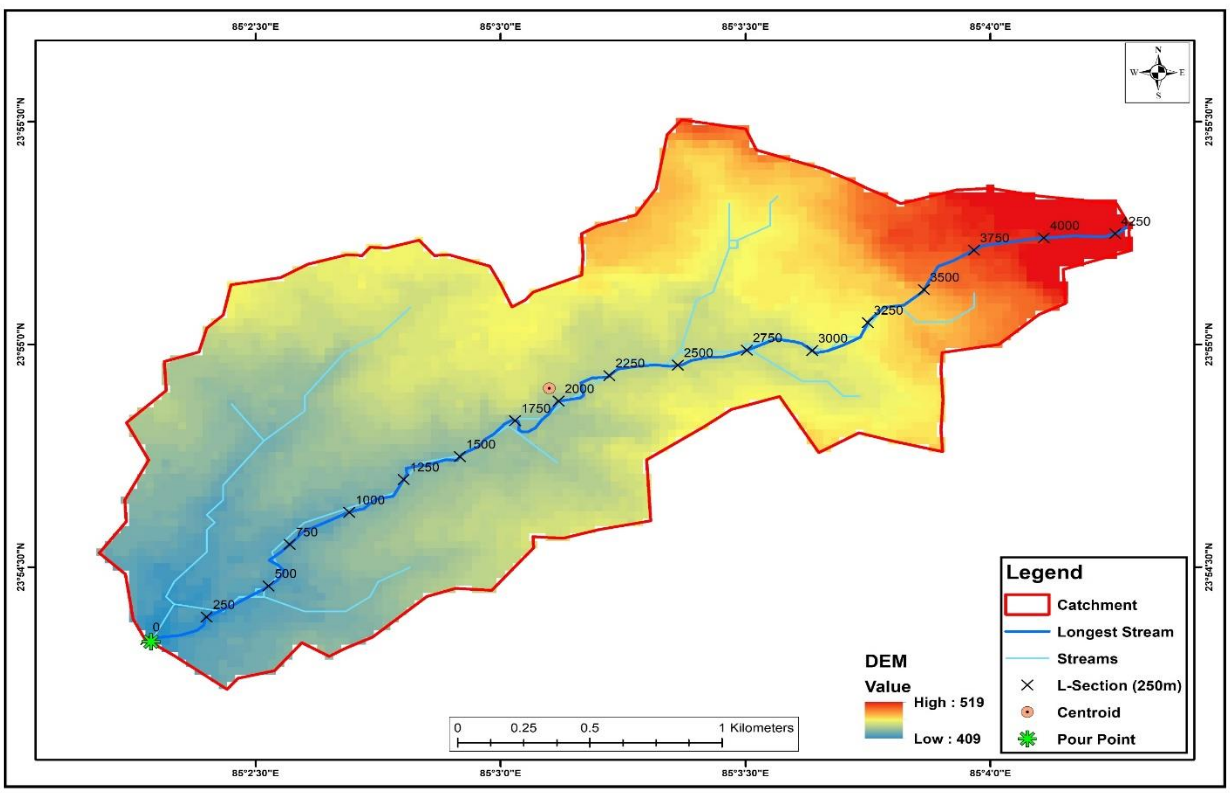


Figure 22 Drainage map marled with the longest stream of Chotki river at entry point

2.7 Cross-sections and L-section of the streams

L-section of the Barki and Chotki rivers are shown in Figs. 23a and 23b, respectively.

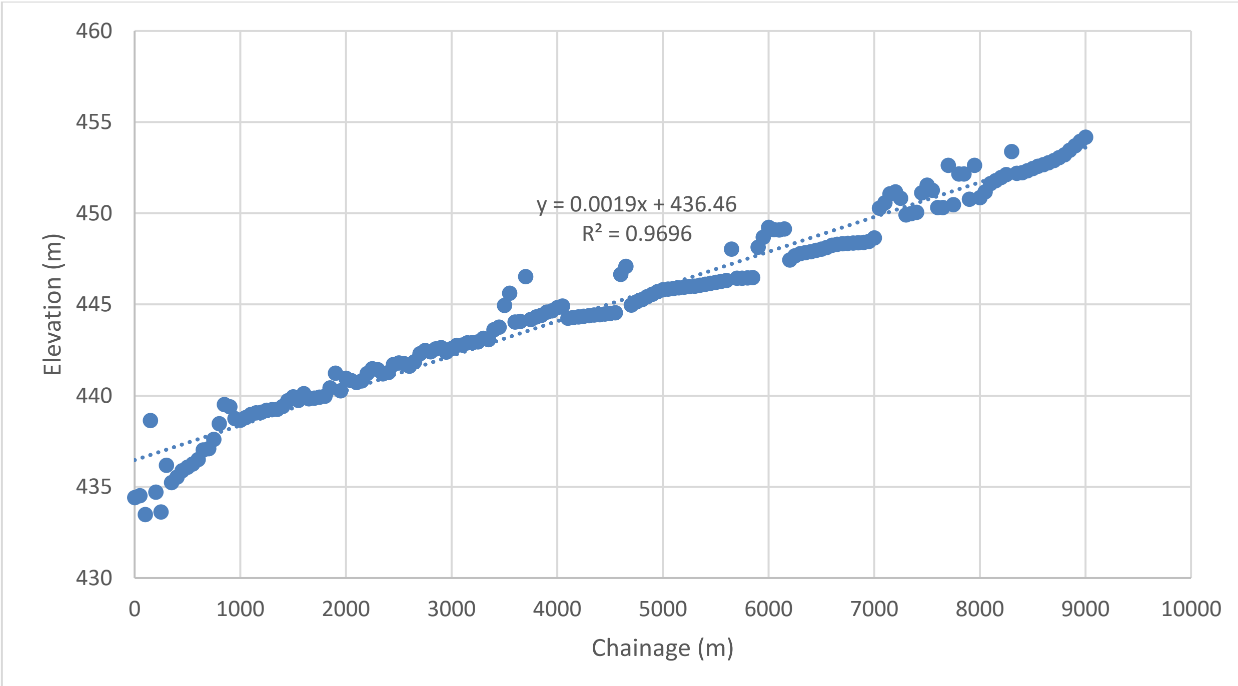


Figure 23a L-section of the Barki river (Chainage = 0 is about 160 m d/s of the Chunroo bridge)

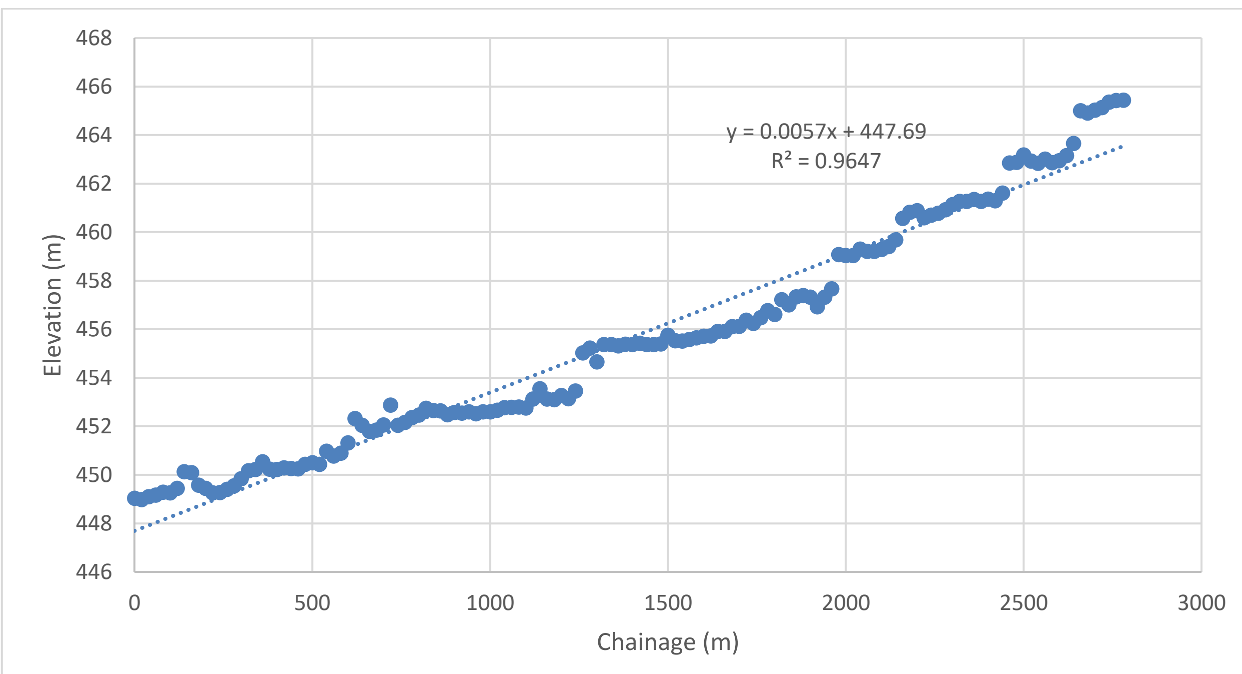


Figure 23b L-section of the Chotki river (Chainage = 0 is at its confluence with Barki river)

Average slope of the Barki river = 0.0019 (1/526)

Average slope of the Chotki river = 0.0057 (1/175)

Noted that bed slope of the Chotli river is higher in its upper reaches compared to its lower reach.

Cross-sections and L-sections of both the rivers are given in Drg. 2 and 3 which are attached with this report.

2.8 Site Visit

A site visit was undertaken on 28/6/2022 by Prof. Z. Ahmad along with officials of M/s Sushee Chandragupt Coal Mine Pvt. Ltd. and the surveyor. Photographs taken during the visit are shown in Figs. 24a-k.

The following points were noted:

a) A road bridge named as Chunroo is constructed over the Barki river just upstream of its confluence with the Chunroo river. The Barki river flow area at this location is peculiar due to rocky bed and banks.

b) Barki river has a well-defined cross-section upstream of a temple which is upstream of the Chunroo bridge. The bed of river is also rocky up to meander of the river.

c) Upstream of the Barki river meander, the river is wide and sandy.

d) Near the meander, right bank of the Barki river is higher than the left bank. Erosion was noticed on the right bank of the river upstream of the meander. A cut off of the meander has initiated, however, a complete cut off has not developed.

e) Chotki river joins the Barki river from left bank. At the confluence, the Barki river is too wide and sandy, however, Chotki river is narrow.

f) Chotki river has a small cross-section at its entry to the mining block.

g) Barki river has a well-defined section at N-W corner of the mining block. Between these two rivers, the terrain is high.

Figure 24a Rocky bed and bank of the Barki river upstream of the Chunroo bridge – upstream of confluence with Chunroo river

Figure 24b Barki river downstream of the Chunroo bridge – near confluence with Chunroo river

Figure 24c Barki river upstream of the its meander

Figure 24d Barki river upstream of the its meander

Figure 24e Barki river at start of the meander

Figure 24f Barki river downstream of the meander (rocky bed)

Figure 24g Barki river at its confluence with Chotki river

Figure 24h Chotki river joining with Barki river from left side

Figure 24i Chotki river at its entry to mining block – a road culvert over the river

Figure 24j Chotki river at its entry to mining block

Figure 24k Barki river at N-W corner of the mining block

3. HYDROLOGICAL STUDY

3.1 Hydro-Metrological Data

Jharkhand receives rain mainly from South Western monsoon wind. The cold weather commences early in November and comes to an end in the middle of March. The hot weather then sets in and lasts till the middle of June. Soon after this, the rainy season commences and continues till the end of September. The beginning of this season occurs when a storm from the Bay of Bengal passes over Jharkhand. The rainy season begins in June and the rainiest months are July and August. There are three distinct areas in Jharkhand where rainfall exceeds 1800 mm. Two of them lie on northern and north-western wings of the state and the third lies in the Netarhat pat.

The Hazaribagh district enjoy healthy and pleasant climate throughout the year. The district receives annual rainfall of 1350 mm and more than 80 percent rainfall occurs during monsoon season. Annual average temperature is 23^0 C. In summer season, the temperature in extreme cases increases to 44^0C and during winter the same come down to 2 to 3^0C (ICAR, Kolkata).

IMD (2011) analysed records of rainfall of twelve raingauge stations in the Hazatibagh for period ranging from 10 to 50 years. The details of the rainfall at these stations are given in Table 2. The average annual rainfall in the district is 1225.6 mm. During the monsoon season June to September the district receives about 85% of the annual rainfall. July is the rainiest month with an average rainfall of 315.7 mm.

In the fifty-year period 1951 to 2000, the highest annual rainfall amounting to 143% of the annual normal occurred in year 1984, while the lowest annual rainfall which was 57% of the normal occurred in year 1966. In the fifty year period, there were 8 years in which the annual rainfall in the district was less than 80% of the normal and none of them were consecutive. The heaviest rainfall recorded in 24 hours at any station in the district was 316.4 mm at Bakkagaoni on 16th September 1976.

Keridari is the nearest IMD rain gauge station of the Chandragupt mining block. The heaviest rainfall recorded in 24 hours at Keridari was 202.0 mm on 6/11/1986. The normal annual rainfall at Keridari is 1074.6 mm and highest annual rainfall was 1955.8 mm in year 1961.

CWC-IMD (2015) (PMP Atlas for Ganga river basin including Yamuna) analysed the rainfall data at Barkagaon from years 1961-2004 and calculated probable maximum precipitation (PMP) for different return periods as follow:

25 year 24- hr rainfall = 19.0 cm

50 year 24- hr rainfall = 21.5 cm

100 year 24-hr rainfall =23.9 cm

Since such PMP data are not available at Keridari, therefore, another nearest rain gauge station of Chandragupt mining block namely Bakagaon is considered herein.

Table 2 Normal and extremes of rainfall Hazaribagh (IMD 2011)

STATION	No. of Years of Data		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	HIGHEST	LOWEST	HEAVIEST RAINFALL in 24 HOURS *	
																ANNUAL RAINFALL AS % OF NORMAL & YEARS **		Amount (mm)	Date
Barhi	46	a	13.8	14.0	15.9	13.9	33.6	178.3	342.9	299.6	223.5	82.7	7.5	8.0	1233.7	155	57	295.1	04 Aug 1943
		b	1.4	1.4	1.2	1.2	2.5	7.6	15.0	14.1	10.3	3.5	0.4	0.6	59.2	(1996)	(1974)		
Bakkagaoni	29	a	10.2	13.8	6.7	13.5	31.8	184.0	341.8	294.4	249.7	69.1	8.4	8.0	1231.4	160	49	316.4	16 Sep 1976
		b	0.9	1.4	0.8	1.1	2.3	8.6	16.4	16.5	11.3	3.5	0.7	0.7	64.2	(1961)	(1966)		
Barkatha	28	a	17.6	16.8	11.7	20.2	33.4	198.1	288.2	294.4	249.1	115.9	6.5	7.8	1259.7	223	52	170.0	01 Sep 1978
		b	1.2	1.3	1.2	1.3	2.2	8.6	15.0	14.8	11.1	3.3	0.5	0.6	61.1	(1978)	(1966)		
Bishnugarh	28	a	7.4	8.4	10.6	16.0	40.2	196.8	340.2	290.4	269.1	85.6	13.2	6.4	1284.3	153	56	241.2	05 Oct 1978
		b	0.7	0.8	1.0	1.5	2.6	9.2	15.7	14.7	11.4	3.3	0.7	0.6	62.2	(1978)	(1966)		
Chauparan	28	a	9.4	13.8	10.1	7.3	22.0	199.6	288.9	249.4	180.5	72.9	5.0	8.3	1067.2	153	59	238.4	16 Jun 1968
		b	0.8	1.3	1.0	1.0	1.8	7.2	13.3	12.9	9.6	3.0	0.4	0.8	53.1	(1961)	(1970)		
Churchu	15	a	10.4	7.5	6.0	7.5	32.3	188.3	375.3	374.0	302.1	76.4	18.5	4.3	1402.6	134	47	200.0	23 Jun 1996
		b	0.7	0.5	0.5	0.8	2.0	9.4	17.2	17.1	13.1	4.4	0.7	0.4	66.8	(1997)	(2000)		
Hazaribagh	50	a	18.6	18.0	16.9	15.8	45.9	190.5	317.9	312.7	226.7	70.4	10.4	9.3	1253.1	159	59	249.2	24 Jun 1911
(Obsy)		b	1.5	1.7	1.8	1.3	3.1	9.5	16.2	15.9	11.3	4.0	0.7	0.7	67.7	(1995)	(1966)		
Ichak	28	a	9.2	17.8	10.1	11.6	43.1	220.7	326.3	327.6	239.9	71.0	11.8	9.3	1298.4	182	24	225.6	06 Jul 1986
		b	0.9	1.3	0.6	1.1	2.6	7.8	15.9	14.7	10.5	3.3	0.4	0.6	59.7	(1986)	(1964)		
Katkamsandy	14	a	11.8	14.5	18.7	8.1	14.0	130.4	331.0	320.2	190.6	68.7	12.0	12.6	1132.6	173	43	189.1	06 Jul 1986
		b	1.0	1.2	1.3	1.0	1.5	6.7	14.4	12.5	9.0	3.0	0.7	1.0	53.3	(1986)	(1995)		
Keridari	35	a	10.9	14.6	10.5	6.0	23.9	160.7	285.8	259.8	197.9	89.3	5.8	9.4	1074.6	182	53	202.0	06 Jul 1986
		b	1.0	1.2	1.0	0.6	2.0	7.9	14.6	14.2	9.4	2.8	0.5	0.7	55.9	(1961)	(1996)		
Pachamba	22	a	23.0	4.6	24.1	17.4	37.9	185.5	280.5	270.0	250.7	92.1	3.5	0.2	1189.5	163	60	300.7	12 Jun 1949
		b	1.1	0.7	0.9	1.6	2.3	9.4	14.6	14.4	11.5	3.9	0.3	0.1	60.8	(1959)	(1966)		
Pirtand	10	a	11.4	10.6	8.0	19.6	42.1	153.3	269.4	349.1	293.6	116.5	1.5	3.8	1278.9	130	60	165.4	24 Sep 1965
		b	1.1	0.5	0.8	1.7	2.5	8.7	15.0	16.1	10.9	4.2	0.2	0.3	62.0	(1968)	(1966)		
Hazaribagh		a	12.8	12.9	12.4	13.1	33.4	182.2	315.7	303.5	239.4	84.2	8.7	7.3	1225.6	143	57		
(District)		b	1.0	1.1	1.0	1.2	2.3	8.4	15.3	14.8	10.8	3.5	0.5	0.6	60.5	(1984)	(1966)		

a: Normal rainfall in mm.
b: Average number of rainy days (i.e. days with rainfall of 2.5 mm or more)
* Based on all available data upto 2006.
** Years of occurrence given in brackets.

3.2 Maximum-Intensity-Duration Curves

The rainfall intensity of duration corresponding to a time of concentration t_c and the desired return period T is found from the rainfall-frequency duration relationship for the given drainage area. This is usually in the form of

$$i(mm/hr) = \frac{kT^{x}}{(t_c + a)^{m}} \tag{1}$$

In the above equation, t_c is in hour and T in year. k, x, a and m are constants for a particular area.

The values of the above constants can be obtained, if hourly rainfall data are made available for long period. As per PMP Atlas for Ganga river basin including Yamuna 2015, wherein rainfall data for 105 years have been analysed at Hazaribagh Rain gauge station, the highest rainfall for different durations of the rainfall are as follow:

1-day highest rainfall = 249 mm on 24/06/1911

2-day highest rainfall = 317 mm on 1-2/08/1917

3-day highest rainfall = 358 mm on 2-4/08/1943

In the absence of hourly and adequate rainfall data near to the site, Bulletin No. 3 of the CSWCRTI, Dehradun on Rainfall Intensity-Duration Period Equation and Nomographs of India have been used in this study. The values of the coefficients in the Eq. (1) as obtained from Bulletin No. 3 for Jamshedpur area are k = 69.3, x = 0.1307, a = 0.5, and m = 0.8737 (Subramanya, 2012). Using these values of the coefficients, IDF curves have been generated for different return periods and given in Table 3 and also shown in the Fig. 25.

Table 3 Maximum rainfall intensity for different duration and return periods (CSWCRTI, Dehradun)

Return period (yr)--->	5	10	25	50	100
Duration (hr)	i (cm/hr)	i (cm/hr)	i (cm/hr)	i (cm/hr)	i (cm/hr)
0.1	13.36	14.63	16.49	18.06	19.77
0.3	10.39	11.38	12.83	14.04	15.37
0.5	8.55	9.36	10.55	11.56	12.65
0.7	7.29	7.98	9.00	9.85	10.79
0.9	6.37	6.98	7.87	8.61	9.43
1.1	5.67	6.21	7.00	7.66	8.39
1.3	5.12	5.60	6.32	6.91	7.57
1.5	4.67	5.11	5.76	6.31	6.90
1.7	4.29	4.70	5.30	5.80	6.35
1.9	3.98	4.36	4.91	5.38	5.89
2.1	3.71	4.06	4.58	5.01	5.49
2.3	3.48	3.81	4.29	4.70	5.15
2.5	3.28	3.59	4.04	4.43	4.84
2.7	3.10	3.39	3.82	4.18	4.58
2.9	2.94	3.21	3.62	3.97	4.34
3.1	2.79	3.06	3.45	3.77	4.13
3.3	2.66	2.92	3.29	3.60	3.94
3.5	2.55	2.79	3.14	3.44	3.77
3.7	2.44	2.67	3.01	3.30	3.61
3.9	2.34	2.57	2.89	3.17	3.47
4.1	2.25	2.47	2.78	3.05	3.33
4.3	2.17	2.38	2.68	2.93	3.21

4.5	2.10	2.29	2.59	2.83	3.10
4.7	2.03	2.22	2.50	2.74	3.00
4.9	1.96	2.15	2.42	2.65	2.90
5.1	1.90	2.08	2.34	2.57	2.81
7.1	1.45	1.59	1.79	1.96	2.15
9.1	1.19	1.30	1.46	1.60	1.75
11.1	1.00	1.10	1.24	1.36	1.49
13.1	0.87	0.96	1.08	1.18	1.29
15.1	0.78	0.85	0.96	1.05	1.15
17.1	0.70	0.76	0.86	0.94	1.03
19.1	0.64	0.70	0.78	0.86	0.94
21.1	0.58	0.64	0.72	0.79	0.86
23.1	0.54	0.59	0.67	0.73	0.80
24.0	0.52	0.57	0.65	0.71	0.77

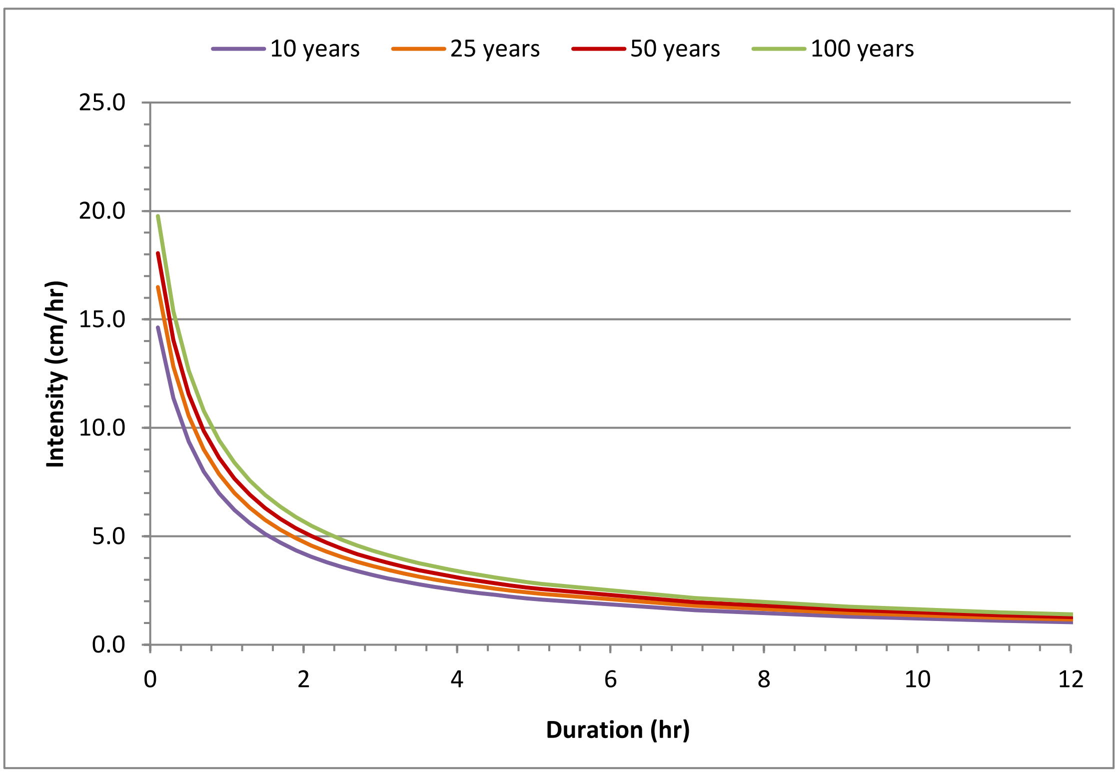


Fig. 25 Intensity Duration Frequency Curves

The developed IDF curves are checked using the iso-pluvial curves given in Central Water Commission's Flood Estimation report for Lower Ganga plains (sub Zone -1g) and PMP Atlas (2015). The iso-pluvial curves for 24-hour rainfall for 25, 50 and 100 years return periods are shown in the Fig. 26, and 27, and 28, respectively. From these figures, the following data are extracted near Chandragupt mining block.

25 year 24- hr rainfall = 22.0 cm

50 year 24- hr rainfall = 25.5 cm

100 year 24-hr rainfall = 28.0 cm

From PMP Atlas for Ganga river basin including Yamuna 2015, the PMP in a day at Barkagaon for different return periods are as follow:

25 year 24- hr rainfall = 19.0 cm

50 year 24- hr rainfall = 21.5 cm

100 year 24-hr rainfall =23.9 cm

Since the 24-hr maximum rainfall obtained from the iso-pluvial curves are slightly on the higher side compared to PMP Atlas. However, in view of recent development of the PMP status by CWC-IMD, 24-hr maximum rainfall as obtained from PMP Atlas are used for the estimation of peak discharge.

Ratios of 24-hr rainfall to short duration rainfall as given in the Fig.18 of CWC's report 1(g) which is reproduced in Fig. 29 herein are given in the Table 4.

