HYDROLOGICAL RISK ASSESSMENT FROM AND WITHIN A TORRENTIAL WATERSHED

A thesis submitted to the

University of Petroleum and Energy Studies

for the Award of

Doctor of Philosophy

in

Civil Engineering

by

PRAMOD KUMAR

Supervisors

DR. SAURABH MITTAL

DR. Y. V. N. KRISHNA MURTHY **DR. VIKAS GARG**

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UNIVERSITY WITH A PURPOSE

DEPARTMENT OF CIVIL ENGINEERING
SCHOOL OF ENGINEERING
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"Rivers are inherently interesting. They mold landscapes, create fertile deltas, provide trade routes, a source for food and water; a place to wash and play; civilisations emerged next to rivers in China, India, Europe, Africa and the Middle East. They sustain life and bring death and destruction. They are ferocious at times; gentle at times. They are placid and mean. They trigger conflict and delineate boundaries. Rivers are the stuff of metaphor and fable, painting and poetry. Rivers unite and divide-a thread that runs from source to exhausted release".

- *(Edward Gargan, The River's Tale, 2003)*

CERTIFICATE

I certify that PRAMOD KUMAR has prepared his thesis entitled "HYDROLOGICAL RISK ASSESSMENT FROM AND WITHIN A TORRENTIAL WATERSHED", for the award of PhD degree of the University of Petroleum & Energy Studies, under my guidance. He has carried out the work at the Department of Civil Engg., University of Petroleum & Energy Studies.

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ABSTRACT

The present study titled '**Hydrological Risk Assessment from and within a Torrential Watershed'** is undertaken for Tangri (Dangri) river, a tributary of Ghaggar and located in Panchkula and Ambala districts of Haryana, India. Physiographically, the watershed of Tangri (Dangri) river and its surroundings are categorised into four major geomorphological units, namely Alluvial Plain, Piedmont, Siwalik and Lesser