Table 4 Computation of rainfall intensity for short duration rainfall for 25, 50 and 100 year return periods (PMP Atlas)

Duration	Ratio of 24-hr rainfall to short duration rainfall	Rainfall (cm)			Intensity (cm/hr)		
hour		25	50	100	25	50	100
hr	%	25	50	100	25	50	100
1	0.35	6.65	7.53	8.37	6.65	7.53	8.37
2	0.45	8.55	9.68	10.76	4.28	4.84	5.38
3	0.52	9.79	11.07	12.31	3.26	3.69	4.10
4	0.56	10.64	12.04	13.38	2.66	3.01	3.35
5	0.61	11.50	13.01	14.46	2.30	2.60	2.89
6	0.64	12.16	13.76	15.30	2.03	2.29	2.55
7	0.68	12.83	14.51	16.13	1.83	2.07	2.30
8	0.71	13.40	15.16	16.85	1.67	1.89	2.11
9	0.74	13.97	15.80	17.57	1.55	1.76	1.95
10	0.76	14.44	16.34	18.16	1.44	1.63	1.82
11	0.78	14.82	16.77	18.64	1.35	1.52	1.69
12	0.80	15.20	17.20	19.12	1.27	1.43	1.59
13	0.83	15.68	17.74	19.72	1.21	1.36	1.52
14	0.85	16.06	18.17	20.20	1.15	1.30	1.44
15	0.86	16.34	18.49	20.55	1.09	1.23	1.37
16	0.88	16.72	18.92	21.03	1.05	1.18	1.31
17	0.90	17.10	19.35	21.51	1.01	1.14	1.27
18	0.92	17.39	19.67	21.87	0.97	1.09	1.21
19	0.93	17.67	20.00	22.23	0.93	1.05	1.17
20	0.95	17.96	20.32	22.59	0.90	1.02	1.13
21	0.96	18.24	20.64	22.94	0.87	0.98	1.09
22	0.98	18.53	20.96	23.30	0.84	0.95	1.06
23	0.99	18.81	21.29	23.66	0.82	0.93	1.03
24	1.00	19.00	21.50	23.90	0.79	0.90	1.00

Intensity of the rainfall obtained from Table 4 is plotted on the IDF curve developed using CSWCRTI Bull. No. 3 for return period 25, 50 and 100 years in the Figs. 30, 31 and 32, respectively. The intensity of rainfall obtained from PMP Atlas is comparable to the CSWRTI Bull No. 3, however, for lower duration, intensity of rainfall obtained from CSWRTI Bull No. 3 is slightly higher. Therefore, IDF curves developed using the CSWRTI Bull No. 3 are used for the estimation of flood discharge.

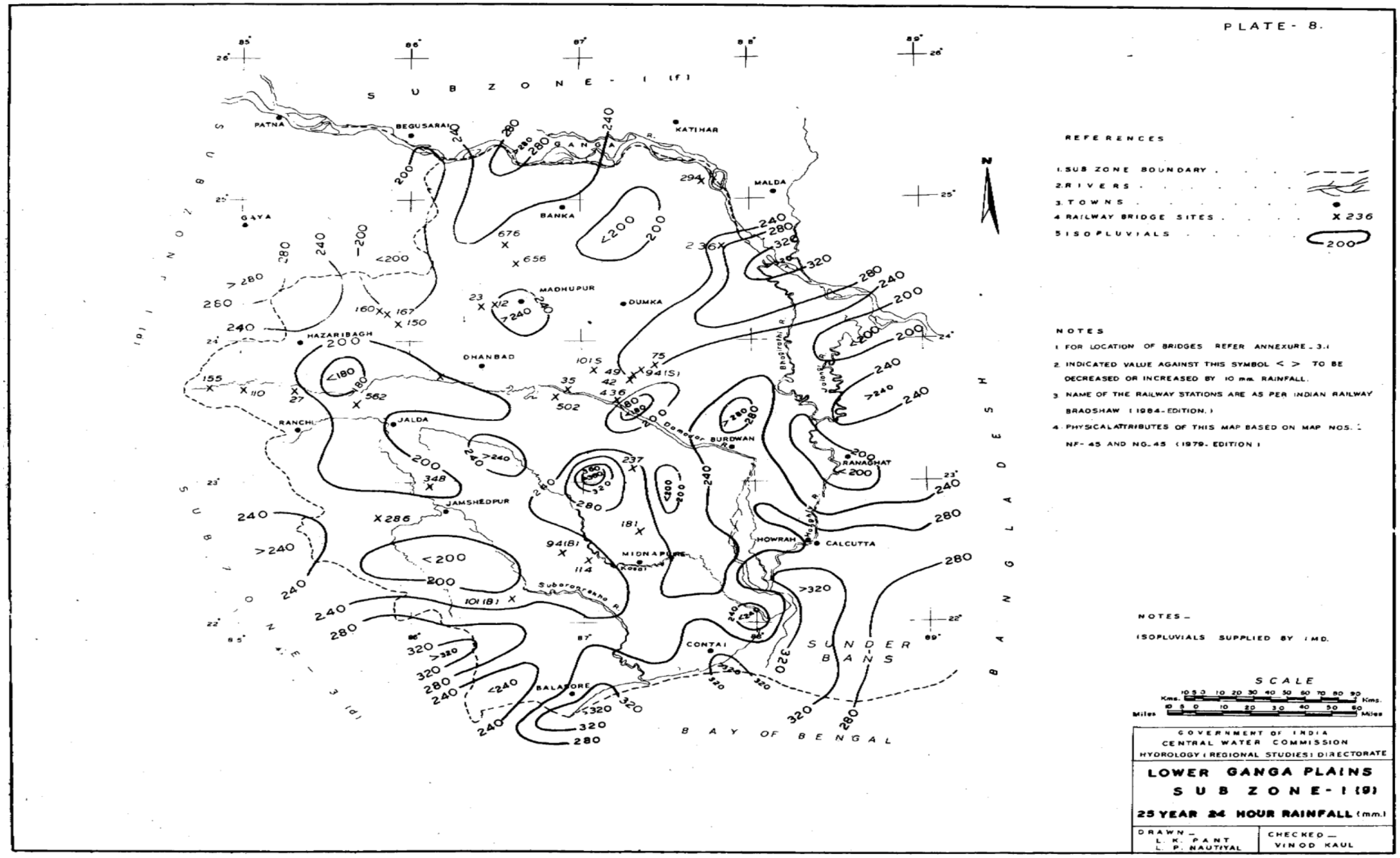


Figure 26 Iso-pluvial map for 25 year 24 hour rainfall

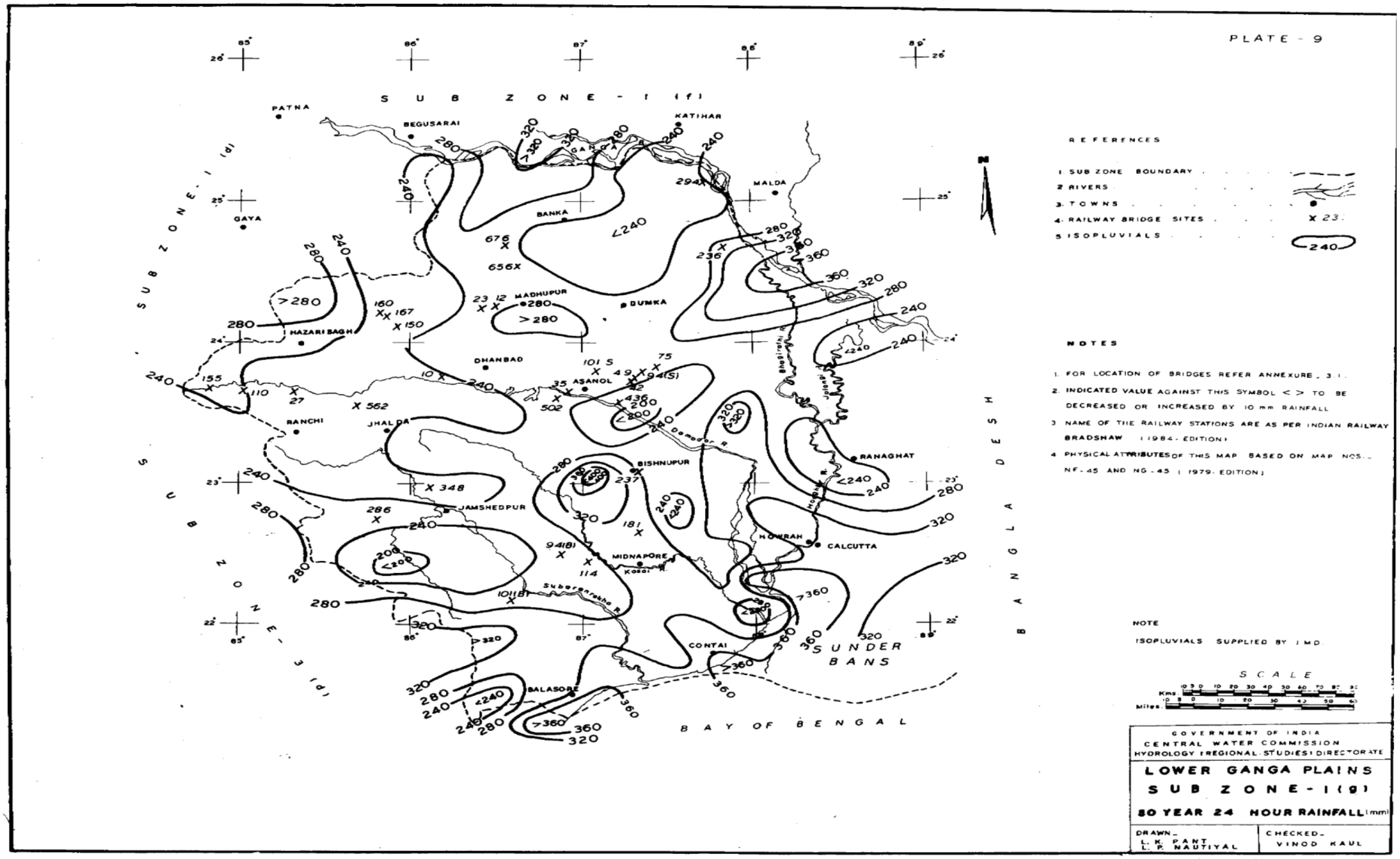


Figure 27 Iso-pluvial map for 50 year 24 hour rainfall

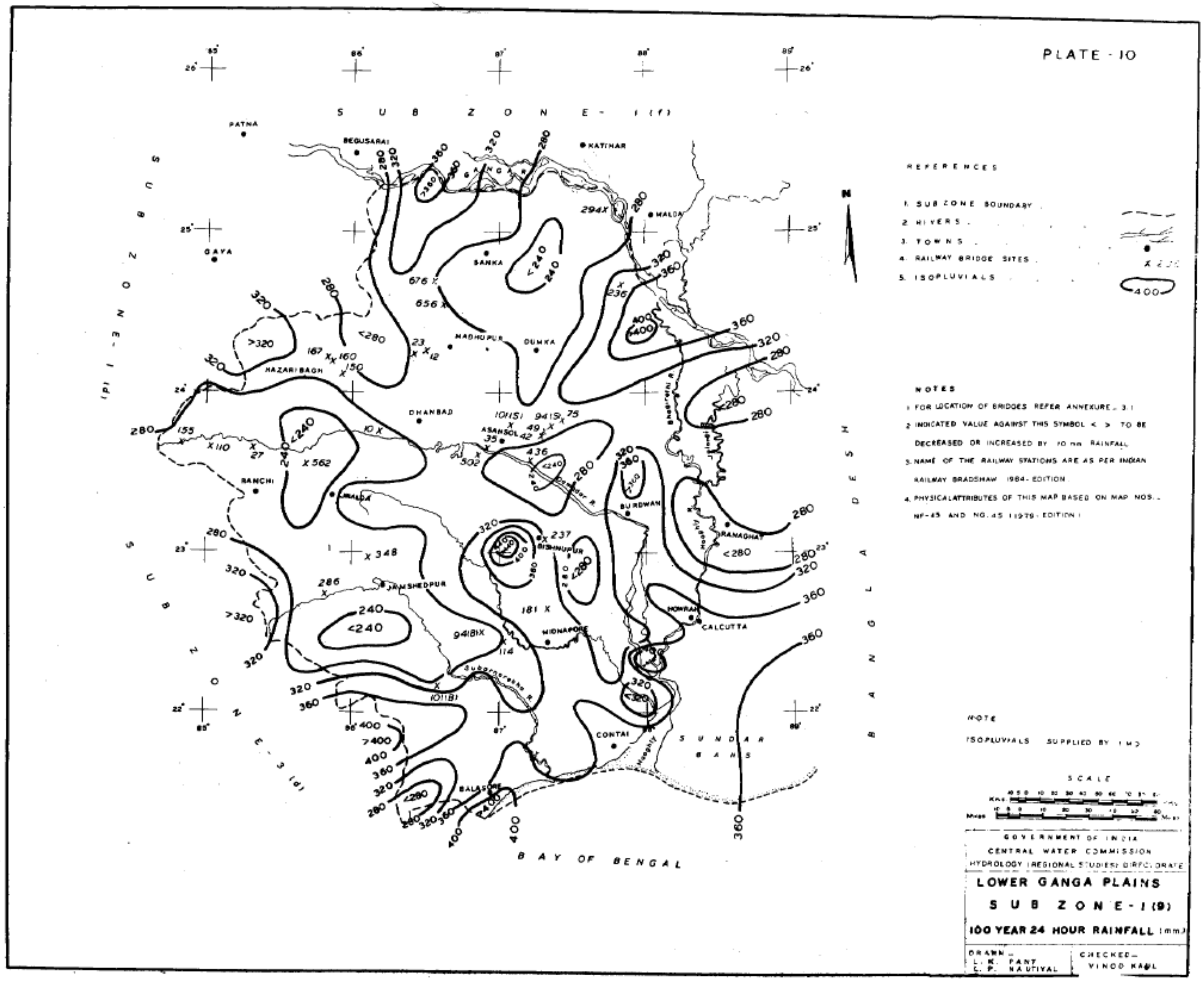


Figure 28 Iso-pluvial map for 100 year 24 hour rainfall

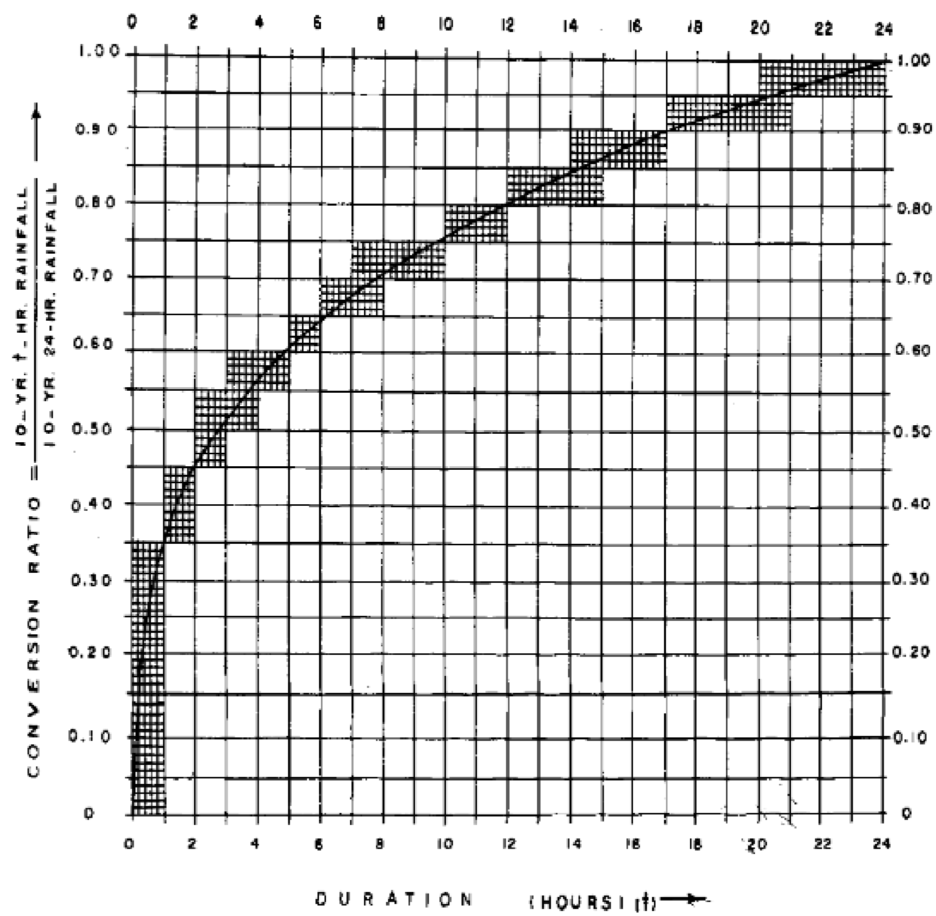


FIG.—10

RATIOS OF 24-HR. POINT RAINFALL TO SHORT DURATION RAINFALL.

DURATION (HRS.)	RATIO
1	0.350
2	0.450
3	0.515
4	0.560
5	0.605
6	0.640
7	0.675
8	0.705
9	0.735
10	0.760
11	0.780
12	0.800
13	0.825
14	0.845
15	0.860
16	0.880
17	0.900
18	0.915
19	0.930
20	0.945
21	0.960
22	0.975
23	0.990
24	1.000

NOTE :- CURVE SUPPLIED BY I.M.D

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER GANGA PLAINS
SUB ZONE - 1 (g)
DURATION VS. CONVERSION RATIO

DRAWN	CHECKED
S.N. MALHOTRA L. P. N AUTIYAL	R. K. GUPTA

Figure 29 Ratio of 24 hour rainfall to short duration rainfall

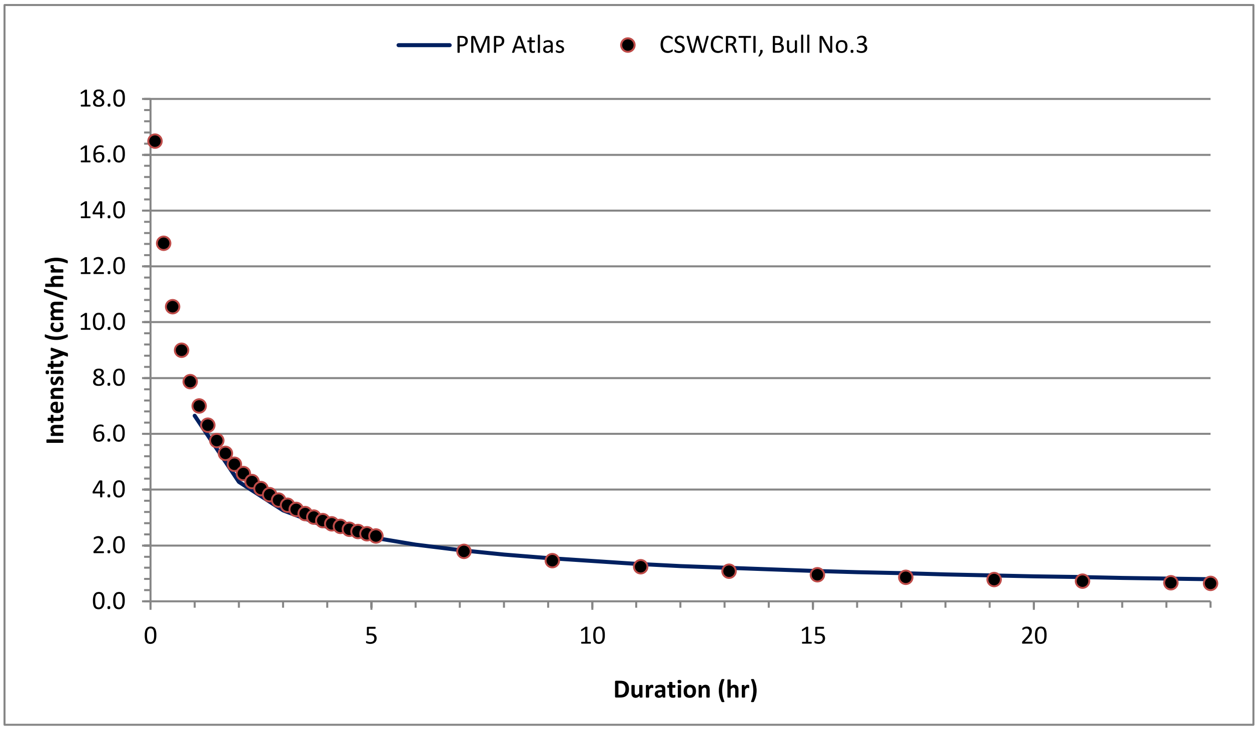


Figure 30 Comparison of IDF curves developed using CSWRTI Bull No. 3 and PMP Atlas for 25-year return period

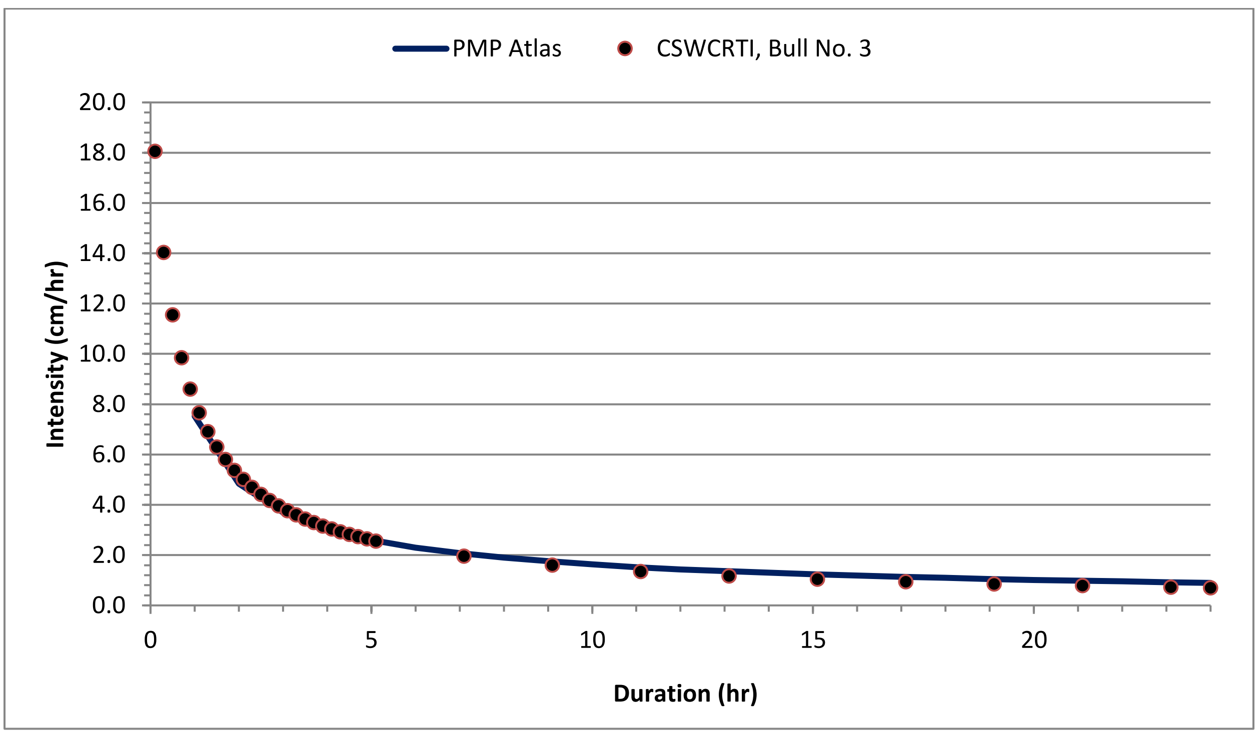


Figure 31 Comparison of IDF curves developed using CSWRTI Bull No. 3 and PMP Atlas for 50-year return period

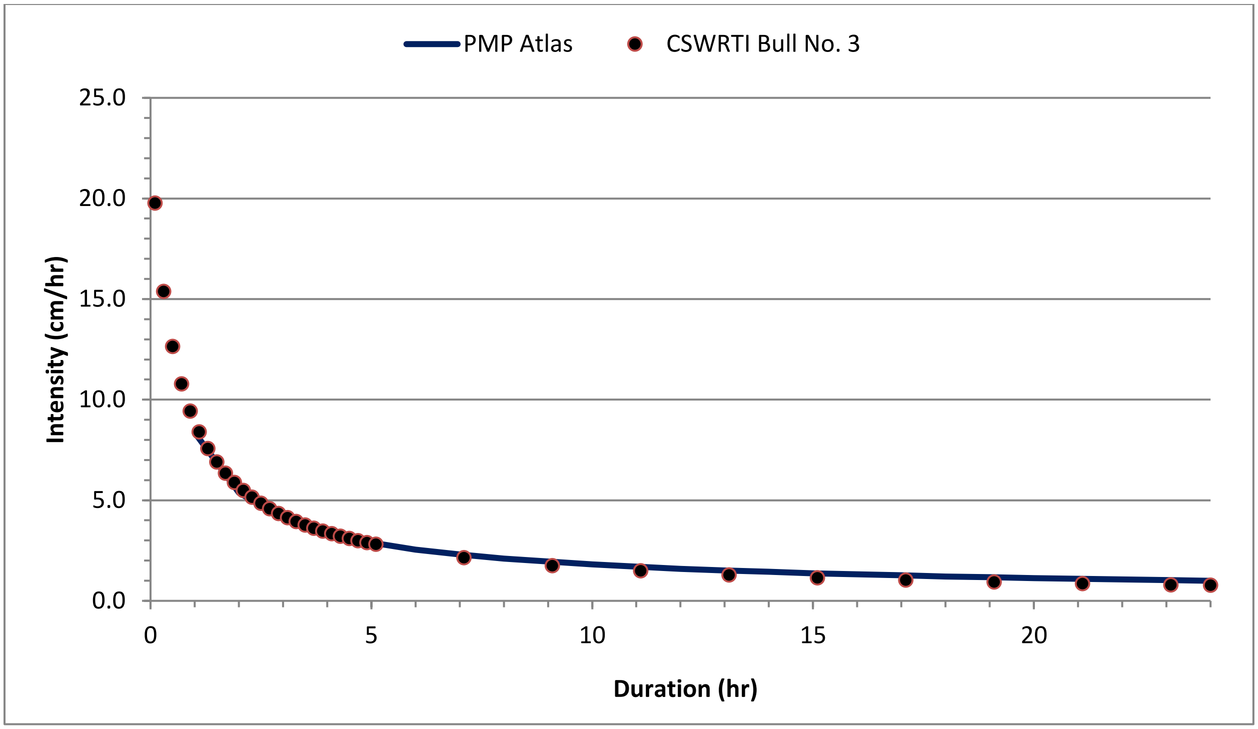


Figure 32 Comparison of IDF curves developed using CSWRTI Bull No. 3 and PMP Atlas for 100-year return period

3.3 Estimation of Peak Discharge

Estimation of peak discharge/runoff is required for design of the diversion channel. Various methods are available in the literature for the estimation of peak runoff discharge from a drainage basin in response to an extreme rainfall. Out of such methods, mostly rational method is being used for catchment of its area less than 50 km^2. For catchments varying in size from 25 to 1000 km^2, unit hydrograph method for estimation of design flood discharge with characteristics of rainfall storm and the basin characteristics for Lower Ganga plains (sub Zone -1g) can be used.

(a) Empirical equations

(i) Dicken's Formula

The Dicken's formula as given below is applicable for central and north Indian catchments

$$Q_p = CA^{3/4} \quad (2)$$

Q = Discharge in m^3/s

A = Catchment area in km^2

C = Dicken's constant varying from 6 to 30

North Indian plains	C =6
North Indian hilly regions	C=11-14
Central India	C=14-28
Coastal Andhra and Orissa	C=22-28

(ii) Modified Dicken's Formula

Uttar Pradesh Irrigation Research Institute (UPIRI), Roorkee proposed the following equation for the estimation of Dicken's coefficient C (Patra 2001)

$$C = 0.442\times\ln(0.6T)\times\ln(1185/P)+4 \qquad (3)$$

where the percentage factor P = (a+6)/(A+a)×100

a = snow covered area in km^2

T = return period

Other empirical equations like Ryves formula, Inglis formula, Fuller's formula, Ali Nawab Jung Bahadur formula are developed for other regions; therefore, they have not been used here for the estimation of peak discharge.

b) Rational Method

The peak runoff discharge from a drainage basin can be obtained by

$$Q = C\, i\, A \qquad (4)$$

Where Q = peak discharge (m^3/s); C = runoff coefficient; i = the mean intensity of rainfall (m/s) for a duration equal to time of concentration, t_c and a return period T; A = drainage area (m^2).

Time of concentration t_c is the time for a drop of water to flow from the remote point in the basin to its outlet and can be estimated from Kirpich's equation

$$t_c = 0.01947 L^{0.77} S^{-0.385} \qquad (5)$$

in which t_i = time of overland flow (minutes); L = maximum length of travel of water (m); S = slope of the drainage area = H/L where, H= difference in elevation between the most remote point on the area and its outlet on the downstream side. Other available equations for the computation of the t_c are given in the Table 5.

The value of runoff coefficient for difference surfaces of the basin is given in the codes and standard books (IRC: SP:50-1999; Subramanya, 2012).

Table 5 Equation for estimation of time of travel for overland flow (Mays, 2004; Gupta, 2015)

S/No	Name	Formula for t_c (min)	Remarks
1	Kirpich (1940)	$t_c = 0.0078 L^{0.77} S^{-0.385}$ L = Length of Channel/ ditch from headwater to outlet, ft S= Average water slope, ft/ft	Developed from SCS data For seven rural basins in Tennessee with well-defined channel and steep slopes (3% to 10%); For overland flow on concrete or asphalt surfaces multiply t_c by 0.4; For concrete channels multiply by 0.2; no adjustments for overland flow on bare soil or flow in roadside ditches
2	Kerby	$t_c = 0.828\left(\frac{rL}{S^{0.5}}\right)^{0.467}$ L = Length of Channel/ ditch from headwater to outlet, ft S= Average water slope, ft/ft	Applicable to L < 1300 ft r = 0.02 smooth pavement = 0.1 bare packed soil = 0.3 rough bare or poor grass = 0.4 average grass = 0.8 dense grass, timber
3	Izzard (1946)	$t_c = \frac{41.025(0.007i + K)L^{0.33}}{S^{0.333} i^{0.667}}$ i = Rainfall intensity, in/h K = Retardance coefficient L = length of flow path, ft S = Slope of flow path, ft/ft	Applicable to iL< 500 Developed in laboratory experiments by Bureau of Public Roads for overland flow on roadway and turf surface, K = 0.007 Smooth asphalt = 0.012 concrete pavement = 0.017 tar and gravel pavement = 0.046 closely clipped sod = 0.060 dense bluegrass turf
4	Bransby-Williams	$t_c = \frac{0.00765L}{S^{0.2} A^{0.1}}$ A = Drainage Area, acre L = length of flow path, ft S = Slope of flow path, ft/ft	

5	Federal Aviation Agency	$t_c = \frac{0.388(1.1-C)L^{0.5}}{S^{0.333}}$ C= Runoff coefficient L = Length of overland flow, ft S = Surface slope, ft/ft	Developed from airfield drainage data assembled by the Corps of Engineers; method is intended for use on airfield drainage problems, but has been used frequently for overland flow in urban basins.
6	Kinematic Wave	$t_c = \frac{0.94L^{0.6}n^{0.6}}{i^{0.4}S^{0.3}}$ i = Rainfall intensity, in/h n = Manning roughness coeff. L = length of overland flow, ft S = Average overland slope, ft/ft	Overland flow equation developed from kinematic wave analysis of surface runoff from developed surface.
7	SCS lag equation (U.S. Soil conservation service (1975)	$t_c = \frac{100L^{0.8}\left[(1000/CN)-9\right]^{0.7}}{1900S^{0.5}}$ L = Hydraulic length of watershed (longest flow path) ft CN = SCS runoff curve number S = Average watershed slope, %	Equation developed by SCS from agricultural watershed data; it has been adapted to small urban basins under 2000 acres; found generally good where area where area is completely paves; for mixed areas it tens to overestimate; adjustment factors are applied to correct for channel improvement and impervious area.

Runoff coefficient C: This represents the integrated effect of the catchment losses hence depends upon the nature of the surface slope and rainfall intensity.

RBF-16 (Flood estimation methods for Catchments less than 25 km^2 in area, Ministry of Railways, RDSO, Lucknow) provides the following equations for the runoff coefficient

Sandy soil/sandy loam/arid zones C = 0.249(RF)$^{0.2}$

Alluvium/Silty loam/coastal areas C = 0.334(RF)$^{0.2}$

R = 24-hour point rainfall and F = Areal reduction factor (point rainfall/areal rainfall)

The values of C for watersheds with agricultural and Forest land covers are given in Table 6 (Subramanya, 2012).

Table 6 Values of C for watersheds with agricultural and Forest land covers (Subramanya, 2012)

Sl. No	Vegetative cover and Slope (%)		Soil Texture		
			Sandy Loam	Clay and Silty Loam	Stiff Clay
1	Cultivated Land				
		0–5	0.30	0.50	0.60
		5–10	0.40	0.60	0.70
		10–30	0.52	0.72	0.82
2	Pasture Land				
		0–5	0.10	0.30	0.40
		5–10	0.16	0.36	0.55
		10–30	0.22	0.42	0.60
3	Forest Land				
		0–5	0.10	0.30	0.40
		5–10	0.25	0.35	0.50
		10–30	0.30	0.50	0.60

If the catchment is heterogeneous with different land use and land cover, the effective runoff can be calculated using

$$Ce = \frac{1}{A}\sum_{i=1}^{n} AiCi \qquad (6)$$

Elemental area of the sub catchment Ai and C_i is its run off coefficient.

(c) Unit Hydrograph Method

Unit hydrograph method for estimation of design flood discharge with characteristics of rainfall storm and the basin characteristics for Lower Ganga plains (sub Zone -1g) is described in Annexure-A.

3.4 Estimation of Peak Runoff from the Catchment of the Chotki river at its confluence with Barki river

The delineated drainage basin of the outside area is shown in the Fig.4.

a) Dicken's Formula

$A = 7.19\ km^2$; $a = 0$; $P = 6/7.19 \times 100 = 83.45$

For T =25 years C = 7.17

For T =50 years C = 7.99

For T =100 years C = 8.8

Estimated peak discharges are

For T =25 years $Q = 31.48\ m^3/s$

For T =50 years $Q = 35.08\ m^3/s$

For T =100 years $Q = 38.64\ m^3/s$

b) Rational method

Area of the catchment $A = 7.19\ km^2$

Length of the longest stream = 6.5 km

Distance of pour point from centroid = 2.7 km

Catchment perimeter = 16.28 km

Drop in the elevation H = 117 m

Slope S= H/L = 18 m/km = 0.018

Manning's coefficient may be obtained from

Manning's roughness coefficient

$n = 0.22\ S^{0.33} = 0.058$ (Golubtsov, 1969)

Valid for $0.004 < S_0 < 0.20$

$n = 0.104\ S^{0.177} = 0.051$ (Bray, 1979)

Valid for $0.0002 < S_0 < 0.01$

Adopted n = 0.055

From RBF-16, Runoff coefficient $C = 0.249(RF)^{0.2} = 0.249(0.95 \times 19)^{0.20} = 0.44$

However, pursuance of the Table 6 indicates

Fine loamy soil, C=0.35

Curve number = 60

Time of concentration obtained by various methods are as follow:

	tc (min)
Kirpich Equation (1940)	78.90
Kerby	175.15
Izzard (1946)	174.58
Bransby-Williams	172.40
FAA (1970)	172.73
Kinematic wave	149.58
SCS lag equation (1975)	474.19

Let us discard the value estimated by SCS lag equation and take average of other values, time of concentration tc = 153.89 min = 2.56 h

Maximum intensity of rainfall for 25 years return period and 1.315 h duration

= 3.97 cm/hr

Maximum intensity of rainfall for 50 years return period and 1.315 h duration

= 4.35 cm/hr

Maximum intensity of rainfall for 100 years return period and 1.315 h duration

= 4.76 cm/hr

Peak discharge for 25 years return period Q=CIA

$$=0.35\times(3.97/(100\times3600)\times7.19\times1000000$$

$$= 27.75\ m^3/s$$

Peak discharge for 50 years return period Q= 30.41 m^3/s

Peak discharge for 100 years return period Q= 33.27 m^3/s

Since Rational method gives better results than the empirical equations like Dicken's formula, thus the values of the discharge estimated using Rational method is adopted.

3.5 Estimation of Peak Runoff from the Catchment of the Chotki river at its entry in the mining block

The delineated drainage basin of the outside area is shown in the Fig.5.

c) Dicken's Formula

A= 3.89 km^2; a= 0; P=6/3.89×100 =154.3

For T =25 years C = 6.44

For T =50 years C = 7.06

For T =100 years C = 7.69

Estimated peak discharges are

For T =25 years Q = 17.84 m^3/s

For T =50 years Q = 19.56 m^3/s

For T =100 years Q = 21.30 m^3/s

d) Rational method

Area of the catchment A = 3.89 km^2

Slope S= 0.024

Manning's coefficient may be obtained from

Manning's roughness coefficient

$n = 0.22\ S^{0.33} = 0.064$ (Golubtsov, 1969)

Valid for $0.004 < S_0 < 0.20$

$n = 0.104\ S^{0.177} = 0.054$ (Bray, 1979)

Valid for $0.0002 < S_0 < 0.01$

Adopted n = 0.06

Fine loamy soil

Runoff coefficient C = 0.35

Curve number = 60

Time of concentration obtained by various methods are as follow:

	tc (min)
Kirpich Equation (1940)	51.56
Kerby	135.31
Izzard (1946)	138.72
Bransby-Williams	114.86
FAA (1970)	127.98
Kinematic wave	113.12
SCS lag equation (1975)	296.25

Let us discard the value estimated by SCS lag equation and take average of other values, time of concentration t_c = 114 min = 1.9 h

Maximum intensity of rainfall for 25 years return period and 1.9 h duration

= 4.91 cm/hr

Maximum intensity of rainfall for 50 years return period and 1.9 h duration

= 5.38 cm/hr

Maximum intensity of rainfall for 100 years return period and 1.9 h duration

= 5.89 cm/hr

Peak discharge for 25 years return period Q=CIA

$$=0.35\times(4.91/(100\times3600)\times3.89\times1000000$$

$$= 18.57\ m^3/s$$

Peak discharge for 50 years return period Q= 20.35 m^3/s

Peak discharge for 100 years return period Q= 22.28 m^3/s

Since Rational method gives better results than the empirical equations like Dicken's formula, thus the values of the discharge estimated using Rational method is adopted.

3.6 Estimation of Peak Runoff from the Catchment of the Barki river at N-W Corner of the mining block

Since the catchment area of the Barki river falls in the lower Ganga plains (Sub Zone-1g), therefore, Unit hydrograph method (sub Zone -1g) for estimation of peak discharge from the Catchment of the Barki river at N-W Corner of the mining block has been used herein.

Details calculation are given in Annexure-A.

The estimated discharge for 25 years return period = 358.41m^3/s

The estimated discharge for 50 years return period = 413.20 m^3/s

The estimated discharge for 100 years return period = 466.20 m^3/s

3.7 Estimation of Peak Runoff from the Catchment of the Barki river at its confluence with Chunro river near Tandla

Unit hydrograph method (sub Zone -1g) for estimation of peak discharge from the Catchment of the Barki river at its confluence with Chunro river near Tandla has been used for the computation of the peak discharges.

Details calculation for 50 years return period are given in Annexure-D.

The estimated discharge for 25 years return period = 336.09 m^3/s

The estimated discharge for 50 years return period = 379.34+0.05×231.5 = 390.915 m^3/s

The estimated discharge for 100 years return period = 443.87 m^3/s

The estimated Peak discharge from the catchment of the Barki river at its confluence with Chunro river near Tandla is slightly lower than its peak discharge at N-W corner of the mining block plus peak discharge of the Chokti river due to attenuation in the peak discharge. For conservative simulation and design, latter one is considered.

4.0 HYDRAULIC MODELLING

4.1 HEC RAS Model

The mathematical model namely; Hydrologic Engineering Center's River Analysis System (HEC-RAS) is being used for Hydraulic and Hydrological investigations and river morphological modeling. This model is developed by the U.S. Army corps of Engineers and it allows us to perform one-dimensional steady, quasi-unsteady, unsteady flow hydraulics, sediment transport/mobile bed computations for quantifying the effects of new structures like a bridge on river morphology.

a) Modeling System

HEC-RAS is an integrated system of software, designed for interaction use in a multi-tasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities (HEC-RAS, 2010).

The HEC-RAS system contains many one-dimensional river analysis including the components for (1) steady flow water surface profile computations; (2) unsteady flow simulation; (3) movable boundary sediment and transport computations. A key element is that all the components use common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

b) Hydraulic Capabilities

The following is a description of the major hydraulic capabilities of HEC-RAS.

i) Steady Flow Water Surface Profiles

This component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a single river reach, a dendritic system, or a full network of channels. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles.

The computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include hydraulics of bridges, and evaluating profiles at river confluences (stream junctions).

The effects of various obstructions such as bridges and other structures on the flood plain are considered in the computations. The steady flow system is designed for application in floodway encroachments. Also, capabilities are available for assessing the change in water surface profiles due to channel improvements, levees etc.

ii) Unsteady Flow Simulation

This component of the HEC-RAS modeling system is capable of simulating one-dimensional unsteady flow through a full network of open channels.

The hydraulic calculations for cross-sections, bridges, and other hydraulic structures that had been developed for the steady flow component are incorporated into the unsteady flow module. Additionally, the unsteady flow component has the ability to model storage areas and hydraulic connections between storage areas, as well as between stream reaches.

iii) Sediment Transport/Movable Boundary Computations

This component of the modeling system is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from bed aggradation and degradation over moderate time periods; typically days, months or years. Applications to single flood events are also possible.

The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring, if the case be.

The model is designed to simulate long-term trends of aggradation and degradation in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. The sediment module works with quasi-unsteady flow. The quasi-unsteady flow assumption approximates a continuous hydrograph with series of discrete steady flow profiles. For each record in the flow series, flow remains constant over a specified time window for sediment transport computations.

HEC RAS also performs the scour at the bridge based on the Richardson equation (CSU).

4.2 Model Development

This section provides a description of the development of a mathematical hydraulic model for the Barki river from N-W corner of the mining block to upstream of its confluence with Chunro river. The mathematical modeling was performed using the Army Corps of Engineer's (USACE) Hydrologic Engineering Center's (HEC) River Analysis System program (HEC-RAS) Version 4.1.0 (2010) steady option. The first step in developing the HEC-RAS model was to create a HEC-RAS geometry file containing the stream, cross sections and channel and overbank downstream reach lengths.

The Barki river is modelled from the Chainage 9000 m which is 150 m upstream of the N-W corner of the mining block to Chainage 375 m. Chotki river joins the Barki river from left side at Chainage 6150 m. Since Barki river upstream of the Chunro bridge is rocky and not well defined, thus the downstream boundary condition is fixed at chainage 375 m, where a well-defined section of the Barki river exists.

The modelled river system in HEC RAS is shown in Fig. 33.

The available cross-sections of the Barki rivers at its different chainages are modelled. Drawing of the plan layout of the Barki river and its chainages at different locations are attached with this report. The reach lengths are provided in the cross-section editor file of HEC RAS.

The values of Manning's roughness coefficient 'n' were assigned to each cross section based on the surface characteristics of the Barki river. Since the Barki river is channelized in its major reaches, a constant Manning's coefficient of 0.015 is assigned to each cross-section (Chow 1959).

The expansion and contraction coefficients were estimated based on the ratio of expansion and contraction of the flow area in the floodplain occurring at various cross-sections. Considering the gradual expansion and contraction, the expansion and contraction coefficients adopted at each cross-section were 0.3 and 0.1 respectively.

Downstream boundary condition is provided as normal depth at Chainage 375 m with bed slope of 0.005. Model has been run for different discharges at the upstream boundary.

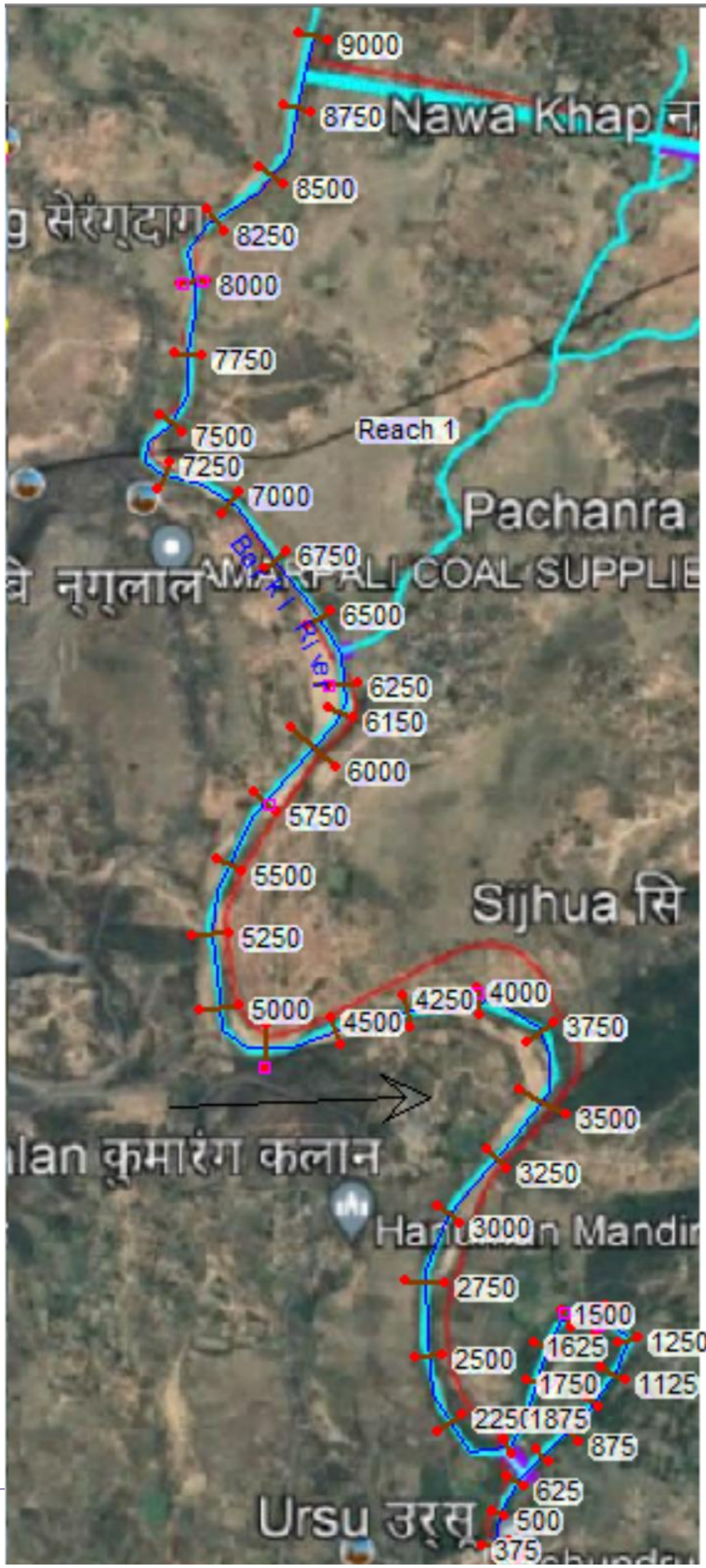


Figure 33 Simulated Barki river with the meander

4.3 Running the Model under Existing Condition

The model was run under the existing condition i.e., no diversion of the Chotki river and no straightening of the meander under the steady state condition. Normal depth was provided at Chainage 375 m with bed slope of 0.005. A discharge of 358.41 m^3/s was provided at Chainage 9000 m and discharge of Chotki river of 27.75 m^3/s was provided at Chainage 6150 m. Computed water surface profile and other hydraulic parameters are given in Annexure-C.

4.4 Diversion of Chokti River

After examination of the contour map of the area from entry of the Chotki river to the mining block area and N-W corner of the mining block and also after examining the bed level of the Chotki river at its entry to mining block and bed level of the Barki river at N-W corner of the mining block, a diversion channel is aligned from the point 23°54'24.02"N, 85° 2'21.02"E to point 23°54'35.02"N, 85° 1'35.48"E as marked in the Fig. 34.

Chainage of the Barki river at N-W corner of the mining block = 8850 m

Chainage of the Barki river at Outfall of the diversion channel = 8750 m

Length of the channel = 1380 m (Ch. 180 m to 1560 m of diversion channel)

Bed level of the Chotki river = 462.0 m

Bed level of the Barki river = 453.0 m

Difference in the bed level = 462-453= 9.0 m

Bed slope, S = 9/1380 = 0.00652

Discharge Q =20.35 m^3/s (50th year return period)

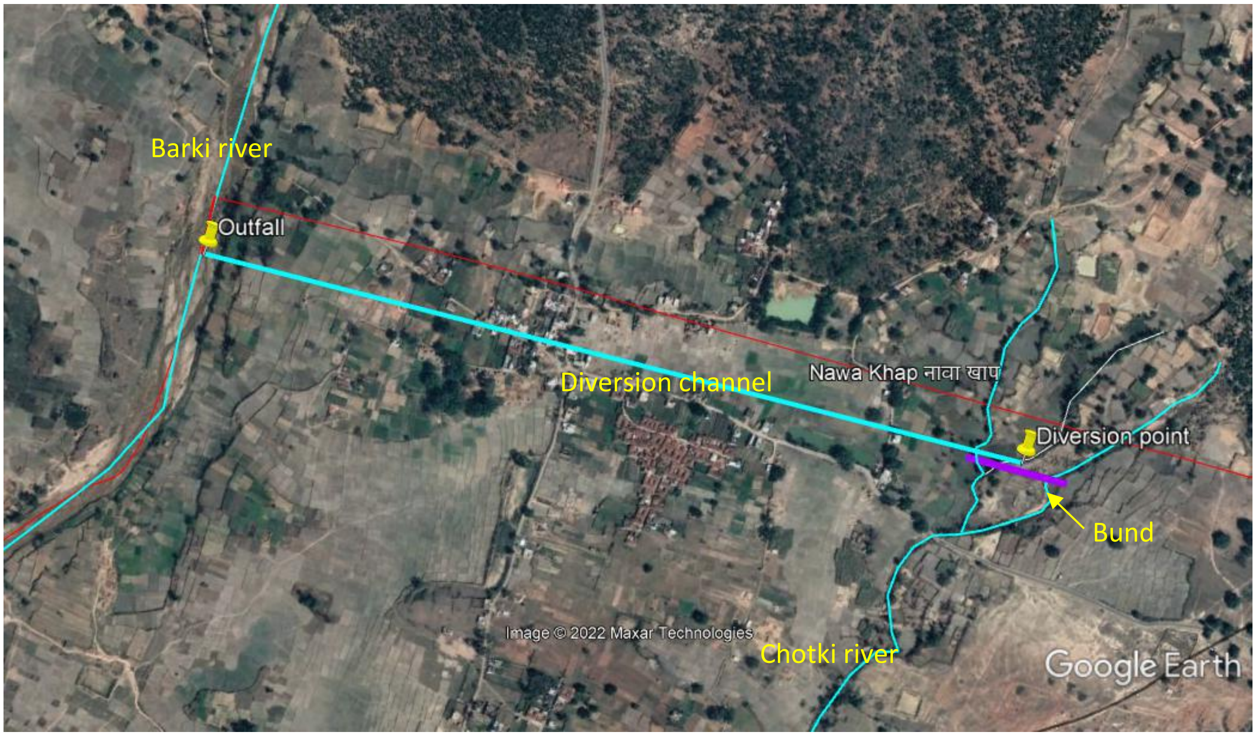


Figure 34 Diversion of the Chotki river

Channel shape = trapezoidal (earthen channel)

Average bed width of the existing Chotki river B = 6.0 m

If one designs this channel as an alluvial channel

Bed slope as per Lacey $S = \frac{f^{5/3}}{3340Q^{1/6}}$

For Q= 20.35 m^3/s and f= 1.36, S = 0.00030 which is much lower than the available slope of 0.00652. Thus, if one designs the channel with bed slope of 0.00652, the channel will be eroded by the flowing water.

If one designs the channel as lined trapezoidal channel of side slope 1V:1.5H and bed width, B = 6.0 m, n=0.015 and S=0.00652, the computed velocity by Manning's equation = 3.86 m/s, which is quite high and will erode the channel. (y=0.74 m)

In view of above, it is decided to provide a modest slope S = 0.0005 and provide step falls at the outfall to Barki river. A trapezoidal earthen of bed width, B= 6.0 m is recommended.

For trapezoidal channel (m = side slope; Y = depth of flow)

Area of flow, $A = BY+mY^2$

Perimeter, $P = B+2Y\sqrt{1+m^2}$

Top width, $T = B+2mY$

Hydraulic radius, $R = A/P$

Here B = 6.0 m

Side slope m = 1.5

S= 0.0005

n= 0.02

Side slope = 1V:1.5H

Manning's equation for the velocity in S.I. units, $V = \frac{1}{n}R^{2/3}S^{1/2}$

From Manning's equation

Velocity, V = 1.30 m/s

Depth of flow Y = 1.80 m

Plan and L-section of the diversion channel is shown in Drg. 4 and a typical cross-section of the diversion channel is shown in Drg. 5.

Drop at Confluence = 462-453-0.0005×1380

= 8.31 m

Let us provide step falls, each of drop 1.0 m and landing length = 5 m, thus 8 steps shall be provided at confluence. Plan and section of the steps fall along with protection works are given in the attached drawing Drg-6.

4.5 Running the model with Diversion of the Chotki River

The model was run under diversion of the Chotki river and its outfall into Barki river. Normal depth was provided at Chainage 375 m with bed slope of 0.005. A discharge of 358.41+18.57 = 376.98 m^3/s was provided at Chainage 9000 m. Computed water surface profile and other hydraulic parameters are given in Annexure-C.

Computed water surface profile under the existing condition compares well with the water surface profile computed with diversion of the Chotki river as shown in Fig. 35. This reveals that effect of diversion of the Chotki river through diversion channel on the flow parameters in the Barki river is negligible.

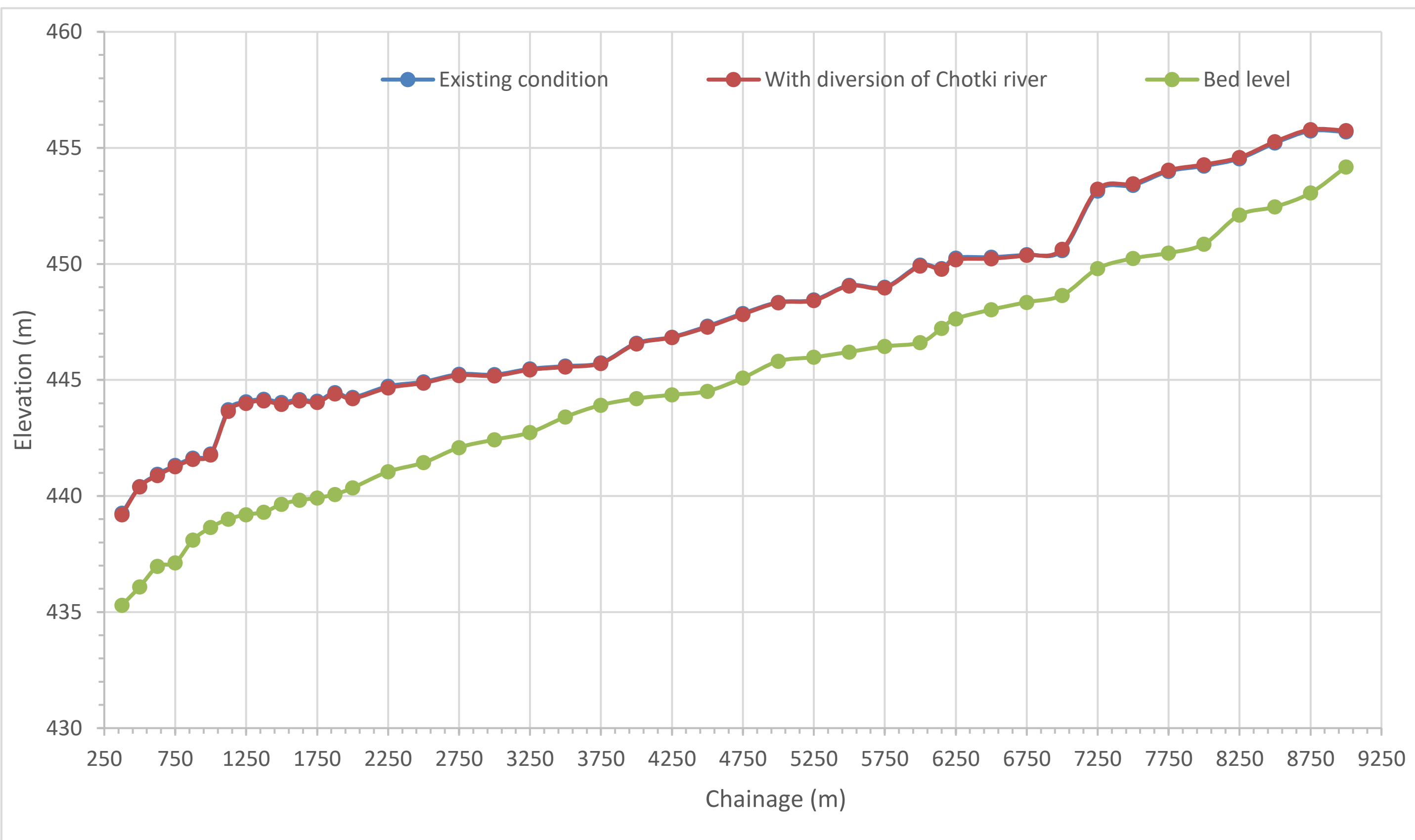


Figure 35 Comparison of computed water surface profiles under the existing condition and diversion of the Chotki river

4.6 Straightening of the Barki River

After examination of the contour map of the area near the meander, it is proposed to provide a cut off channel of 100 m long starting from 23°51'59.14"N; 85° 1'50.54"E to 23°51'56.51"N, 85° 1'52.64"E as shown in the Fig. 36. An earthen embankment/bund has to be provided towards left side to block the inlet and outlet channels of the meander as shown in the Fig. 36a. It is proposed to provide earthen embankment with 1V:2H both sides slope and top width of 6.0 m. Slope protection and launching apron shall be provided towards the river side.

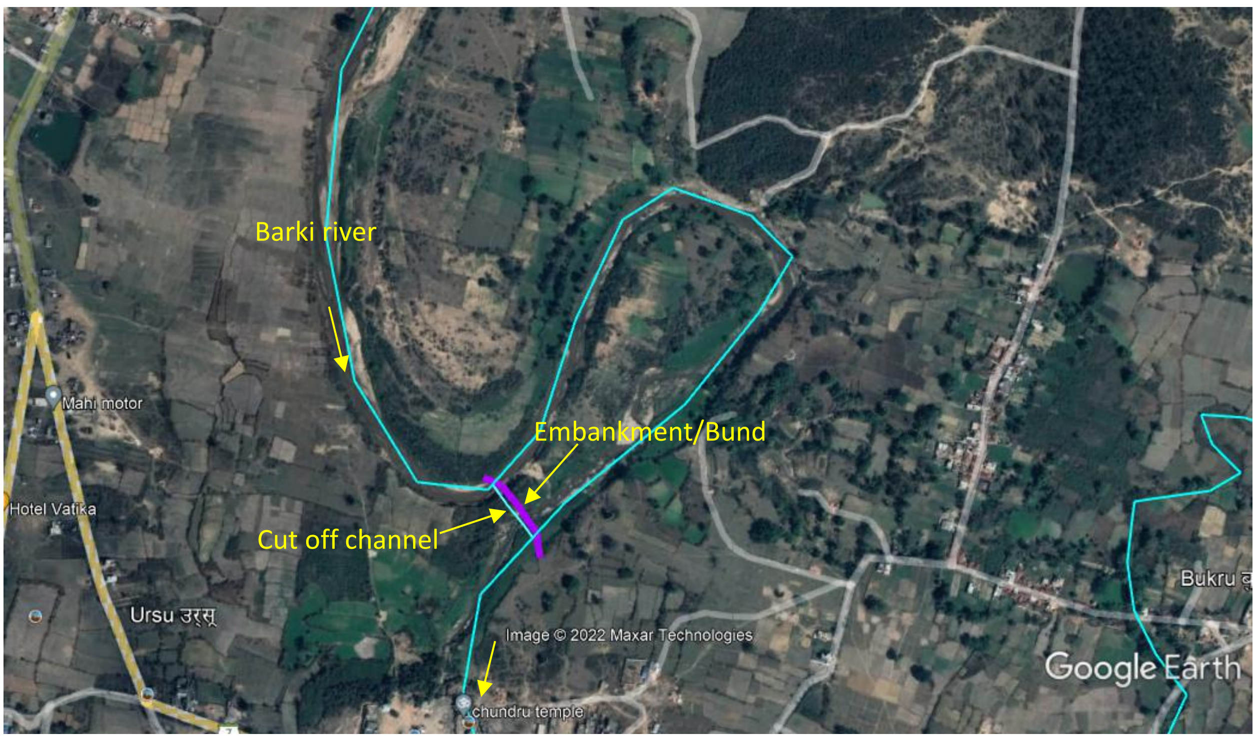
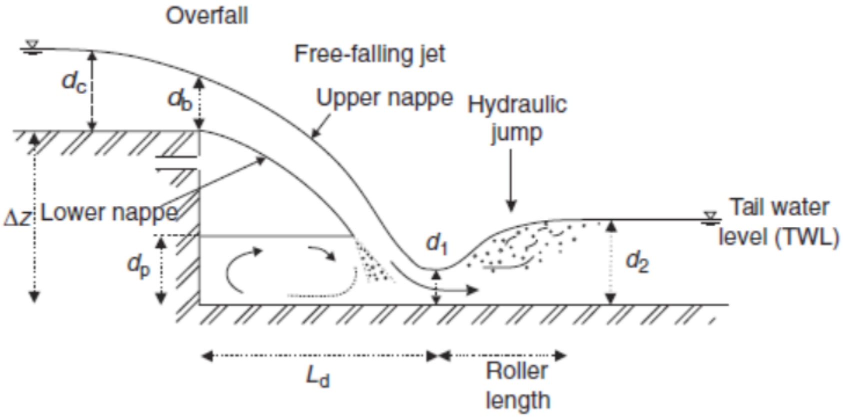


Figure 36a Location of the Embankment at the meander

Since the bed level of the river at Chainage 2000 is 440.36 m and at Chainage 625 is 436,97 m, thus it is proposed to two provide two drop impact falls in the cutoff channel. Design of the drop impact is carried out as given in the Chanson (2004) and shown in Fig. 36b.



$$\frac{L_d}{\Delta z} = 4.30\left(\frac{d_c}{\Delta z}\right)^{0.81}$$

$$\frac{d_p}{\Delta z} = \left(\frac{d_c}{\Delta z}\right)^{0.66}$$

$$\frac{d_1}{\Delta z} = 0.54\left(\frac{d_c}{\Delta z}\right)^{1.275}$$

$$\frac{d_2}{\Delta z} = 1.66\left(\frac{d_c}{\Delta z}\right)^{0.81}$$

Figure 36b Design methodology of drop impact fall (Chanson 2004)

Let us design the fall for 50 years return period discharge of 433.55 m^3/s. Provide a rectangular channel of bed width 40 m.

Q= 433.55 m^3/s

B = 40 m

Provide two drops each of 2.5 m, total drop = 5.0 m

Δz = 2.5 m

Unit discharge, q = 433.55/40=10.84 $m^3/s/m$

Critical depth d_c = 2.29 m

L_d = 10.0 m

d_p = 2.36 m

d_1 = 1.21 m

d_2 = 3.86 m

Let us provide 15 m length of the drop to accommodate roller also. Total length of the channel would 40 m.

In the remaining 60 m length of the cut off channel, it would be trapezoidal in shape of bed width 35 m and side slope of 1V:2H. The cutoff channel will reduce the length of the Barki river by 1175 m.

Chainage 625 m and Chainage 2000 m are same as the existing Barki river. Chainage 675 m, 775 m are introduced which are having trapezoidal channel of bed width 35 m and bed level 435 m and 440 m, respectively as shown in Fig. 37. Chainage 825 m is same as chainage 2000 m of the existing channel. Thus, the channel is dummy of length zero from chainage 825 m to chainage 2000 m in the case of straightening of the Barki river.

A typical cross-section of the cutoff channel is shown in Drg. 7a and two falls are shown in Drg. 7b.

Figure 37 Modelling of the cutoff channel (straightening of the Barki river)

4.7 Running the Model under Diversion of Chotki River and Straightening of the Barki River

The model was run under diversion of the Chotki river and straightening of the Barki river. Normal depth was provided at Chainage 375 m with bed slope of 0.005. A discharge of 376.98 m^3/s was provided at Chainage 9000 m. Computed water surface profile and other hydraulic parameters are given in Annexure-C.

For the comparison of computed water level under diversion of the Chotki river and straightening of the Barki river with existing condition, a dummy channel of zero length from Chainage 825 m to Chainage 2000 m is considered. Such comparison is shown in Fig. 38, which reveals that from chainage 2000 m to 2500 m, the water level under moderated condition is lower than the existing condition, however, there is negligible changes in water level upstream of the Chainage 2500 m. There is no difference in the water level between Chainage 375 m to Chainage 625 m. A steep water surface slope was found in the cut off channel, which is obvious due to straightening of the Barki river and provision of fall. Velocity in this channel is of the order of 4.0 m/s, which is quite high and regrade the bed for its stabilisation over the time. There would not be any changes in the bed level of the river downstream of the Chainage 625 m due to rocky bed as observed during site visit. The model takes critical flow at Chainage 500 m and 375 m due to their narrow sections.

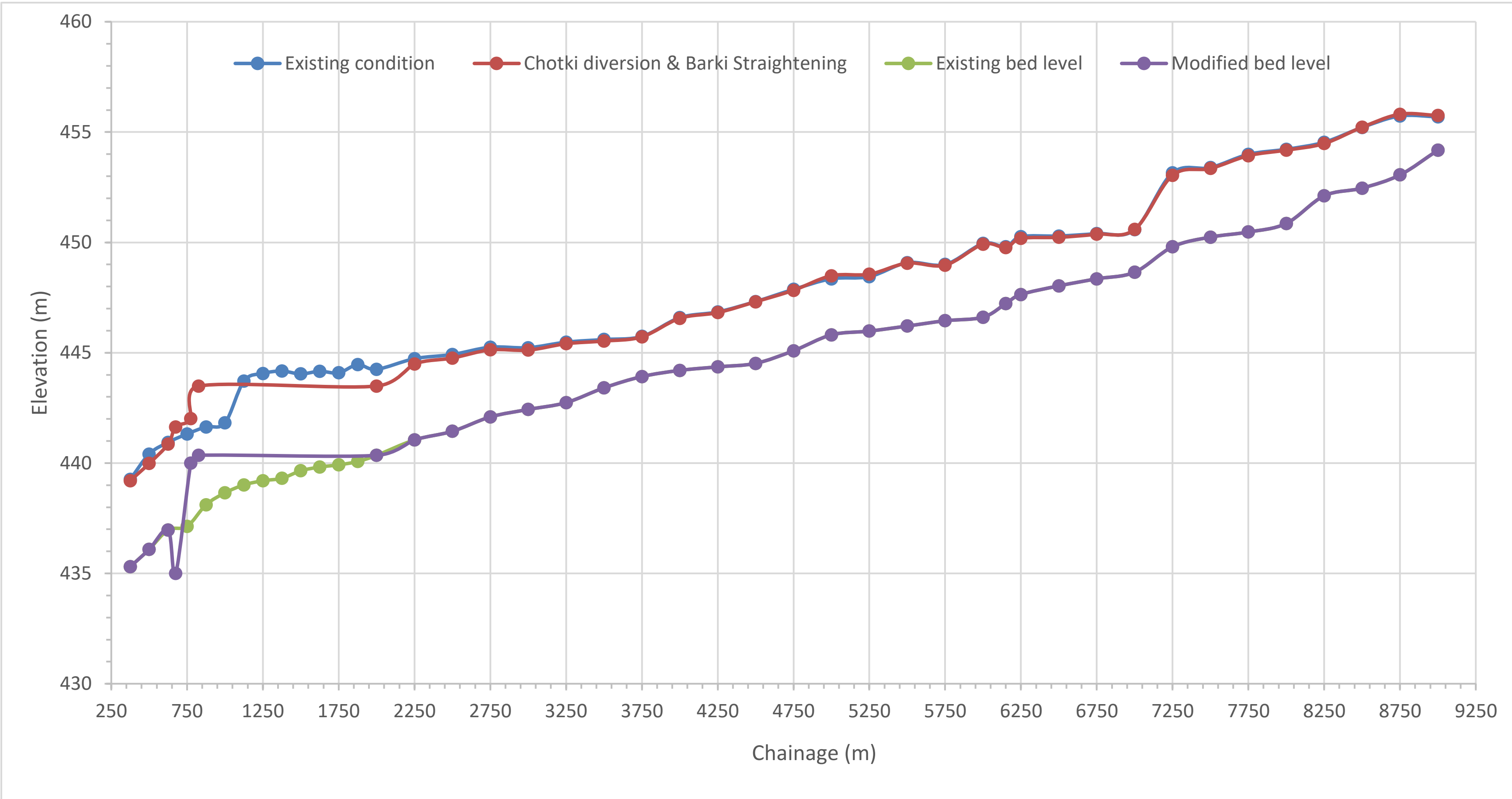


Figure 38 Comparison of computed water surface profiles under the existing condition and diversion of the Chotki river & straightening of Barki river (Channel is dummy of zero length from Chainage 825 m to Chainage 2000 m under diversion of the Chotki river & straightening of Barki river)

4.8 Running the Model under Moderated Condition for 50 years discharge

The model was run under diversion of the Chotki river and straightening of the Barki river for 50 years peak discharge of 433.55 m^3/s. Normal depth was provided at Chainage 375 m with bed slope of 0.005. A discharge of 433.55 m^3/s was provided at Chainage 9000 m. It was found that at some locations computed water level is higher than the left bank. Such locations are near the Chainages 6150 m, 4500 m, 4000 m and 2500 m as shown in Figs. 39a-d. It is suggested that in a length of about 100 m at each chainage, earthen levees of height 1.5 m, side slope 1V:2H and top width of 2.5 m be provided to control the ingress of the flood water in the mining block area.

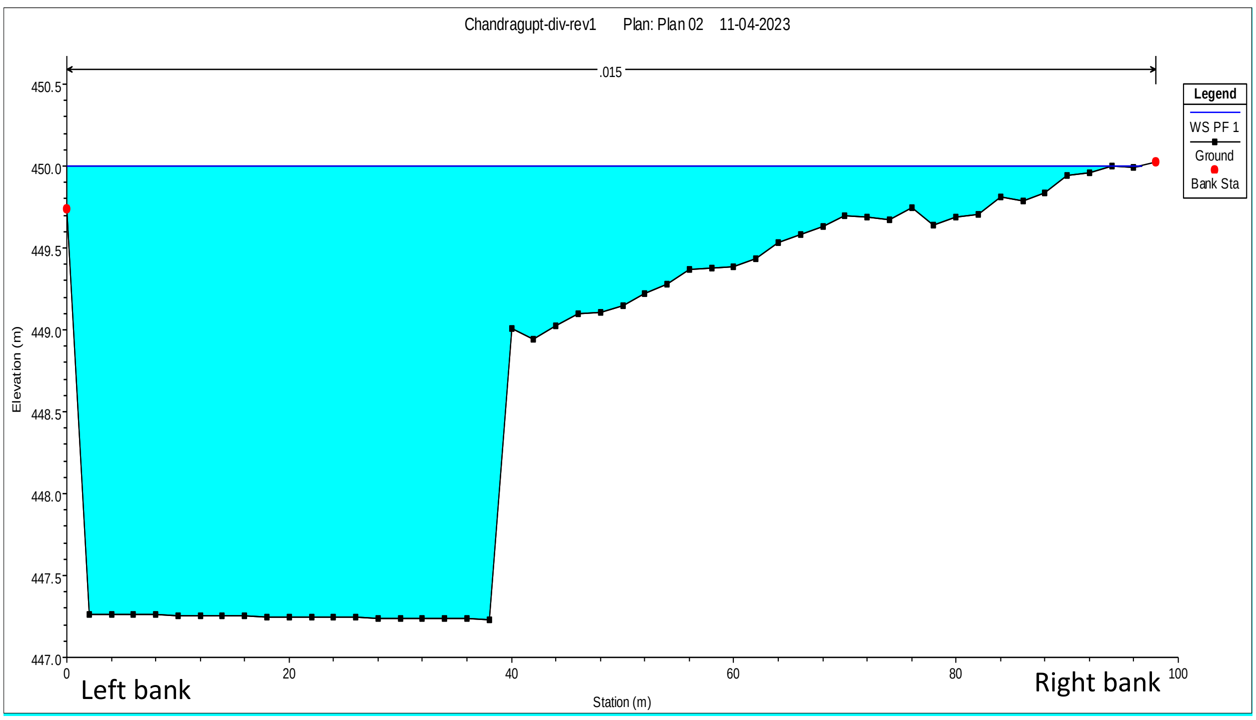


Figure 39a Computed water level at Chainage 6150 m for 50 years return period discharge (Offset 0 is left bank)

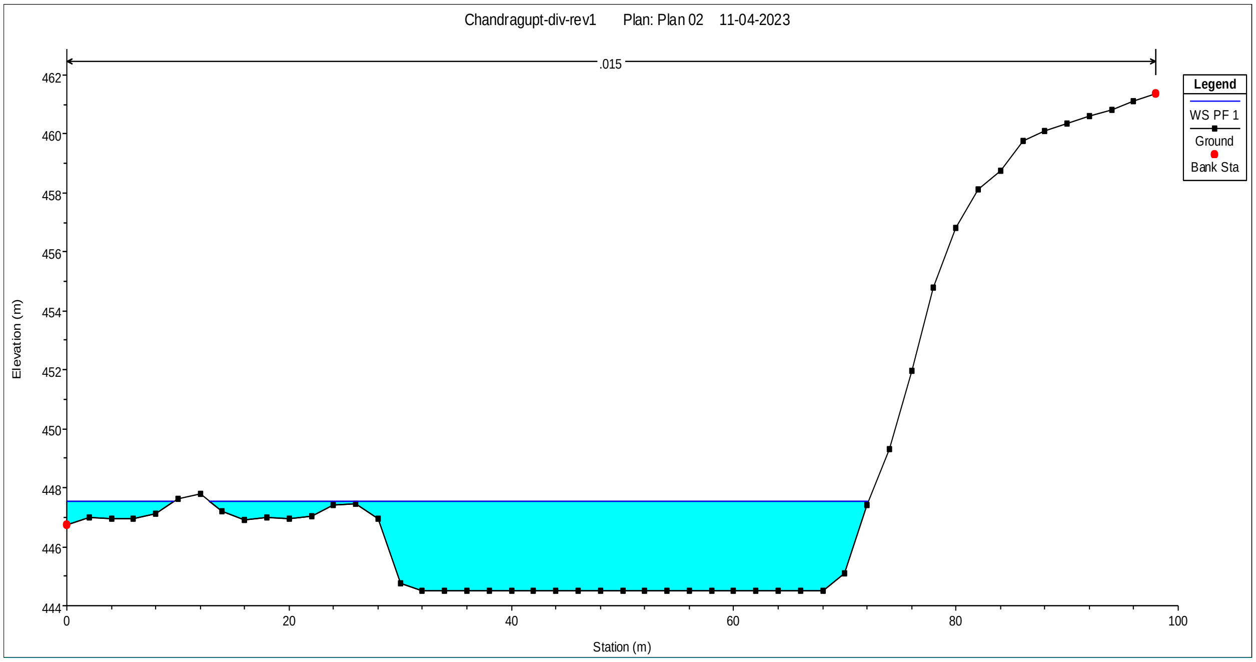


Figure 39b Computed water level at Chainage 4500 m for 50 years return period discharge

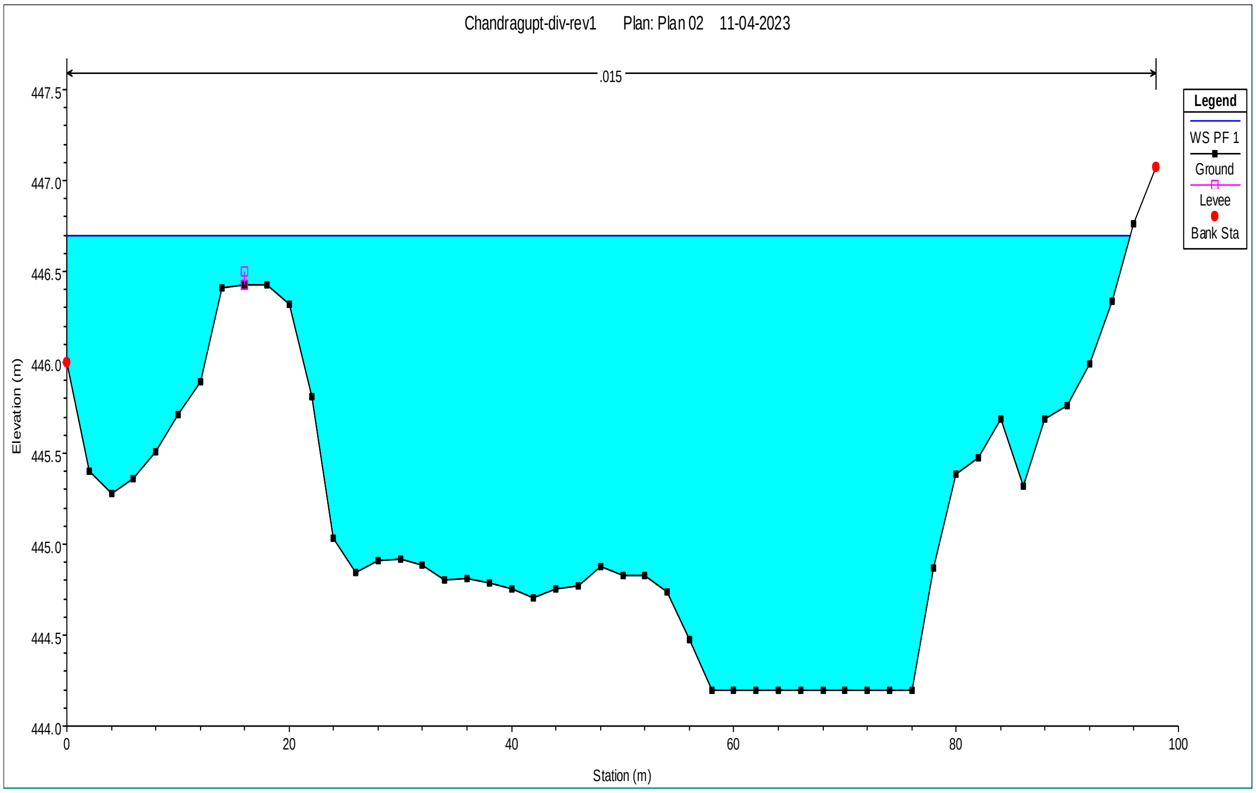


Figure 39c Computed water level at Chainage 4000 m for 50 years return period discharge

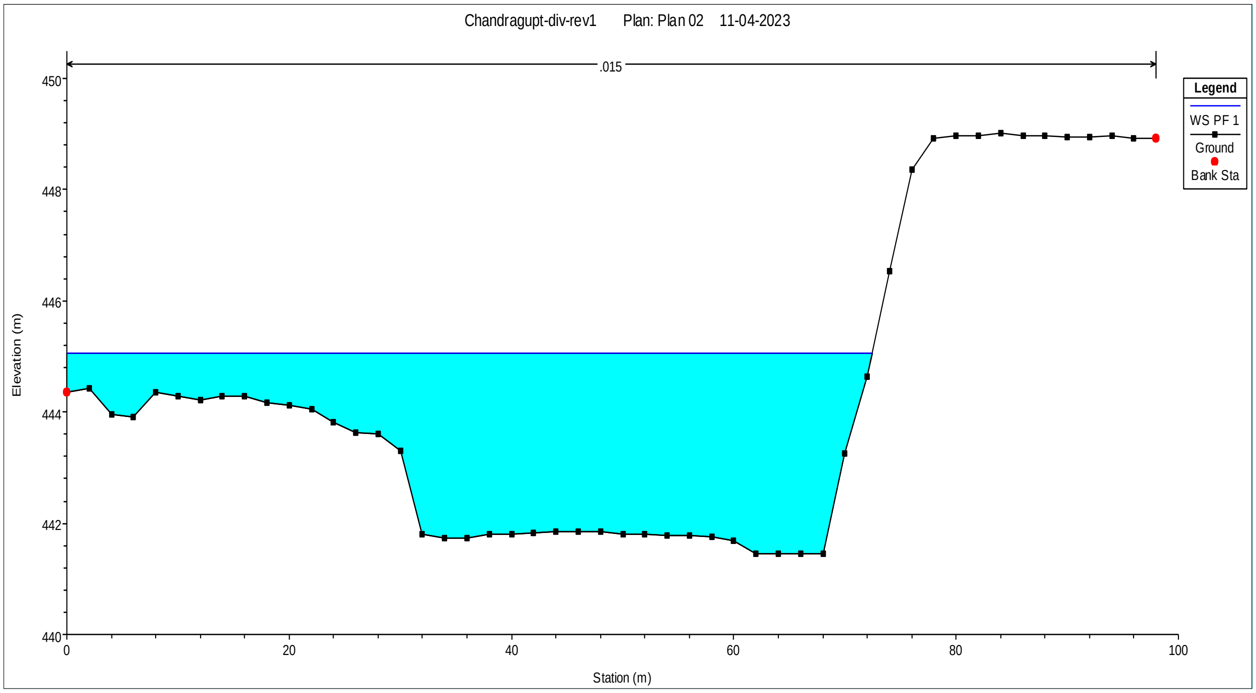


Figure 39d Computed water level at Chainage 2500 m for 50 years return period discharge

5.0 DESIGN OF PROTECTION WORKS

a) Straightening of the Barki river at Meander

After examination of the contour map of the area near the meander, it is proposed to provide a cut off channel of 100 m long starting from 23°51'59.14"N; 85° 1'50.54"E to 23°51'56.51"N, 85° 1'52.64"E as shown in the Fig. 36a. An earthen embankment/bund has to be provided towards left side to block the inlet and outlet channels of the meander as shown in the Fig. 36a. It is proposed to provide earthen embankment with 1V:2H both sides slope and top width of 6.0 m. Slope protection and launching apron shall be provided towards the river side.

Five samples of the river bed material were collected from Barki and Choti rivers and analysed for particle size gradation in the Hydraulics Laboratory of Dept. of Civil Eng., IIT Roorkee. Details of the gradation data are given in Annexure-B. The gradation curves are shown in Fig.40.

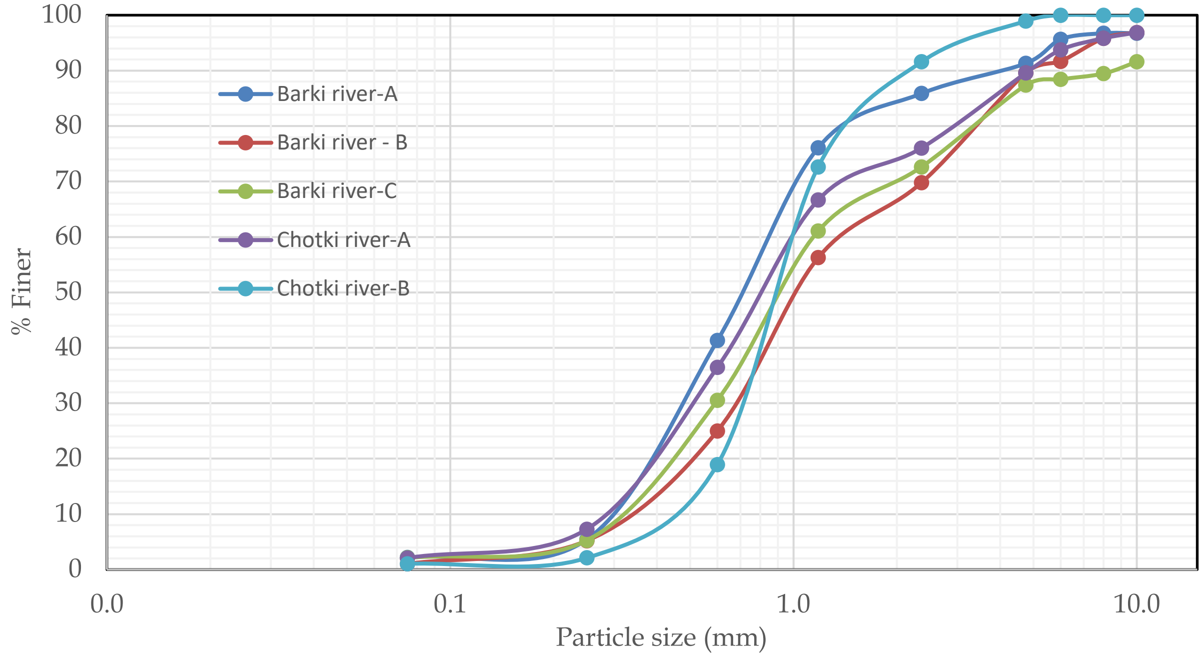


Figure 40 Gradation curve of river bed material

Median size of the sediment d= 0.6 mm

Silt factor f = $1.76\sqrt{d}$ = 1.36, adopted f=1 for conservative design.

Discharge in the Barki river for 100 years return period

= 466.20 + 22.28 = 488.48 m^3/s, let design for 500 m^3/s

At chainage 775 m

Bed level = 440.0 m

Water level = 442.19 m

The top level of the bund = 442.19+1.5 =443.79 m. keep at 440 m.

Top level varies from 440 m to 435 m

Let design the protection works for 100 years return period discharge i.e., 466.2+22.26 = 488.48 m^3/s say 500 m^3/s.

The thickness T required for the bank revetment is related to high flood discharge by the following empirical equation:

$$T = 0.06\, Q^{1/3} \quad \text{in SI units} \qquad (7)$$

The value of T for the design discharge Q = 500 m^3/s is

$$T = 0.06\,(500)^{1/3} = 0.48 \text{ m} \qquad \text{Adopt } 0.5 \text{ m}$$

For stones of relative density 2.65, the minimum size of stone that is not likely to be washed out during flood is given by (Garde and Ranga Raju, 2000):

$$d_{min} = 0.023 \text{ to } 0.046\ U_{max}^2 \qquad (8)$$

in which d_{min} is expressed in m, and U_{max} is the maximum velocity of flow (in m/s) in the vicinity of the bund.

From mathematical model study, average velocity = 4 m/s

$$d_{min} = 0.023\,(4.0)^2 = 0.368 \text{ m, adopt } 0.30 \text{ to } 0.40 \text{ m}$$

A sand-gravel filter of thickness 0.30 m be placed on the sloping surface facing to river flow to prevent washing out of fine material from the sub-grade or backfill and the revetment may be provided over this filter.

As per IS142621:1995, weight of boulders in kg for the design of slope protection is

$$W = \frac{0.02323}{K}\frac{G}{(G-1)^3}V^6 \qquad (9)$$

$$K = \sqrt{1 - \sin^2\theta/\sin^2\phi} \qquad (10)$$

Φ = angle of repose = 30 degree (assumed)

θ = Embankment slope (1:2) = 26.57 degree (assumed)

K = 0.51

G=2.65

Maximum velocity V = 4.0 m/s

$$W = \frac{0.02323}{0.51}\frac{2.65}{(2.65-1)^3}4.0^6 = 110.06 \text{ kg (approx. 43 cm dia. size)}$$

Weight of the boulder in kg on bed

$$W = \frac{0.02323}{1}\frac{G}{(G-1)^3}V^6$$

W = 56.13 kg (approx. 17.16 cm dia, size)

Thickness of the protection layer

$$T = \frac{V^2}{2g}\frac{1}{(G-1)^{\blacksquare}} \qquad (11)$$

$$T = \frac{4^2}{2\times 9.81}\frac{1}{(2.65-1)^{\blacksquare}} = 0.494 \text{ m}$$

For the revetment, 0.30 m thick boulders in 1:6 mortar is suggested.

It is proposed that boulders in wire crates on the bed in a thickness of 0.80 m be provided.

Plan, L-section and cross-section of embankment for cutoff channel are given in Drg. 8.

b) Protection works at outfall of the Chotki river into Barki river

It is proposed to provide an earthen embankment of top with of 4.50 m and side slopes of 1V:2H to block the mouth of the Chotki river at its confluence with Barki river. Location of the proposed embankment/bund is shown in Fig. 41. One layer of loose boulders of size 30 cm or 20 cm thick gabion mattress shall be provided over 200 mm thick sand-gravel filter on slope of the embankment towards Barki river side.

A launching apron of width of 4.0 m with two layers of loose boulders of size 30 cm (Thickness = 0.50 m) or 30 cm thick gabion mattress shall be provided. A typical section of the proposed earthen embankment is shown in Drg. 9.

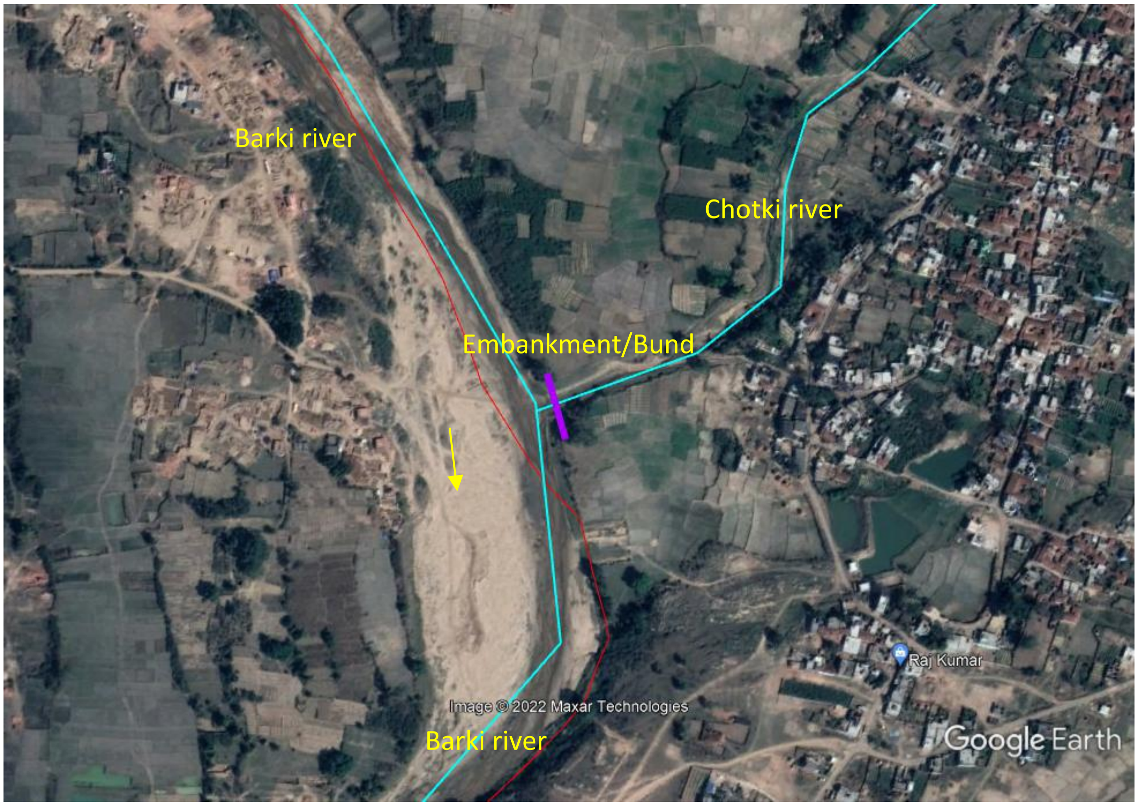


Figure 41 Location of the Embankment at the meander

c) Protection works to divert the Chotki river to Barki river

It is proposed to provide an earthen embankment for top width 3.0 m and side slopes of 1V:2H. Location of the proposed embankment/bund is shown in Fig. 42. One layer of loose boulders of size 30 cm (Thickness = 0.3 m) or 20 cm thick gabion mattress shall be provided over 200 mm thick sand-gravel filter on the slope of water face and turfing on the other slope.

A launching apron of width of 4.0 m with two layers of loose boulders of size 30 cm (Thickness = 0.50 m) or 30 cm thick gabion mattress shall be provided. A typical section of the proposed earthen embankment is shown in Drg. 10.

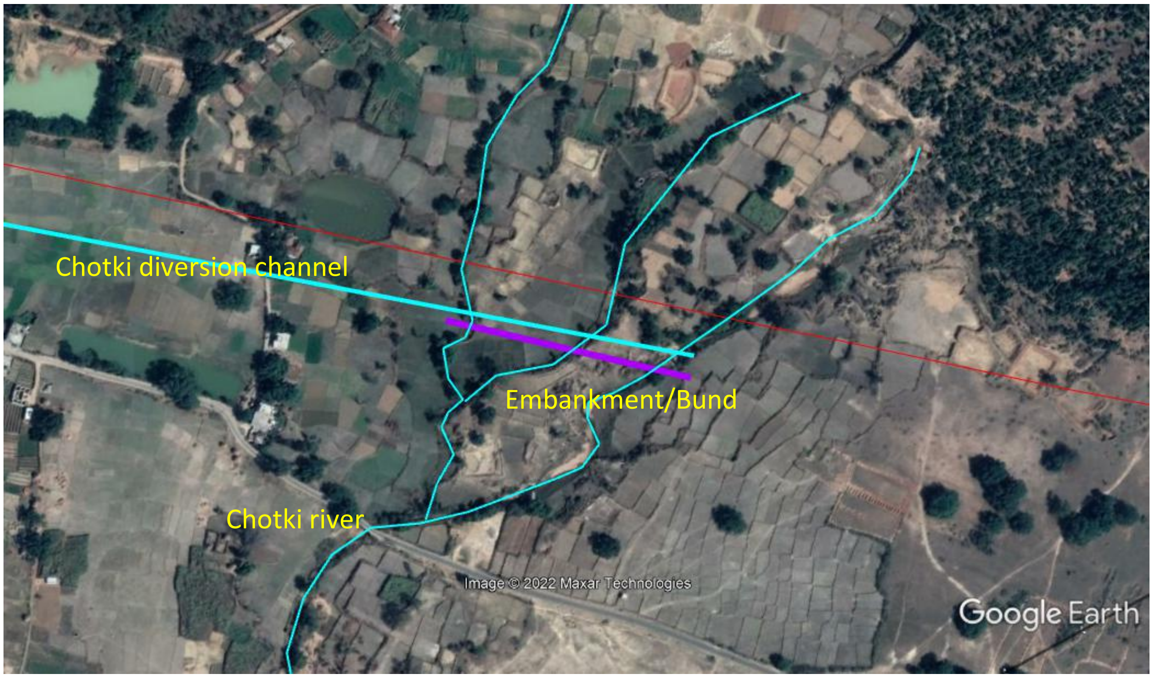


Figure 42 Location of the Embankment at the meander

6 CONCLUSIONS AND RECOMMENDATIONS

Following conclusions are derived from this study:

a) Topographical map of the Chandragupt mining block has been developed by carrying out the Drone survey and attached with this report.

b) Digital elevation map, Drainage map, Slope map and Land use Land cover map have been developed using Cartosat data for a) Barki river at its confluence with Chunro river near Tandla and at north-west corner of the mining block, and b) Chotki river at its confluence with Barki river and its entry point to mining block. Major land use in the catchment of the Barki and Chotki rivers is forest followed by agriculture.

c) Catchment areas of the Barki river at N-W corner of mining block and at confluence of Chunro river are 201.8 km^2 and 2315 km^2, respectively. While catchment areas of the Chotki river at its entry point to the mining block and at confluence with Barki river are 3.89 km^2 and 7.19 km^2, respectively.

d) Average slope of the Barki and Chotki rivers are 0.0019 (1/526) and 0.0057 (1/175), respectively. The bed slope of the Chotki river is higher in its upper reaches compared to its lower reach.
e) As per CWC-IMD (2015) (PMP Atlas for Ganga river basin including Yamuna) the probable maximum precipitation (PMP) at Barkagaon which is nearby rain gauge station of the mining block in 24-hr for return periods of 25, 50, and 100 years are 19.0 cm, 21.5 cm and 23.9 cm, respectively.
f) The intensity of rainfall obtained from PMP Atlas is comparable to the CSWRTI Bull No. 3, however, for lower duration, intensity of rainfall obtained from CSWRTI Bull No. 3 is slightly higher. Therefore, IDF curves developed using the CSWRTI Bull No. 3 are used for the estimation of flood discharge.
g) Estimated peak discharge in Barki river at N-W corner of mining block for 25, 50, and 100 years return period are 358.41, 413.20 and 466.20 m^3/s, respectively. Estimated peak discharge in Chotki river at its entry to the mining block for 25, 50, and 100 years return period are 18.57, 20.35 and 22.28 m^3/s, respectively. While estimated peak discharge in Chotki river at confluence with Barki river for 25, 50, and 100 years return period are 27.75, 30.41 and 33.27 m^3/s, respectively
h) Since the lease for mining block is for 25 years, therefore, the developed hydraulic model on HEC RAS platform is run for discharge of 25 years return period. However, for raising the banks of the Barki river, 50 years return period discharge has been taken and for the protection works 100 years return period discharge has been taken.
i) Initially the developed 1D HEAC RAS model was run for existing condition under the steady state condition. Normal depth was provided at Chainage 375 m with bed slope of 0.005. A discharge of 358.41 m^3/s was provided at Chainage 9000 m and discharge of Chotki river of 27.75 m^3/s was provided at Chainage 6150 m.

j) After examination of the contour map of the area from entry of the Chotki river to the mining block area and N-W corner of the mining block and also after examining the bed level of the Chotki river at its entry to mining block and bed level of the Barki river at N-W corner of the mining block, a diversion channel is aligned from the point 23°54'24.02"N, 85° 2'21.02"E to point 23°54'35.02"N, 85° 1'35.48"E. The diversion channel is of trapezoidal shape of bed width of 6.0 m, bed slope of 0.0005 and side slope of 1V:1.5H. The length of the diversion channel is 1380 m.

k) The model was run under diversion of the Chotki river and its outfall into Barki river and results are compared with the existing one. Computed water surface profile under the existing condition compares well with the water surface profile computed with diversion of the Chotki river. This reveals that effect of diversion of the Chotki river through diversion channel on the flow parameters in the Barki river is negligible

l) After examination of the contour map of the area near the meander, it is proposed to provide a cut off channel of 100 m long starting from 23°51'59.14"N ; 85° 1'50.54"E to 23°51'56.51"N, 85° 1'52.64"E. An earthen embankment/bund has to be provided towards left side to block the inlet and outlet channels of the meander.

m) Since the bed level of the river at Chainage 2000 is 440.36 m and at Chainage 625 is 436.97 m, thus it is proposed to provide two drop impact falls in the cutoff channel. Accordingly, two drop impact falls each of drop 2.5 m are provided.

n) In the remaining 60 m length, the cut off channel of trapezoidal shape of bed width of 35 m and side slope of 1V:2H is provided. The cutoff channel will reduce the length of the Barki river by 1175 m.

o) Comparison of computed water level under diversion of the Chotki river and straightening of the Barki river with existing condition reveals that from chainage 2000 m to 2500 m, the water level under moderated condition is lower than the existing condition, however, there is negligible changes in water level upstream of the Chainage 2500 m. There is no difference in the water level between Chainage 375 m to Chainage 625 m. Velocity in this channel is of the order of 4.0 m/s, which is quite high and regrade the bed for its stabilisation over the time. There would not be any changes in the bed level of the river downstream of the Chainage 625 m due to rocky bed as observed during site visit.

p) The model was run under diversion of the Chotki river and straightening of the Barki river for 50 years peak discharge of 433.55 m^3/s. It was found that at some locations computed water level is higher than the left bank. Such locations are near the Chainages 6150 m, 4500 m, 4000 m and 2500 m. It is suggested that in a length of about 100 m at each chainages earthen levees of height 1.5 m, side slope 1V:2H and top width of 2.5 m be provided to control the ingress of the flood water in the mining block area.

q) It is proposed to provide an earthen embankment of top with of 4.50 m and side slopes of 1V:2H to block the mouth of the Chotki river at its confluence with Barki river. One layer of loose boulders of size 30 cm or 20 cm thick gabion mattress shall be provided over 200 mm thick sand-gravel filter on side slope of the embankment towards Barki river side. A launching apron of width of 4.0 m with two layers of loose boulders of size 30 cm (Thickness = 0.50 m) or 30 cm thick gabion mattress shall be provided.

r) It is proposed to provide an earthen embankment for top width 3.0 m and side slopes of 1V:2H at entry of the Chotki river to mining block to divert it to Barki river. One layer of loose boulders of size 30 cm (Thickness = 0.3 m) or 20 cm thick gabion mattress shall be provided over 200 mm thick sand-gravel filter on the slope of water face and turfing on the other slope. A launching apron of width of 4.0 m with two layers of loose boulders of size 30 cm (Thickness = 0.50 m) or 30 cm thick gabion mattress shall be provided.

s) It is recommended to execute the proposed diversion channel, cut off channel for straightening of the Barki river, falls and embankments/bund for the protection works to pass safely flood water through the Barki river.

t) Diversion of the Chokti river and the straightening of meander of the Barki river would not affect the flow downstream of the Chainage 375 m. Thus, any structure on the Barki river or Chunro river would not be affected with proposed diversion.

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Annexure-A

ESTIMATION PEAK DISCHARGE FROM BASIN OF BARKI RIVER

1.0 Unit hydrograph (UHG) method

A procedure for estimation of design flood discharge with characteristics of rainfall storm and the basin characteristics for Lower Ganga plains (sub Zone -1g) has been proposed by Central Water Commission, New Delhi vide report No. LG-1(g)/R-1/94. The procedure is applicable for catchments varying in size from 25 to 1000 km^2. As the catchment of the Barki river falls in the Lower Ganga plains sub Zone-1g, this procedure is adopted to estimate the design flood.

The various steps necessary to estimate the design flood are as under

- (i) Preparation of catchment area plan of the catchment.
- (ii) Determination of physiographic parameters viz., the catchment area, A; the length of the longest stream, L; and equivalent stream slope, S.
- (iii) Determination of 1-hr synthetic uint hydrograph parameters, i.e., the unit discharge, q_p; the peak discharge, Q_p; the basin lag, t_p; the period of UHG, T_m; widths of the UHG at 50% of Q_P, W_{50}; widths of the UHG at 75% of Q_P, W_{75}; width of the rising limb of UHG at 50% of Q_P, WR_{50}; width of the rising limb of UHG at 75% of Q_P, WR_{75}; and time base of unit hydrograph, T_B.
- (iv) Preparation of a synthetic unit hydrograph
- (v) Estimation of design storm duration, T_D
- (vi) Estimation of point rainfall and areal rainfall for design storm duration, T_D.
- (vii) Distribution of areal rainfall during design storm duration (T_D) to obtain rainfall increments for unit duration intervals.
- (viii) Estimation of rainfall excess units after subtraction of design loss rate from rainfall increments.
- (ix) Estimation of base flow.
- (x) Computation of design flood peak.

(xi) Computation of design flood hydrograph.

The following relationships have been used for the computation of parameters of a 1–hr unit synthetic unit hydrograph.

$$q_P = \frac{0.6617}{(L/\sqrt{S})^{0.515}} \quad (\text{m}^3\text{/s per km}^2)$$

$$t_P = \frac{1.8833}{q_P{}^{0.94}} \quad (\text{hr})$$

$$T_m = t_P + t_r/2 = t_p + 0.5 \quad (\text{hr})$$

$$W_{50} = \frac{1.7897}{q_P{}^{1.006}} \quad (\text{hr})$$

$$W_{75} = \frac{0.8955}{q_P{}^{1.061}} \quad (\text{hr})$$

$$WR_{50} = \frac{0.5524}{q_P{}^{1.012}} \quad (\text{hr})$$

$$WR_{75} = \frac{0.2984}{q_P{}^{1.012}} \quad (\text{hr})$$

$$T_B = 12.4755 \times t_P{}^{0.721} \quad (\text{hr})$$

$$Q_P = Aq_P \quad (\text{m}^3\text{/s})$$

In the above relationships A in km^2; L in km; and S in m/km.

(a) Preparation of catchment area plan

The boundary of the catchment area of the Barki river is delineated using Cartosat-1 DEM and shown in Fig. 3.

(b) Determination of physiographic parameters

The following physiographic parameters have been determined from the catchment area plan:

The catchment area, A = 201.80 km^2

Longest length of the River, L = 33.235 km

The longitudinal bed level of the Barki river upstream of the outlet is shown in Fig. A1, and equivalent slope is calculated in Table A1.

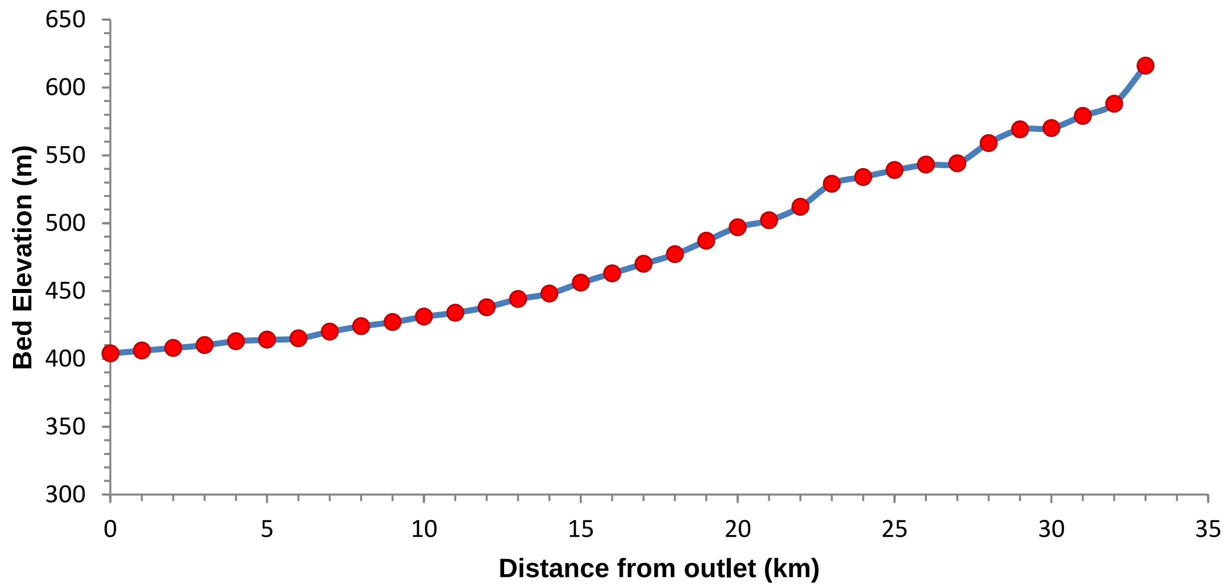


Figure A1 Longitudinal section of the tributary (0 km corresponds to outfall)

Table A1 Computation of equivalent bed slope

S. No.	Distance (km)	Bed Elevation (m)	Height above datum (m)	Length of each segment, L_i (km)	$D_{i-1}+D_i$ (m)	$L_i(D_{i-1}+D_i)$ (m.km)
1	0	404	0.0			
2	1	406	2.0	1.00	2	2.00
3	2	408	4.0	1.00	6	6.00
4	3	410	6.0	1.00	10	10.00
5	4	413	9.0	1.00	15	15.00
6	5	414	10.0	1.00	19	19.00
7	6	415	11.0	1.00	21	21.00
8	7	420	16.0	1.00	27	27.00
9	8	424	20.0	1.00	36	36.00
10	9	427	23.0	1.00	43	43.00
11	10	431	27.0	1.00	50	50.00
12	11	434	30.0	1.00	57	57.00
13	12	438	34.0	1.00	64	64.00
14	13	444	40.0	1.00	74	74.00
15	14	448	44.0	1.00	84	84.00
16	15	456	52.0	1.00	96	96.00

17	16	463	59.0	1.00	111	111.00
18	17	470	66.0	1.00	125	125.00
19	18	477	73.0	1.00	139	139.00
20	19	487	83.0	1.00	156	156.00
21	20	497	93.0	1.00	176	176.00
22	21	502	98.0	1.00	191	191.00
23	22	512	108.0	1.00	206	206.00
24	23	529	125.0	1.00	233	233.00
25	24	534	130.0	1.00	255	255.00
26	25	539	135.0	1.00	265	265.00
27	26	543	139.0	1.00	274	274.00
28	27	544	140.0	1.00	279	279.00
29	28	559	155.0	1.00	295	295.00
30	29	569	165.0	1.00	320	320.00
31	30	570	166.0	1.00	331	331.00
32	31	579	175.0	1.00	341	341.00
33	32	588	184.0	1.00	359	359.00
34	33	616	212.0	1.00	396	396.00
					Total	5056

Equivalent slope, S $= \sum L_i(D_{i-1}+D_i)/L^2$

Where L_i = length of i^{th} segment in km

D_i = Bed elevation of the River at i

Computation for equivalent slope is carried out in the Table A1.

Equivalent slope, S $= \sum L_i(D_{i-1}+D_i)/L^2 = 5056/33.235^2 = 4.58$ m/km

(c) Determination of 1-hr synthetic unit hydrograph parameters

A unit period of 1-hr has been adopted. The unit hydrograph is assumed to represent a hydrograph of surface flow from 1cm depth of effective rainfall. The unit hydrograph parameters have been computed and reported herein:

$$q_P = \frac{0.6617}{(L/\sqrt{S})^{0.515}} = 0.16 \text{ m}^3\text{/s per km}^2$$

$$t_P = \frac{1.8833}{{q_P}^{0.94}} = 10.47 \text{ hr}$$

$$T_m = t_P + t_r/2 = t_p + 0.5 = 10.97$$

$W_{50} = \frac{1.7897}{{q_P}^{1.006}}$ =11.23 hr

$W_{75} = \frac{0.8955}{{q_P}^{1.061}}$ = 6.74 hr

$WR_{50} = \frac{0.5524}{{q_P}^{1.012}}$ = 3.5 hr

$WR_{75} = \frac{0.2984}{{q_P}^{1.012}}$ = 1.89 hr

$T_B = 12.4755 \times {t_P}^{0.721}$ =67.85 hr

$Q_P = Aq_P$ = 32.52 m^3/s

Adopted value of T_m = 11 hr

t_p = 11 hr

(d) Preparation of 1-hr synthetic unit hydrograph parameters

Considering the computed parameters, a 1-hr unit hydrograph was plotted. The runoff volume of the unit hydrograph was computed to check if it conforms to 1 cm depth over the catchment. The falling limb was suitably adjusted to have 1 cm depth of effective rainfall. The adjusted 1-hr unit hydrograph ordinates are given in Table A2 and plotted in Fig. A2.

Table A2 Coordinates of 1-hr unit hydrograph

T (hr)	Discharge, Q (m^3/s)	T (hr)	Discharge, Q (m^3/s)	T (hr)	Discharge, Q (m^3/s)
0	0.00	23	12.00	46	4.00
1	0.25	24	11.00	47	4.00
2	0.50	25	10.50	48	4.00
3	1.00	26	10.00	49	3.00
4	2.00	27	9.50	50	3.00
5	3.00	28	9.50	51	2.50
6	7.00	29	9.00	52	2.00
7	12.00	30	9.00	53	1.50
8	16.26	31	8.50	54	1.50
9	24.39	32	8.50	55	1.50
10	30.00	33	8.00	56	1.50
11	32.52	34	8.00	57	1.00
12	31.00	35	7.50	58	1.00
13	29.50	36	7.50	59	1.00
14	27.00	37	7.00	60	1.00

15	25.50	38	7.00	61	0.75
16	24.39	39	6.50	62	0.75
17	22.00	40	6.50	63	0.50
18	19.00	41	6.00	64	0.50
19	16.26	42	6.00	65	0.50
20	15.00	43	5.00	66	0.25
21	14.00	44	5.00	67	0.25
22	13.00	45	5.00	68	0.00

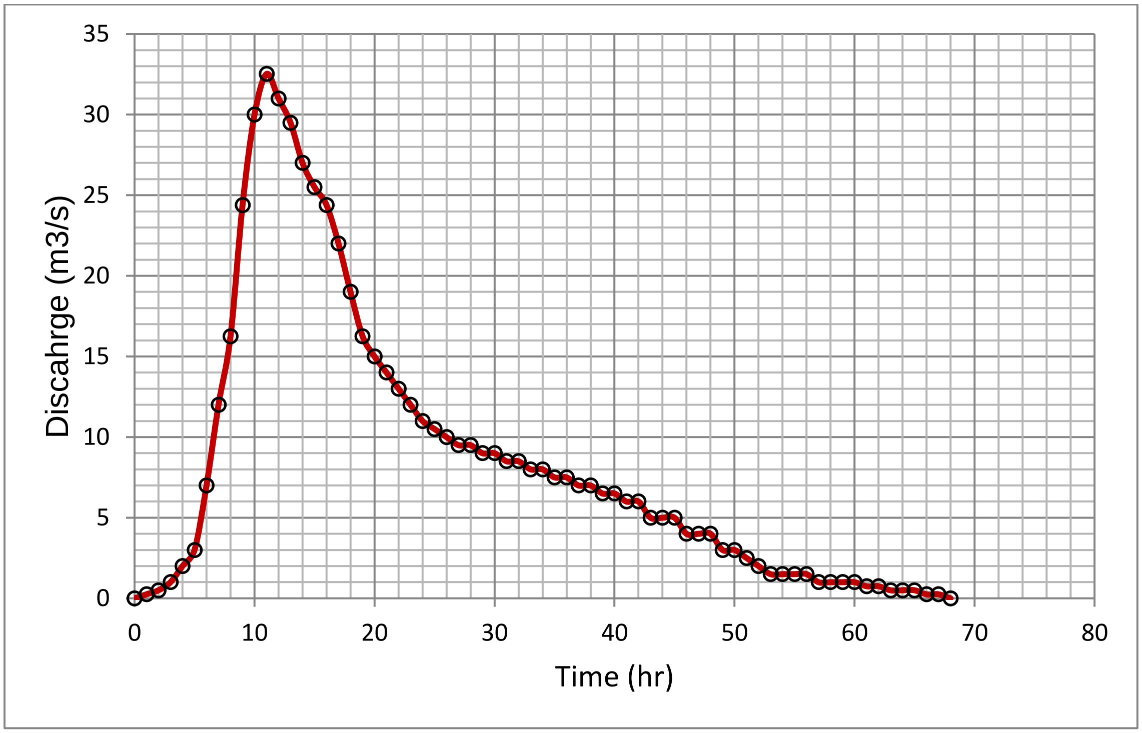


Figure A2 1-hr unit hydrograph

(e) Estimation of design storm duration

The design storm duration is

T_D=1.1 t_P = 1.1×10.47 = 11.52 hr

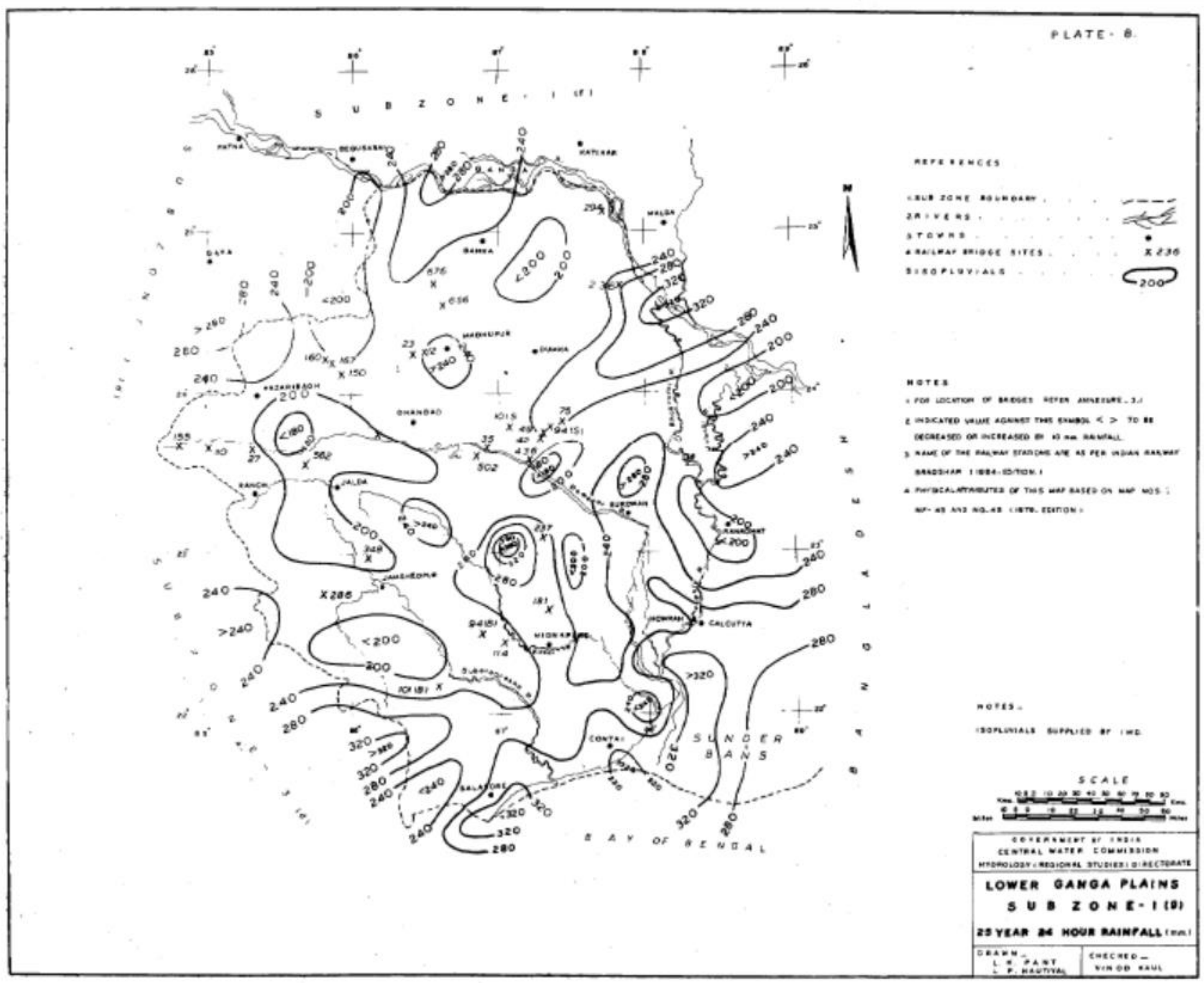
The adopted storm duration T_D = 12 hr

(f) Estimation of point rainfall and areal rainfall

The point rainfall for 25-year return period for a duration of 24-hr is read from the Isopluvial map of CWC i.e., Plate-B (Fig. A3a). The value of 25-year, 24-hr point rainfall = 22 cm. However, from PMP Atlas, 24-hr point rainfall = 19.0 cm.

The design storm duration (T_D) for the catchment is 12 hr. The point rainfall estimated for 24-hr storm duration = 22 cm. For 12-hr rainfall duration, the point rainfall = 0.8×19= 15.20 cm (See Fig. 10 of CWC report).

This 1-hr point rainfall has to be converted to 1-hr areal rainfall as per Fig. 12b of CWC's Flood estimation report for Lower Ganga Plain Sub Zone 1(g). The ratio for point rainfall to areal rainfall for catchment area of 201.8 km^2 and 12-hr storm duration is 0.95 (See Fig. 12b of CWC report) and corresponding 12-hr areal rainfall = 15.20×0.95 = 14.44 cm



(a)

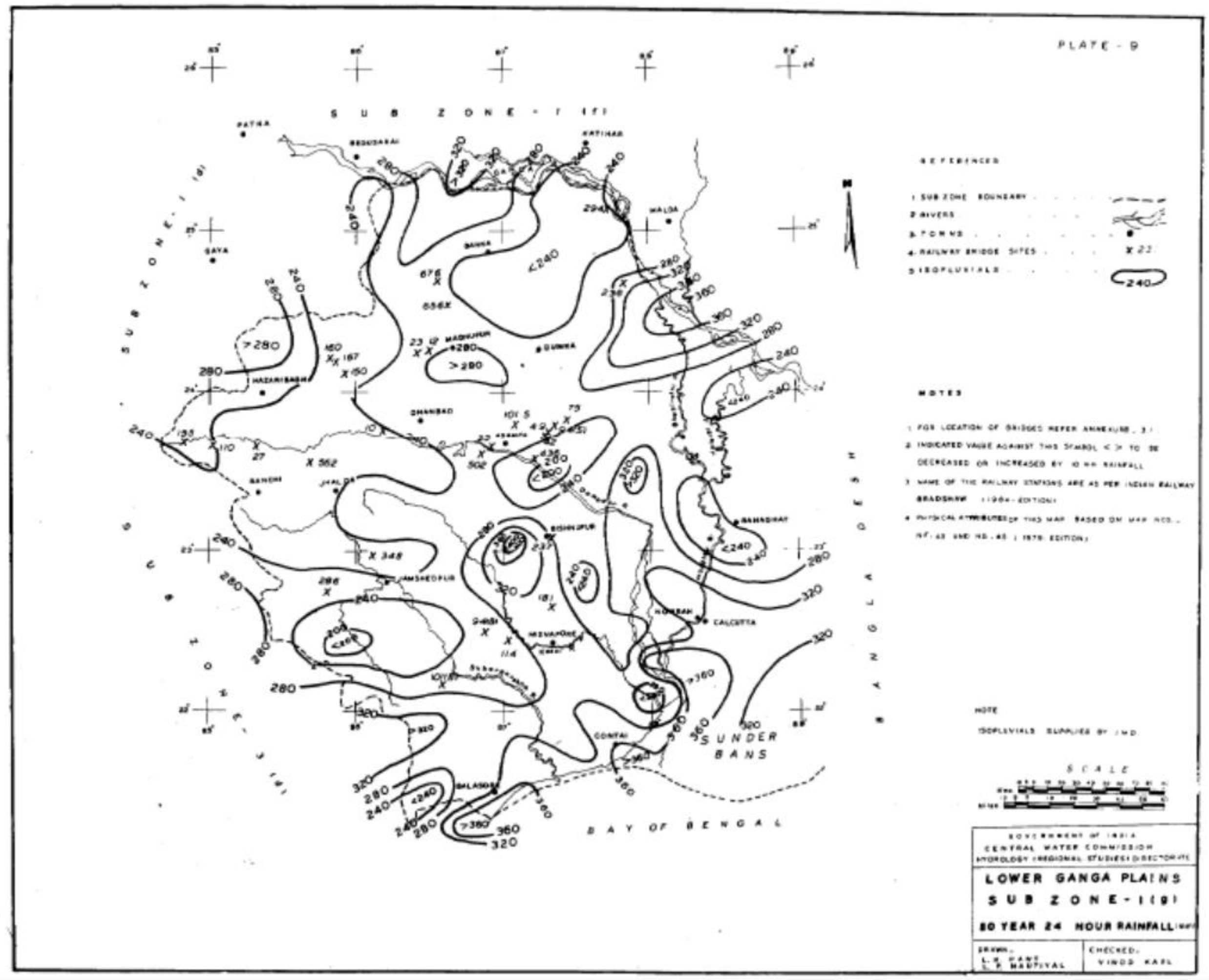
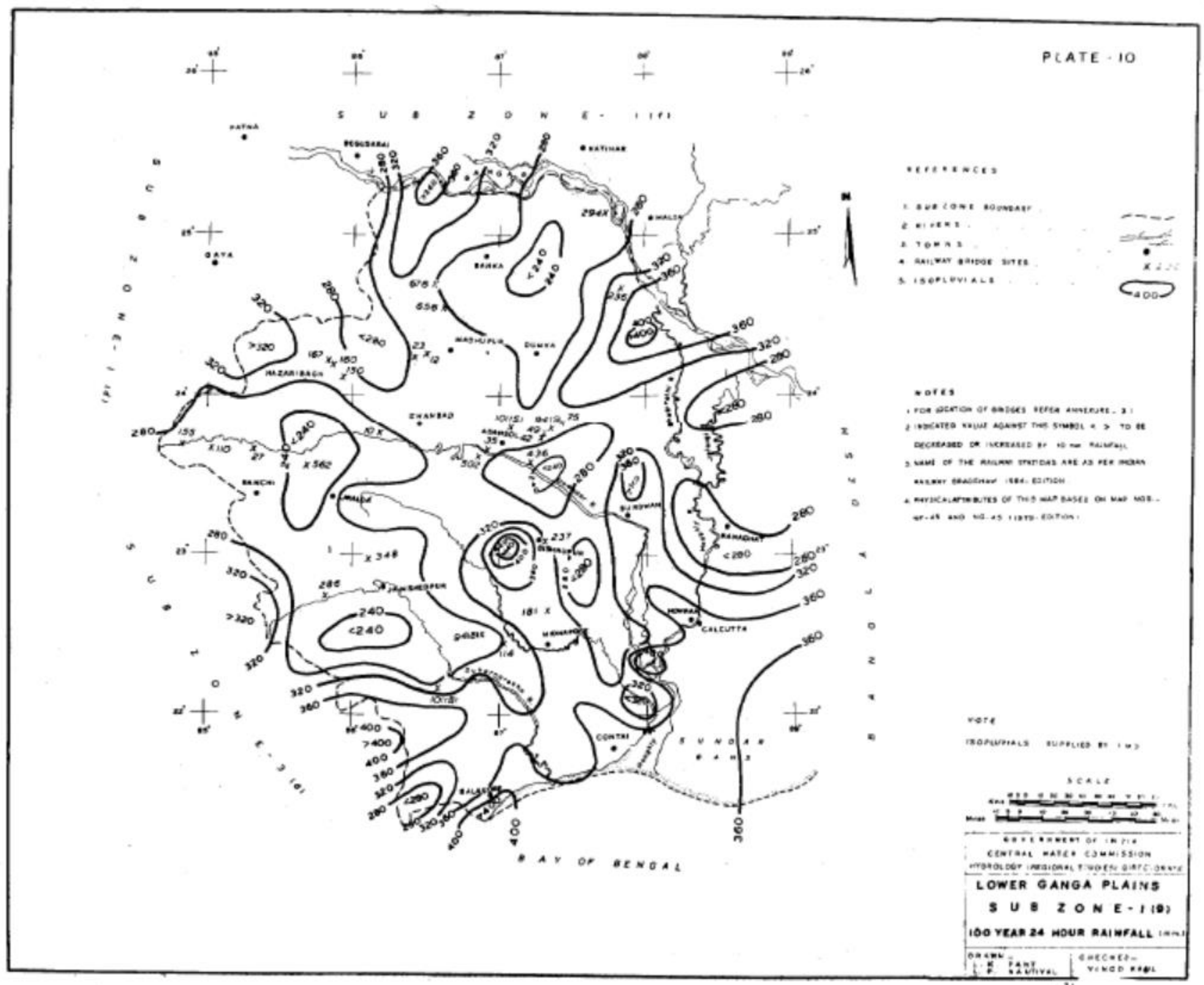


PLATE - 9
REFERENCES
1 SUB ZONE BOUNDARY
2 RIVERS
3 TOWNS
4 RAILWAY BRIDGE SITES
5 ISOPLUVIALS
NOTES
NOTE
ISOPLUVIALS SUPPLIED BY IMD
SCALE
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
LOWER GANGA PLAINS
SUB ZONE - 1(g)
50 YEAR 24 HOUR RAINFALL
CHECKED
VINOD KAPL
CALCUTTA
SUNDER BANS
BAY OF BENGAL
PATNA
GAYA
MALDA
DHANBAD
JAMSHEDPUR
BALASORE
CONTAI

(b)



(c)

Figure A3 Isopluvial maps for return period a) 25 years, b) 50 years and c) 100 years and duration rainfall 24 hr (CWC 1994)

(g) Time distribution of areal rainfall

The areal rainfall estimate for 25-yr return period for a design storm duration of 12-hr has been split into 1-hr rainfall increments using the time distribution coefficients given in Fig.11 of CWC's Flood estimation report for Lower Ganga Plain Sub Zone 1(g). The 1-hr rainfall increment are given in Table A3.

Table A3 Rainfall increments and effective 12-hr rainfall

Duration (hr)	Distribution Coefficient	Storm rainfall (cm)	Rainfall increments (cm)	Loss rate (cm)	Effective 12-hr rainfall (cm)
1	0.38	5.49	5.49	0.27	5.22
2	0.55	7.94	2.45	0.27	2.18
3	0.65	9.39	1.44	0.27	1.17
4	0.73	10.54	1.16	0.27	0.89
5	0.8	11.55	1.01	0.27	0.74
6	0.86	12.42	0.87	0.27	0.60
7	0.9	13.00	0.58	0.27	0.31
8	0.93	13.43	0.43	0.27	0.16
9	0.955	13.79	0.36	0.27	0.09
10	0.977	14.11	0.32	0.27	0.05
11	0.989	14.28	0.17	0.27	-0.10
12	1.00	14.44	0.16	0.27	-0.11
		total	14.44	3.24	8.58

(h) Estimation of rainfall excess

A design value of loss rate of 0.27 cm/hr is subtracted from each of the increments to give the rainfall excess. For 1-hr, the loss for one hour to be subtracted = 1× 0.27 = 0.27 cm. The computed 1-hr effective rainfall is given in Table A3.

(i) Estimation of base flow

Adopting a design base flow of 0.05 m^3/s per km^2 as recommended by CWC's Flood estimation report for the Lower Ganga Plain Sub Zone 1(g), base flow for the catchment under study was estimated 0.05×201.81= 10.09 m^3/s.

(j) Estimation of design flood & flood hydrograph

For the estimation of the peak discharge, the effective rainfall increments are rearranged against UHG ordinates such that the maximum rainfall is placed against the maximum UHG ordinates, next lower value of effective rainfall against next lower value of UHG ordinate and so on. Sum of the product of UHG ordinate and effective 12-hr rainfall gives total direct runoff to which base flow is added to obtain total peak discharge as given in Table A4.

Table A4 Design flood for 25-yr return period

1-hr UHG (m^3/s)	12-hr effective rainfall (cm)	Direct runoff (m^3/s)
32.5	5.22	169.66
31.0	2.18	67.73
30.0	1.17	35.22
29.5	0.89	26.11
27.0	0.74	20.00
25.5	0.60	15.21
24.4	0.31	7.50
24.4	0.16	3.98
22.0	0.09	2.00
19.0	0.05	0.91
	Total direct runoff =	348.32 m^3/s
	Base flow =	10.09 m^3/s
	Design flood =	358.41 m^3/s

The computation for flood hydrograph has been carried out in the Table A5 and the resulting hydrograph is shown in Fig. A4.

Table A5 Computation of flood hydrograph

Time	UG	Rainfall Excess (cm)										Base flow	Flood
hr	m^3/s	0.15	0.23	0.4	0.73	0.9	1.07	2.57	6.08	1.4	0.1	m^3/s	m^3/s
0	0.0	0.00										10.09	10.09
1	0.3	0.02	0.00									10.09	10.11
2	0.5	0.05	0.04	0.00								10.09	10.18
3	1.0	0.09	0.08	0.08	0.00							10.09	10.34
4	2.0	0.18	0.16	0.15	0.15	0.00						10.09	10.74
5	3.0	0.27	0.33	0.31	0.30	0.19	0.00					10.09	11.48
6	7.0	0.64	0.49	0.62	0.60	0.37	0.22	0.00				10.09	13.02
7	12.0	1.09	1.14	0.92	1.19	0.74	0.44	0.55	0.00			10.09	16.17
8	16.3	1.48	1.96	2.15	1.79	1.48	0.89	1.09	1.30	0.00		10.09	22.23
9	24.4	2.22	2.65	3.69	4.17	2.22	1.77	2.18	2.61	0.29	0.00	10.09	31.91
10	30.0	2.73	3.98	5.00	7.16	5.19	2.66	4.37	5.22	0.59	0.01	10.09	46.99
11	32.5	2.96	4.90	7.50	9.70	8.89	6.20	6.55	10.43	1.17	0.02	10.09	68.42
12	31.0	2.82	5.31	9.23	14.55	12.04	10.62	15.29	15.65	2.35	0.05	10.09	98.00
13	29.5	2.68	5.06	10.00	17.89	18.07	14.39	26.22	36.52	3.52	0.10	10.09	144.54
14	27.0	2.46	4.81	9.54	19.39	22.22	21.59	35.52	62.61	8.22	0.14	10.09	196.60
15	25.5	2.32	4.41	9.07	18.49	24.09	26.56	53.29	84.83	14.09	0.33	10.09	247.56
16	24.4	2.22	4.16	8.31	17.59	22.96	28.79	65.54	127.24	19.09	0.57	10.09	306.57
17	22.0	2.00	3.98	7.84	16.10	21.85	27.44	71.05	156.52	28.63	0.78	10.09	346.28
18	19.0	1.73	3.59	7.50	15.21	20.00	26.11	67.73	169.66	35.22	1.16	10.09	358.00
19	16.3	1.48	3.10	6.77	14.55	18.89	23.90	64.45	161.73	38.18	1.43	10.09	344.57
20	15.0	1.36	2.65	5.84	13.12	18.07	22.57	58.99	153.91	36.39	1.55	10.09	324.56
21	14.0	1.27	2.45	5.00	11.33	16.30	21.59	55.71	140.86	34.63	1.48	10.09	300.72
22	13.0	1.18	2.28	4.61	9.70	14.08	19.47	53.29	133.04	31.70	1.41	10.09	280.85
23	12.0	1.09	2.12	4.31	8.95	12.05	16.82	48.07	127.24	29.94	1.29	10.09	261.95
24	11.0	1.00	1.96	4.00	8.35	11.11	14.39	41.51	114.78	28.63	1.22	10.09	237.04

25	10.5	0.96	1.80	3.69	7.75	10.37	13.28	35.52	99.13	25.83	1.16	10.09	209.58
26	10.0	0.91	1.71	3.38	7.16	9.63	12.39	32.77	84.83	22.31	1.05	10.09	186.24
27	9.5	0.86	1.63	3.23	6.56	8.89	11.51	30.59	78.26	19.09	0.91	10.09	171.61
28	9.5	0.86	1.55	3.08	6.26	8.15	10.62	28.40	73.04	17.61	0.78	10.09	160.44
29	9.0	0.82	1.55	2.92	5.96	7.78	9.74	26.22	67.82	16.44	0.72	10.09	150.05
30	9.0	0.82	1.47	2.92	5.67	7.41	9.29	24.03	62.61	15.26	0.67	10.09	140.24
31	8.5	0.77	1.47	2.77	5.67	7.04	8.85	22.94	57.39	14.09	0.62	10.09	131.69
32	8.5	0.77	1.39	2.77	5.37	7.04	8.41	21.85	54.78	12.91	0.57	10.09	125.95
33	8.0	0.73	1.39	2.61	5.37	6.67	8.41	20.76	52.17	12.33	0.52	10.09	121.04
34	8.0	0.73	1.31	2.61	5.07	6.67	7.97	20.76	49.56	11.74	0.50	10.09	117.00
35	7.5	0.68	1.31	2.46	5.07	6.30	7.97	19.66	49.56	11.15	0.48	10.09	114.73
36	7.5	0.68	1.22	2.46	4.77	6.30	7.52	19.66	46.95	11.15	0.45	10.09	111.27
37	7.0	0.64	1.22	2.31	4.77	5.93	7.52	18.57	46.95	10.57	0.45	10.09	109.02
38	7.0	0.64	1.14	2.31	4.47	5.93	7.08	18.57	44.35	10.57	0.43	10.09	105.57
39	6.5	0.59	1.14	2.15	4.47	5.56	7.08	17.48	44.35	9.98	0.43	10.09	103.32
40	6.5	0.59	1.06	2.15	4.17	5.56	6.64	17.48	41.74	9.98	0.41	10.09	99.87
41	6.0	0.55	1.06	2.00	4.17	5.19	6.64	16.39	41.74	9.39	0.41	10.09	97.62
42	6.0	0.55	0.98	2.00	3.88	5.19	6.20	16.39	39.13	9.39	0.38	10.09	94.16
43	5.0	0.45	0.98	1.85	3.88	4.82	6.20	15.29	39.13	8.80	0.38	10.09	91.87
44	5.0	0.45	0.82	1.85	3.58	4.82	5.75	15.29	36.52	8.80	0.36	10.09	88.33
45	5.0	0.45	0.82	1.54	3.58	4.44	5.75	14.20	36.52	8.22	0.36	10.09	85.97
46	4.0	0.36	0.82	1.54	2.98	4.44	5.31	14.20	33.91	8.22	0.33	10.09	82.21
47	4.0	0.36	0.65	1.54	2.98	3.70	5.31	13.11	33.91	7.63	0.33	10.09	79.63
48	4.0	0.36	0.65	1.23	2.98	3.70	4.43	13.11	31.30	7.63	0.31	10.09	75.80
49	3.0	0.27	0.65	1.23	2.39	3.70	4.43	10.92	31.30	7.04	0.31	10.09	72.34
50	3.0	0.27	0.49	1.23	2.39	2.96	4.43	10.92	26.09	7.04	0.29	10.09	66.20
51	2.5	0.23	0.49	0.92	2.39	2.96	3.54	10.92	26.09	5.87	0.29	10.09	63.79
52	2.0	0.18	0.41	0.92	1.79	2.96	3.54	8.74	26.09	5.87	0.24	10.09	60.83
53	1.5	0.14	0.33	0.77	1.79	2.22	3.54	8.74	20.87	5.87	0.24	10.09	54.59

54	1.5	0.14	0.24	0.62	1.49	2.22	2.66	8.74	20.87	4.70	0.24	10.09	52.00
55	1.5	0.14	0.24	0.46	1.19	1.85	2.66	6.55	20.87	4.70	0.19	10.09	48.94
56	1.5	0.14	0.24	0.46	0.89	1.48	2.21	6.55	15.65	4.70	0.19	10.09	42.61
57	1.0	0.09	0.24	0.46	0.89	1.11	1.77	5.46	15.65	3.52	0.19	10.09	39.49
58	1.0	0.09	0.16	0.46	0.89	1.11	1.33	4.37	13.04	3.52	0.14	10.09	35.22
59	1.0	0.09	0.16	0.31	0.89	1.11	1.33	3.28	10.43	2.94	0.14	10.09	30.78
60	1.0	0.09	0.16	0.31	0.60	1.11	1.33	3.28	7.83	2.35	0.12	10.09	27.26
61	0.8	0.07	0.16	0.31	0.60	0.74	1.33	3.28	7.83	1.76	0.10	10.09	26.25
62	0.8	0.07	0.12	0.31	0.60	0.74	0.89	3.28	7.83	1.76	0.07	10.09	25.75
63	0.5	0.05	0.12	0.23	0.60	0.74	0.89	2.18	7.83	1.76	0.07	10.09	24.55
64	0.5	0.05	0.08	0.23	0.45	0.74	0.89	2.18	5.22	1.76	0.07	10.09	21.76
65	0.5	0.05	0.08	0.15	0.45	0.56	0.89	2.18	5.22	1.17	0.07	10.09	20.91
66	0.3	0.02	0.08	0.15	0.30	0.56	0.66	2.18	5.22	1.17	0.05	10.09	20.49
67	0.3	0.02	0.04	0.15	0.30	0.37	0.66	1.64	5.22	1.17	0.05	10.09	19.72
68	0.0	0.00	0.04	0.08	0.30	0.37	0.44	1.64	3.91	1.17	0.05	10.09	18.09
69			0.00	0.08	0.15	0.37	0.44	1.09	3.91	0.88	0.05	10.09	17.06
70				0.00	0.15	0.19	0.44	1.09	2.61	0.88	0.04	10.09	15.48
71					0.00	0.19	0.22	1.09	2.61	0.59	0.04	10.09	14.82
72						0.00	0.22	0.55	2.61	0.59	0.02	10.09	14.08
73							0.00	0.55	1.30	0.59	0.02	10.09	12.55
74								0.00	1.30	0.29	0.02	10.09	11.71
75									0.00	0.29	0.01	10.09	10.40
76										0.00	0.01	10.09	10.10
77											0.00	10.09	10.09

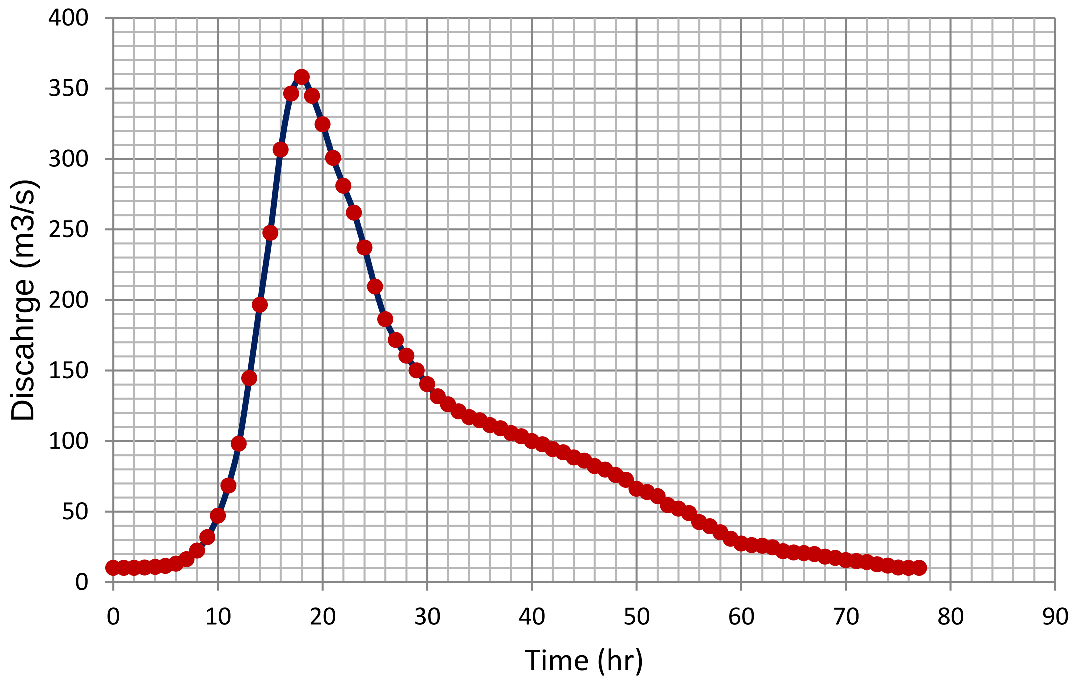


Figure A4 Flood hydrograph for 25 years return period

Following the above steps, peak discharge for 50 years return period is estimated as 413.21 m^3/s and developed storm is shown in Fig. A5.

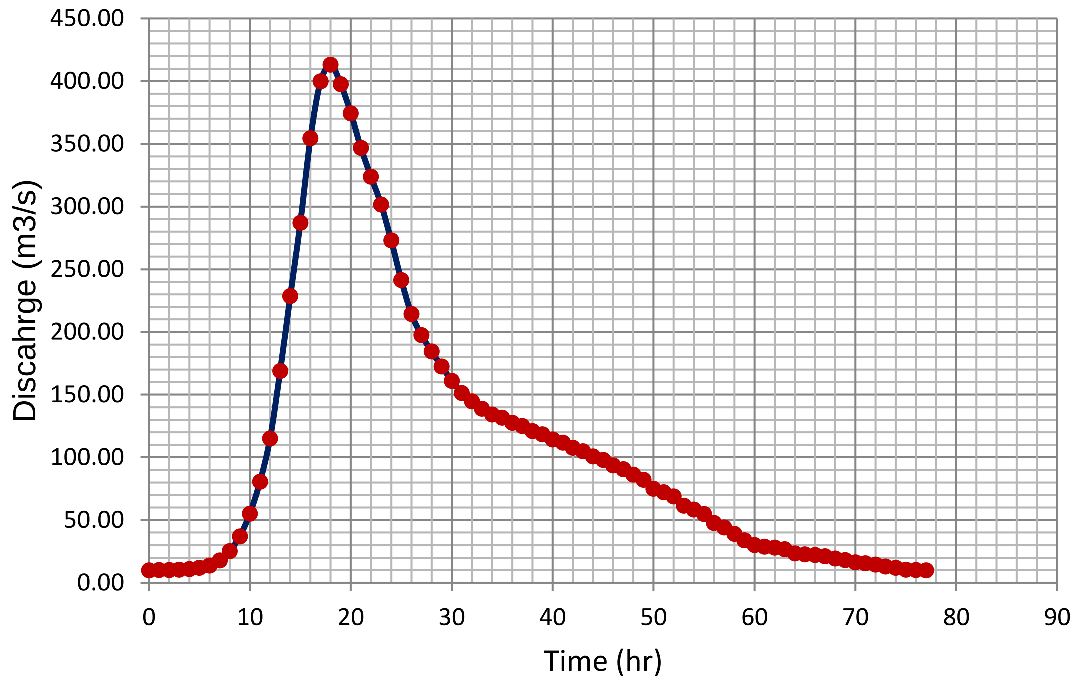


Figure A5 Flood hydrograph for 50 years return period

Following the above steps, peak discharge for 100 years return period is estimated as 466.20 m^3/s and developed storm is shown in Fig. A6.

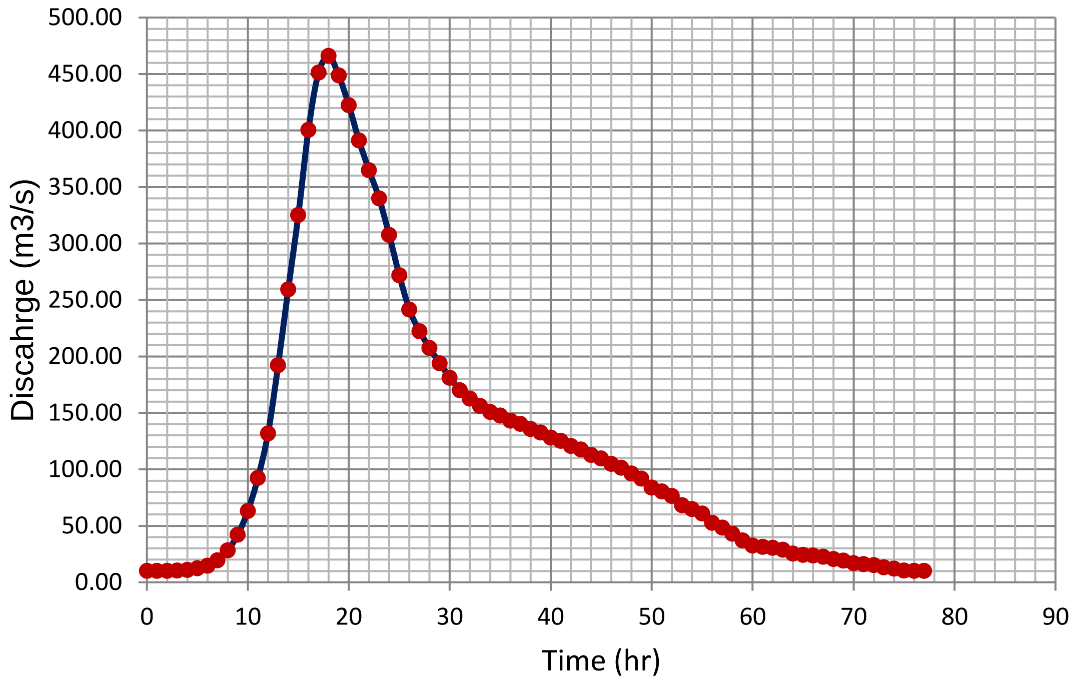


Figure A6 Flood hydrograph for 100 years return period

Annexure-B

GRDADATION OF RIVER BED MATERIAL

SAMPLE No. Barki river -A					
Sieve Analysis of Sand Sample of Site No.A.					
S.No.	IS Sieve Size (mm)	Retained Weight (kg)	Cummulative Retained Weight (kg)	Cummulative Retained Weight %	Cummulative Weight Passing
1	10.0	0.015	0.015	3.26	96.74
2	8.0	0.000	0.015	3.26	96.74
3	6.0	0.005	0.020	4.35	95.65
4	4.75	0.020	0.040	8.70	91.30
5	2.36	0.025	0.065	14.13	85.87
6	1.18	0.045	0.110	23.91	76.09
7	0.6	0.160	0.270	58.70	41.30
8	0.25	0.165	0.435	94.57	5.43
9	0.075	0.015	0.450	97.83	2.17
10	PAN	0.010	0.460	100.00	0.00
	Total Weight	0.460			

SAMPLE No. Barki river-B					
Sieve Analysis of Sand Sample of Site No.1. 2					
S.No.	**IS Sieve Size**	**Retained Weight (kg)**	**Cummulative Retained Weight (kg)**	**Cummulative Retained Weight %**	**Cummulative Weight Passing**
1	10.0	0.015	0.015	3.13	96.88
2	8.0	0.005	0.020	4.17	95.83
3	6.0	0.020	0.040	8.33	91.67
4	4.75	0.010	0.050	10.42	89.58
5	2.36	0.095	0.145	30.21	69.79
6	1.18	0.065	0.210	43.75	56.25
7	0.6	0.150	0.360	75.00	25.00
8	0.25	0.095	0.455	94.79	5.21
9	0.075	0.020	0.475	98.96	1.04
10	PAN	0.005	0.480	100.00	0.00
	Total Weight	0.480			

SAMPLE No. Barki river-C					
Sieve Analysis of Sand Sample of Site No.1. 3					
S.No.	IS Sieve Size	Retained Weight (kg)	Cummulative Retained Weight (kg)	Cummulative Retained Weight %	Cummulative Weight Passing
1	10.0	0.040	0.040	8.42	91.58
2	8.0	0.010	0.050	10.53	89.47
3	6.0	0.005	0.055	11.58	88.42
4	4.75	0.005	0.060	12.63	87.37
5	2.36	0.070	0.130	27.37	72.63
6	1.18	0.055	0.185	38.95	61.05
7	0.6	0.145	0.330	69.47	30.53
8	0.25	0.120	0.450	94.74	5.26
9	0.075	0.015	0.465	97.89	2.11
10	PAN	0.010	0.475	100.00	0.00
	Total Weight	0.475			

SAMPLE NO. Chotki river-A					
Sieve Analysis of Sand Sample of Site No.1. 4					
S.No.	IS Sieve Size	Retained Weight (kg)	Cummulative Retained Weight (kg)	Cummulative Retained Weight %	Cummulative Weight Passing
1	10.0	0.015	0.015	3.13	96.88
2	8.0	0.005	0.020	4.17	95.83
3	6.0	0.010	0.030	6.25	93.75
4	4.75	0.020	0.050	10.42	89.58
5	2.36	0.065	0.115	23.96	76.04
6	1.18	0.045	0.160	33.33	66.67
7	0.6	0.145	0.305	63.54	36.46
8	0.25	0.140	0.445	92.71	7.29
9	0.075	0.025	0.470	97.92	2.08
10	PAN	0.010	0.480	100.00	0.00
	Total Weight	0.480		**435.42**	

SAMPLE N0. Chotki river-B

Sieve Analysis of Sand Sample of Site No.1. 5					
S.No.	IS Sieve Size	Retained Weight	Cummulative Retained Weight (kg)	Cummulative Retained Weight %	Cummulative Weight Passing
1	10.0	0.000	0.000	0.00	100.00
2	8.0	0.000	0.000	0.00	100.00
3	6.0	0.000	0.000	0.00	100.00
4	4.75	0.005	0.005	1.05	98.95
5	2.36	0.035	0.040	8.42	91.58
6	1.18	0.090	0.130	27.37	72.63
7	0.6	0.255	0.385	81.05	18.95
8	0.25	0.080	0.465	97.89	2.11
9	0.075	0.005	0.470	98.95	1.05
10	PAN	0.005	0.475	100.00	0.00
	Total Weight	0.475			

a) Model Results under Existing Condition

Reach	Chainage	Discharge	Bed level	Water level	Energy slope	Velocity	Flow Area	Top Width	Froude number
	(m)	(m3/s)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Reach 1	9000	358.41	454.18	455.69	0.002033	3.84	93.35	63.54	1.01
Reach 1	8750	358.41	453.06	455.73	0.000254	1.93	185.82	74.57	0.39
Reach 1	8500	358.41	452.46	455.21	0.000338	2.1	170.97	74.82	0.44
Reach 1	8250	358.41	452.11	454.54	0.000927	3.14	114.06	58.13	0.72
Reach 1	8000	358.41	450.86	454.22	0.00058	2.59	138.6	66	0.57
Reach 1	7750	358.41	450.47	453.99	0.000513	2.75	130.47	51.65	0.55
Reach 1	7500	358.41	450.24	453.39	0.000448	2.2	162.82	82.11	0.5
Reach 1	7250	358.41	449.8	453.15	0.000563	2.58	139.09	65.66	0.57
Reach 1	7000	358.41	448.65	450.58	0.001741	4.11	87.24	47.04	0.96
Reach 1	6750	358.41	448.35	450.4	0.001002	3.24	110.78	56.72	0.74
Reach 1	6500	358.41	448.03	450.29	0.000657	2.77	129.16	60.85	0.61
Reach 1	6250	358.41	447.64	450.26	0.000402	2.15	166.69	80.99	0.47
Reach 1	6150	386.16	447.23	449.8	0.001797	3.37	114.68	86.25	0.93
Reach 1	6000	386.16	446.61	449.95	0.00038	1.67	230.72	154.99	0.44
Reach 1	5750	386.16	446.45	449	0.001897	4.13	93.55	53.52	1
Reach 1	5500	386.16	446.21	449.08	0.000225	1.77	218.6	91.32	0.36
Reach 1	5250	386.16	445.98	448.45	0.000214	1.7	227.61	96.98	0.35
Reach 1	5000	386.16	445.81	448.35	0.000224	1.79	215.47	87.58	0.36
Reach 1	4750	386.16	445.09	447.87	0.000238	1.6	241.43	122.46	0.36
Reach 1	4500	386.16	444.52	447.32	0.000999	3.15	122.46	64.11	0.73
Reach 1	4250	386.16	444.36	446.85	0.000811	2.72	141.77	80.74	0.66
Reach 1	4000	386.16	444.2	446.59	0.000991	2.71	142.26	95.18	0.71
Reach 1	3750	386.16	443.92	445.74	0.002129	3.51	110.09	89.65	1.01
Reach 1	3500	386.16	443.41	445.6	0.000488	1.87	206.93	143.4	0.5
Reach 1	3250	386.16	442.74	445.48	0.000308	1.95	197.55	89.25	0.42
Reach 1	3000	386.16	442.43	445.23	0.000284	1.97	195.54	83.14	0.41
Reach 1	2750	386.16	442.09	445.25	0.000144	1.44	267.4	108.82	0.29
Reach 1	2500	386.16	441.44	444.92	0.000552	2.52	152.99	72.31	0.55
Reach 1	2250	386.16	441.05	444.73	0.000625	2.67	144.46	69.33	0.59
Reach 1	2000	386.16	440.35	444.25	0.000775	3.56	108.34	39.12	0.68
Reach 1	1875	386.16	440.07	444.46	0.000307	2.22	180.04	70	0.43
Reach 1	1750	386.16	439.92	444.09	0.000754	3.18	121.32	50.95	0.66
Reach 1	1625	386.16	439.82	444.16	0.000451	2.48	155.43	65.1	0.51
Reach 1	1500	386.16	439.65	444.04	0.000455	2.58	149.64	57.51	0.51
Reach 1	1375	386.16	439.31	444.17	0.00014	1.5	257.81	95.35	0.29

Reach 1	1250	386.16	439.2	444.06	0.000174	1.93	200.2	59.19	0.33
Reach 1	1125	386.16	439.01	443.72	0.00059	2.98	129.58	49.35	0.59
Reach 1	1000	386.16	438.65	441.82	0.001757	4.91	78.66	32.45	1.01
Reach 1	875	386.16	438.11	441.64	0.000418	2.32	166.41	73.21	0.49
Reach 1	750	386.16	437.13	441.32	0.000528	3.17	122	39.23	0.57
Reach 1	625	386.16	436.97	440.94	0.000892	3.86	99.99	35.34	0.73
Reach 1	500	386.16	436.09	440.41	0.001234	4.68	82.52	26.85	0.85
Reach 1	375	386.16	435.3	439.26	0.001763	5.4	71.51	24.38	1.01

b) Model Results under Diversion of the Chotki River

Reach	Chainage	Discharge	Bed level	Water level	Energy slope	Velocity	Flow Area	Top Width	Froude number
	(m)	(m3/s)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Reach 1	9000	376.98	454.18	455.75	0.002009	3.9	96.69	63.71	1.01
Reach 1	8750	376.98	453.06	455.79	0.000262	1.98	190.1	74.8	0.4
Reach 1	8500	376.98	452.46	455.27	0.000345	2.15	175.61	75.35	0.45
Reach 1	8250	376.98	452.11	454.59	0.000952	3.22	117.04	58.65	0.73
Reach 1	8000	376.98	450.86	454.28	0.000579	2.64	143.05	66	0.57
Reach 1	7750	376.98	450.47	454.04	0.000538	2.83	133.14	52.14	0.57
Reach 1	7500	376.98	450.24	453.46	0.000446	2.24	168.6	82.83	0.5
Reach 1	7250	376.98	449.8	453.22	0.000578	2.63	143.26	66.87	0.57
Reach 1	7000	376.98	448.65	450.64	0.001738	4.18	90.09	47.14	0.97
Reach 1	6750	376.98	448.35	450.37	0.00116	3.45	109.16	56.57	0.79
Reach 1	6500	376.98	448.03	450.23	0.000789	3.01	125.38	60.12	0.66
Reach 1	6250	376.98	447.64	450.18	0.0005	2.35	160.83	80.44	0.53
Reach 1	6150	376.98	447.23	449.77	0.001789	3.38	111.57	83.16	0.93
Reach 1	6000	376.98	446.61	449.91	0.000396	1.68	224.44	154.83	0.45
Reach 1	5750	376.98	446.45	448.97	0.001908	4.11	91.79	53.15	1
Reach 1	5500	376.98	446.21	449.06	0.000221	1.74	216.16	90.81	0.36
Reach 1	5250	376.98	445.98	448.42	0.000212	1.68	224.73	96.75	0.35
Reach 1	5000	376.98	445.81	448.33	0.000222	1.77	213.05	87.51	0.36
Reach 1	4750	376.98	445.09	447.83	0.000241	1.59	236.49	121.94	0.37
Reach 1	4500	376.98	444.52	447.28	0.001002	3.14	120.08	63.45	0.73
Reach 1	4250	376.98	444.36	446.83	0.000807	2.7	139.83	80.66	0.65
Reach 1	4000	376.98	444.2	446.56	0.000996	2.69	139.93	95.06	0.71
Reach 1	3750	376.98	443.92	445.72	0.00214	3.48	108.23	89.41	1.01
Reach 1	3500	376.98	443.41	445.56	0.0005	1.87	201.23	141.27	0.5
Reach 1	3250	376.98	442.74	445.44	0.00031	1.94	194.15	89.22	0.42
Reach 1	3000	376.98	442.43	445.18	0.000289	1.97	191.49	82.74	0.41
Reach 1	2750	376.98	442.09	445.2	0.000147	1.44	261.96	108.46	0.3

Reach 1	2500	376.98	441.44	444.87	0.000573	2.53	149.05	72.25	0.56
Reach 1	2250	376.98	441.05	444.66	0.000657	2.69	139.88	68.86	0.6
Reach 1	2000	376.98	440.35	444.2	0.000784	3.55	106.15	38.89	0.69
Reach 1	1875	376.98	440.07	444.4	0.000315	2.21	175.98	70	0.44
Reach 1	1750	376.98	439.92	444.03	0.000737	3.19	118.24	48.7	0.65
Reach 1	1625	376.98	439.82	444.1	0.000463	2.49	151.47	64.44	0.52
Reach 1	1500	376.98	439.65	443.95	0.000445	2.73	138.15	49.14	0.52
Reach 1	1375	376.98	439.31	444.1	0.000144	1.5	251.86	94.96	0.29
Reach 1	1250	376.98	439.2	444	0.000176	1.92	196.61	59.1	0.34
Reach 1	1125	376.98	439.01	443.65	0.000589	2.98	126.42	47.99	0.59
Reach 1	1000	376.98	438.65	441.78	0.001764	4.88	77.3	32.33	1.01
Reach 1	875	376.98	438.11	441.58	0.00043	2.33	162.03	72.6	0.5
Reach 1	750	376.98	437.13	441.27	0.000528	3.14	120.01	39.03	0.57
Reach 1	625	376.98	436.97	440.89	0.000897	3.85	98.04	35.02	0.73
Reach 1	500	376.98	436.09	440.39	0.0012	4.6	81.89	26.75	0.84
Reach 1	375	376.98	435.3	439.2	0.001768	5.37	70.19	24.18	1.01

c) Model Results under Diversion of the Chotki River and Straightening of Barki River

Reach	Chainage	Discharge	Bed level	Water level	Energy slope	Velocity	Flow Area	Top Width	Froude number
	(m)	(m3/s)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Reach 1	9000	376.98	454.18	455.75	0.002009	3.9	96.69	63.71	1.01
Reach 1	8750	376.98	453.06	455.81	0.000255	1.97	191.71	74.89	0.39
Reach 1	8500	376.98	452.46	455.22	0.000368	2.19	171.86	74.96	0.46
Reach 1	8250	376.98	452.11	454.48	0.001124	3.41	110.59	57.69	0.79
Reach 1	8000	376.98	450.86	454.18	0.000668	2.76	136.49	65.51	0.61
Reach 1	7750	376.98	450.47	453.93	0.000609	2.96	127.16	51.04	0.6
Reach 1	7500	376.98	450.24	453.35	0.000524	2.36	159.8	81.73	0.54
Reach 1	7250	376.98	449.8	453.04	0.000729	2.86	131.88	64.72	0.64
Reach 1	7000	376.98	448.65	450.59	0.001896	4.3	87.68	47.05	1.01
Reach 1	6750	376.98	448.35	450.37	0.001161	3.45	109.13	56.57	0.79
Reach 1	6500	376.98	448.03	450.23	0.000787	3	125.46	60.12	0.66
Reach 1	6250	376.98	447.64	450.18	0.0005	2.34	160.87	80.45	0.53
Reach 1	6150	376.98	447.23	449.77	0.001779	3.37	111.8	83.21	0.93
Reach 1	6000	376.98	446.61	449.92	0.000394	1.68	224.81	154.84	0.44
Reach 1	5750	376.98	446.45	448.97	0.001908	4.11	91.79	53.15	1
Reach 1	5500	376.98	446.21	449.06	0.000221	1.74	216.23	90.83	0.36
Reach 1	5250	376.98	445.98	448.56	0.000177	1.58	238.08	97.81	0.32

Reach 1	5000	376.98	445.81	448.49	0.000181	1.66	227.05	87.91	0.33
Reach 1	4750	376.98	445.09	447.83	0.000241	1.59	236.46	121.94	0.37
Reach 1	4500	376.98	444.52	447.31	0.000969	3.1	121.62	63.88	0.72
Reach 1	4250	376.98	444.36	446.82	0.000818	2.71	139.3	80.64	0.66
Reach 1	4000	376.98	444.2	446.56	0.000994	2.69	139.98	95.07	0.71
Reach 1	3750	376.98	443.92	445.72	0.002139	3.48	108.24	89.41	1.01
Reach 1	3500	376.98	443.41	445.53	0.000524	1.91	197.38	139.41	0.51
Reach 1	3250	376.98	442.74	445.41	0.000326	1.97	191.25	89.19	0.43
Reach 1	3000	376.98	442.43	445.12	0.000316	2.03	186.05	82.36	0.43
Reach 1	2750	376.98	442.09	445.13	0.00016	1.48	254.79	107.98	0.31
Reach 1	2500	376.98	441.44	444.76	0.000681	2.67	141.32	72.14	0.61
Reach 1	2250	376.98	441.05	444.49	0.000734	2.93	128.81	60.76	0.64
Reach 1	2000	376.98	440.35	443.49	0.0018	4.72	79.89	35.85	1.01
Reach 1	825	376.98	440.35	443.49	0.0018	4.72	79.89	35.85	1.01
Reach 1	775	376.98	440	442.01	0.001872	4.27	88.26	48.02	1.01
Reach 1	675	376.98	435	441.64	0.000028	1.08	348.44	60	0.14
Reach 1	625	376.98	436.97	440.86	0.000922	3.89	97.03	34.86	0.74
Reach 1	500	376.98	436.09	439.98	0.001733	5.28	71.42	25.06	1
Reach 1	375	376.98	435.3	439.2	0.001768	5.37	70.19	24.18	1.01

Note: Channel is dummy of zero length from Chainage 825 m to Chainage 2000 m under diversion of the Chotki river & straightening of Barki river.

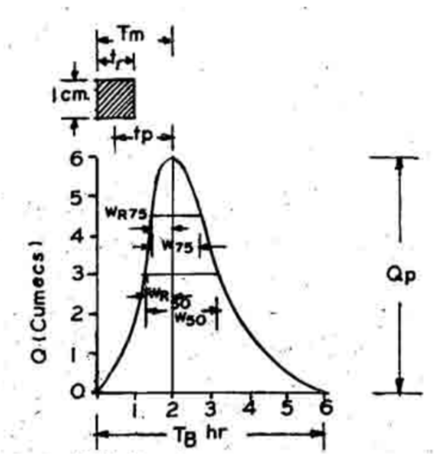
UNIT HYDROGRAPH METHOD

A	231.5	km2
L	43.13	km
S	3.65	m/km
L/Sqrt(S)	22.58	
tr	1.0	hr

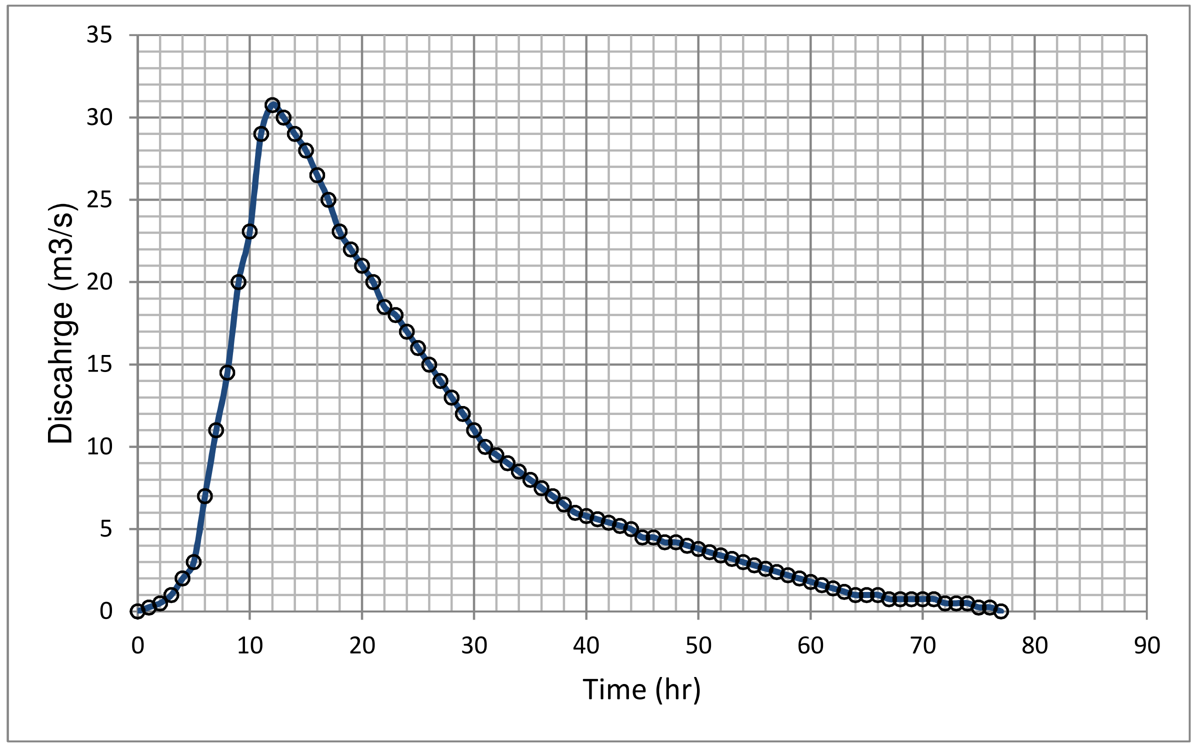
qp	0.13	
tp	12.55	
W50	13.63	
W75	8.35	
WR50	4.26	
WR75	2.30	
TB	77.32	
TD	13.81	
Qp	30.77	m3/s
Tm	13.05	hr
tr	1.0	hr
Adopted TD	14	hr
Adopted Tm	13	hr
Adopted tp	12	hr

$$q_p = 0.6617 \, (L / \sqrt{S})^{-0.515}$$
$$t_p = 1.8833 \, (q_p)^{-0.940}$$
$$W_{50} = 1.7897 \, (q_p)^{-1.006}$$
$$W_{75} = 0.8955 \, (q_p)^{-1.061}$$
$$W_{R50} = 0.5524 \, (q_p)^{-1.012}$$
$$W_{R75} = 0.2984 \, (q_p)^{-1.012}$$
$$T_B = 12.4755 \, (t_p)^{0.721}$$
$$T_m = t_p + t_r / 2$$
$$Q_p = q_p \times A$$

Table A-3



	T (hr)	Q (m3/s)	
	0	0	450
	1	0.25	1350
	2	0.5	2700
	3	1	5400
	4	2.00	9000
	5	3.00	18000
	6	7.00	32400
	7	11.00	45900
50%	8	14.50	62100
	9	20.00	77536
75%	10	23.08	93736
	11	29.00	107581
Peak	12	30.77	109381
	13	30.00	106200
	14	29.00	102600
	15	28.00	98100
	16	26.50	92700
	17	25.00	86536
75%	18	23.08	81136
	19	22.00	77400
	20	21	73800
	21	20.00	69300
50%	22	18.5	65700
	23	18	63000
	24	17	59400
	25	16	55800
	26	15	52200
	27	14	48600
	28	13	45000
	29	12	41400
	30	11	37800
	31	10	35100
	32	9.5	33300
	33	9	31500
	34	8.5	29700
	35	8	27900
	36	7.5	26100
	37	7	24300
	38	6.5	22500
	39	6	21240
	40	5.8	20520
	41	5.6	19800
	42	5.4	19080
	43	5.2	18360
	44	5	17100
	45	4.5	16200
	46	4.5	15660
	47	4.2	15120
	48	4.2	14760
	49	4	14040
	50	3.8	13320
	51	3.6	12600
	52	3.4	11880



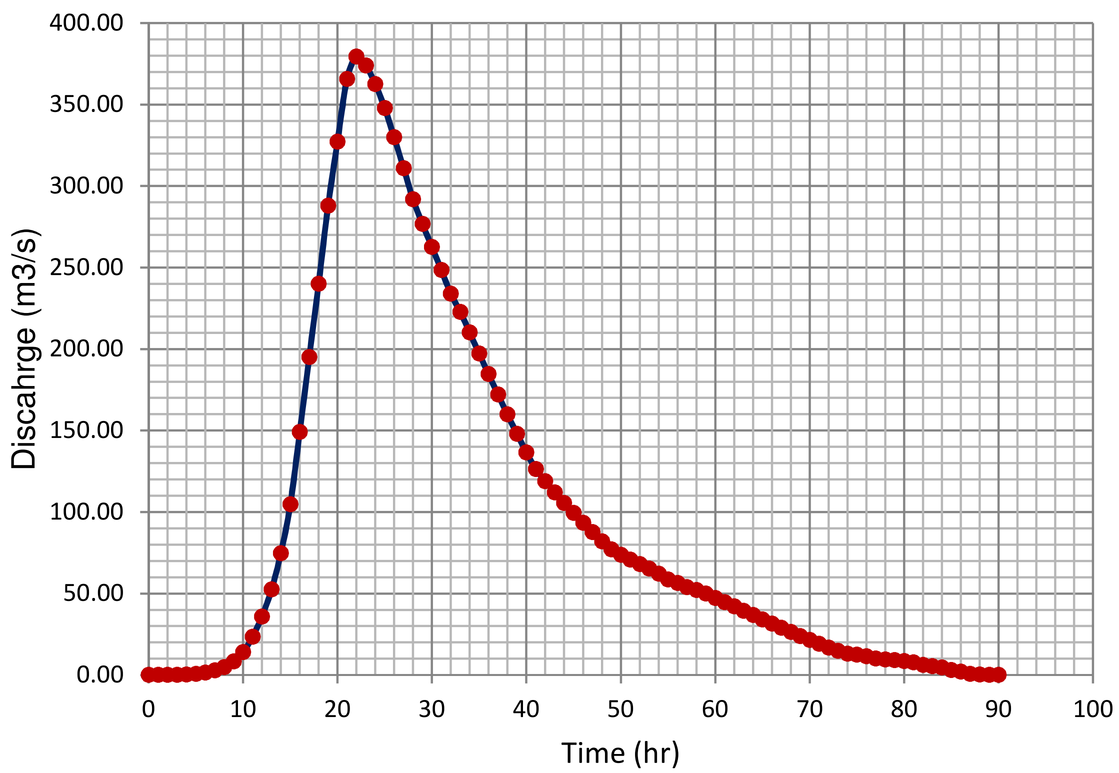
53	3.2	11160
54	3	10440
55	2.8	9720
56	2.6	9000
57	2.4	8280
58	2.2	7560
59	2	6840
60	1.8	6120
61	1.6	5400
62	1.4	4680
63	1.2	3960
64	1	3600
65	1	3600
66	1	3150
67	0.75	2700
68	0.75	2700
69	0.75	2700
70	0.75	2700
71	0.75	2250
72	0.5	1800
73	0.5	1800
74	0.5	1350
75	0.25	900
76	0.25	450
77	0	0
		2381196.8
		1.03 cm

50-year 24 hour rainfall	21.5	cm
Converson factor from point to a	0.94	
Rainfall for Td duration factor	0.84	
Aerial raifall & Td hr rainfall corre	0.79	
14 hr rainfall	16.98	cm

Design loss rate 2.7 mm/hr
Base flow = 0.05 m3/s/sqkm

Effective 14-hr rainfall

Duration (I	Dist. Coeff.	Storm r/f (cm)	r/f inc (cm)	loss rate (cm)	eff 14 hr r/f cm)
1	0.32	5.43	5.43	0.27	5.16
2	0.48	8.15	2.72	0.27	2.45
3	0.58	9.85	1.70	0.27	1.43
4	0.65	11.03	1.19	0.27	0.92
5	0.7	11.88	0.85	0.27	0.58
6	0.75	12.73	0.85	0.27	0.58
7	0.8	13.58	0.85	0.27	0.58
8	0.84	14.26	0.68	0.27	0.41
9	0.88	14.94	0.68	0.27	0.41
10	0.91	15.45	0.51	0.27	0.24
11	0.94	15.96	0.51	0.27	0.24
12	0.96	16.30	0.34	0.27	0.07
13	0.98	16.64	0.34	0.27	0.07
14	1.00	16.98	0.34	0.27	0.07
		total	16.98	3.78	9.04



50-year flood peak 1hr eff r/f direct ru-off
UG Ord

Time	UG	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	Total
hr	m3/s	0.07	0.07	0.07	0.24	0.41	0.58	0.58	0.58	0.92	2.45	5.16	1.43	0.41	0.24	m3/s
0	0.0	0.00														0.00
1	0.3	0.02	0.00													0.02
2	0.5	0.03	0.02	0.00												0.05
3	1.0	0.07	0.03	0.02	0.00											0.12
4	2.0	0.14	0.07	0.03	0.06	0.00										0.30
5	3.0	0.21	0.14	0.07	0.12	0.10	0.00									0.64
6	7.0	0.49	0.21	0.14	0.24	0.20	0.14	0.00								1.42
7	11.0	0.76	0.49	0.21	0.48	0.41	0.29	0.14	0.00							2.78
8	14.5	1.01	0.76	0.49	0.72	0.82	0.58	0.29	0.14	0.00						4.81
9	20.0	1.39	1.01	0.76	1.68	1.23	1.16	0.58	0.29	0.23	0.00					8.32
10	23.1	1.60	1.39	1.01	2.63	2.86	1.74	1.16	0.58	0.46	0.61	0.00				14.04
11	29.0	2.02	1.60	1.39	3.47	4.50	4.05	1.74	1.16	0.92	1.22	1.29	0.00			23.36
12	30.8	2.14	2.02	1.60	4.79	5.93	6.37	4.05	1.74	1.84	2.45	2.58	0.36	0.00		35.85
13	30.0	2.09	2.14	2.02	5.52	8.18	8.39	6.37	4.05	2.76	4.89	5.16	0.71	0.10	0.00	52.38
14	29.0	2.02	2.09	2.14	6.94	9.44	11.58	8.39	6.37	6.43	7.34	10.32	1.43	0.20	0.06	74.74
15	28.0	1.95	2.02	2.09	7.36	11.86	13.36	11.58	8.39	10.10	17.12	15.49	2.86	0.41	0.12	104.70
16	26.5	1.84	1.95	2.02	7.18	12.59	16.79	13.36	11.58	13.32	26.91	36.14	4.28	0.82	0.24	148.99
17	25.0	1.74	1.84	1.95	6.94	12.27	17.81	16.79	13.36	18.37	35.47	56.79	9.99	1.23	0.48	195.01
18	23.1	1.60	1.74	1.84	6.70	11.86	17.36	17.81	16.79	21.19	48.92	74.86	15.70	2.86	0.72	239.96
19	22.0	1.53	1.60	1.74	6.34	11.45	16.79	17.36	17.81	26.63	56.45	103.25	20.70	4.50	1.68	287.83
20	21.0	1.46	1.53	1.60	5.98	10.84	16.21	16.79	17.36	28.26	70.94	119.13	28.55	5.93	2.63	327.21
21	20.0	1.39	1.46	1.53	5.52	10.23	15.34	16.21	16.79	27.55	75.26	149.71	32.94	8.18	3.47	365.58
22	18.5	1.29	1.39	1.46	5.26	9.44	14.47	15.34	16.21	26.63	73.39	158.84	41.40	9.44	4.79	**379.34**
23	18.0	1.25	1.29	1.39	5.03	9.00	13.36	14.47	15.34	25.71	70.94	154.87	43.92	11.86	5.52	373.96
24	17.0	1.18	1.25	1.29	4.79	8.59	12.73	13.36	14.47	24.34	68.49	149.71	42.83	12.59	6.94	362.55
25	16.0	1.11	1.18	1.25	4.43	8.18	12.16	12.73	13.36	22.96	64.82	144.55	41.40	12.27	7.36	347.77
26	15.0	1.04	1.11	1.18	4.31	7.57	11.58	12.16	12.73	21.19	61.16	136.80	39.97	11.86	7.18	329.84
27	14.0	0.97	1.04	1.11	4.07	7.36	10.71	11.58	12.16	20.20	56.45	129.06	37.83	11.45	6.94	310.94
28	13.0	0.90	0.97	1.04	3.83	6.95	10.42	10.71	11.58	19.29	53.82	119.13	35.69	10.84	6.70	291.87
29	12.0	0.83	0.90	0.97	3.59	6.54	9.84	10.42	10.71	18.37	51.37	113.57	32.94	10.23	6.34	276.64
30	11.0	0.76	0.83	0.90	3.35	6.14	9.26	9.84	10.42	16.99	48.92	108.41	31.41	9.44	5.98	262.66
31	10.0	0.70	0.76	0.83	3.11	5.73	8.68	9.26	9.84	16.53	45.26	103.25	29.98	9.00	5.52	248.45
32	9.5	0.66	0.70	0.76	2.87	5.32	8.10	8.68	9.26	15.61	44.03	95.51	28.55	8.59	5.26	233.91
33	9.0	0.63	0.66	0.70	2.63	4.91	7.52	8.10	8.68	14.69	41.59	92.92	26.41	8.18	5.03	222.65
34	8.5	0.59	0.63	0.66	2.39	4.50	6.95	7.52	8.10	13.78	39.14	87.76	25.70	7.57	4.79	210.07
35	8.0	0.56	0.59	0.63	2.27	4.09	6.37	6.95	7.52	12.86	36.69	82.60	24.27	7.36	4.43	197.18
36	7.5	0.52	0.56	0.59	2.15	3.89	5.79	6.37	6.95	11.94	34.25	77.44	22.84	6.95	4.31	184.54
37	7.0	0.49	0.52	0.56	2.03	3.68	5.50	5.79	6.37	11.02	31.80	72.27	21.41	6.54	4.07	172.06
38	6.5	0.45	0.49	0.52	1.91	3.48	5.21	5.50	5.79	10.10	29.35	67.11	19.99	6.14	3.83	159.87
39	6.0	0.42	0.45	0.49	1.79	3.27	4.92	5.21	5.50	9.18	26.91	61.95	18.56	5.73	3.59	147.97
40	5.8	0.40	0.42	0.45	1.68	3.07	4.63	4.92	5.21	8.72	24.46	56.79	17.13	5.32	3.35	136.55
41	5.6	0.39	0.40	0.42	1.56	2.86	4.34	4.63	4.92	8.27	23.24	51.62	15.70	4.91	3.11	126.37
42	5.4	0.38	0.39	0.40	1.44	2.66	4.05	4.34	4.63	7.81	22.02	49.04	14.28	4.50	2.87	118.80
43	5.2	0.36	0.38	0.39	1.39	2.45	3.76	4.05	4.34	7.35	20.79	46.46	13.56	4.09	2.63	112.01
44	5.0	0.35	0.36	0.38	1.34	2.37	3.47	3.76	4.05	6.89	19.57	43.88	12.85	3.89	2.39	105.55
45	4.5	0.31	0.35	0.36	1.29	2.29	3.36	3.47	3.76	6.43	18.35	41.30	12.13	3.68	2.27	99.36
46	4.5	0.31	0.31	0.35	1.24	2.21	3.24	3.36	3.47	5.97	17.12	38.72	11.42	3.48	2.15	93.36
47	4.2	0.29	0.31	0.31	1.20	2.13	3.13	3.24	3.36	5.51	15.90	36.14	10.71	3.27	2.03	87.53
48	4.2	0.29	0.29	0.31	1.08	2.05	3.01	3.13	3.24	5.33	14.68	33.56	9.99	3.07	1.91	81.93
49	4.0	0.28	0.29	0.29	1.08	1.84	2.89	3.01	3.13	5.14	14.19	30.97	9.28	2.86	1.79	77.05

50	3.8	0.26	0.28	0.29	1.01	1.84	2.60	2.89	3.01	4.96	13.70	29.94	8.57	2.66	1.68	73.69
51	3.6	0.25	0.26	0.28	1.01	1.72	2.60	2.60	2.89	4.78	13.21	28.91	8.28	2.45	1.56	70.80
52	3.4	0.24	0.25	0.26	0.96	1.72	2.43	2.60	2.60	4.59	12.72	27.88	7.99	2.37	1.44	68.06
53	3.2	0.22	0.24	0.25	0.91	1.64	2.43	2.43	2.60	4.13	12.23	26.84	7.71	2.29	1.39	65.32
54	3.0	0.21	0.22	0.24	0.86	1.55	2.32	2.43	2.43	4.13	11.01	25.81	7.42	2.21	1.34	62.19
55	2.8	0.19	0.21	0.22	0.81	1.47	2.20	2.32	2.43	3.86	11.01	23.23	7.14	2.13	1.29	58.51
56	2.6	0.18	0.19	0.21	0.77	1.39	2.08	2.20	2.32	3.86	10.27	23.23	6.42	2.05	1.24	56.42
57	2.4	0.17	0.18	0.19	0.72	1.31	1.97	2.08	2.20	3.67	10.27	21.68	6.42	1.84	1.20	53.91
58	2.2	0.15	0.17	0.18	0.67	1.23	1.85	1.97	2.08	3.49	9.78	21.68	6.00	1.84	1.08	52.17
59	2.0	0.14	0.15	0.17	0.62	1.15	1.74	1.85	1.97	3.31	9.30	20.65	6.00	1.72	1.08	49.83
60	1.8	0.13	0.14	0.15	0.57	1.06	1.62	1.74	1.85	3.12	8.81	19.62	5.71	1.72	1.01	47.24
61	1.6	0.11	0.13	0.14	0.53	0.98	1.50	1.62	1.74	2.94	8.32	18.58	5.43	1.64	1.01	44.65
62	1.4	0.10	0.11	0.13	0.48	0.90	1.39	1.50	1.62	2.76	7.83	17.55	5.14	1.55	0.96	42.01
63	1.2	0.08	0.10	0.11	0.43	0.82	1.27	1.39	1.50	2.57	7.34	16.52	4.85	1.47	0.91	39.37
64	1.0	0.07	0.08	0.10	0.38	0.74	1.16	1.27	1.39	2.39	6.85	15.49	4.57	1.39	0.86	36.73
65	1.0	0.07	0.07	0.08	0.34	0.65	1.04	1.16	1.27	2.20	6.36	14.45	4.28	1.31	0.81	34.11
66	1.0	0.07	0.07	0.07	0.29	0.57	0.93	1.04	1.16	2.02	5.87	13.42	4.00	1.23	0.77	31.50
67	0.8	0.05	0.07	0.07	0.24	0.49	0.81	0.93	1.04	1.84	5.38	12.39	3.71	1.15	0.72	28.88
68	0.8	0.05	0.05	0.07	0.24	0.41	0.69	0.81	0.93	1.65	4.89	11.36	3.43	1.06	0.67	26.32
69	0.8	0.05	0.05	0.05	0.24	0.41	0.58	0.69	0.81	1.47	4.40	10.32	3.14	0.98	0.62	23.83
70	0.8	0.05	0.05	0.05	0.18	0.41	0.58	0.58	0.69	1.29	3.91	9.29	2.86	0.90	0.57	21.42
71	0.8	0.05	0.05	0.05	0.18	0.31	0.58	0.58	0.58	1.10	3.42	8.26	2.57	0.82	0.53	19.08
72	0.5	0.03	0.05	0.05	0.18	0.31	0.43	0.58	0.58	0.92	2.94	7.23	2.28	0.74	0.48	16.80
73	0.5	0.03	0.03	0.05	0.18	0.31	0.43	0.43	0.58	0.92	2.45	6.19	2.00	0.65	0.43	14.70
74	0.5	0.03	0.03	0.03	0.18	0.31	0.43	0.43	0.43	0.92	2.45	5.16	1.71	0.57	0.38	13.09
75	0.3	0.02	0.03	0.03	0.12	0.31	0.43	0.43	0.43	0.69	2.45	5.16	1.43	0.49	0.34	12.37
76	0.3	0.02	0.02	0.03	0.12	0.20	0.43	0.43	0.43	0.69	1.83	5.16	1.43	0.41	0.29	11.51
77	0.0	0.00	0.02	0.02	0.12	0.20	0.29	0.43	0.43	0.69	1.83	3.87	1.43	0.41	0.24	9.99
78		0.00	0.00	0.02	0.06	0.20	0.29	0.29	0.43	0.69	1.83	3.87	1.07	0.41	0.24	9.41
79		0.00	0.00	0.00	0.06	0.10	0.29	0.29	0.29	0.69	1.83	3.87	1.07	0.31	0.24	9.04
80		0.00	0.00	0.00	0.00	0.10	0.14	0.29	0.29	0.46	1.83	3.87	1.07	0.31	0.18	8.55
81		0.00	0.00	0.00	0.00	0.00	0.14	0.14	0.29	0.46	1.22	3.87	1.07	0.31	0.18	7.69
82		0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.14	0.46	1.22	2.58	1.07	0.31	0.18	6.11
83		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.23	1.22	2.58	0.71	0.31	0.18	5.38
84		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.61	2.58	0.71	0.20	0.18	4.52
85		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61	1.29	0.71	0.20	0.12	2.94
86		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.29	0.36	0.20	0.12	1.97
87		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.10	0.12	0.58
88		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.06	0.16
89		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06
90		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00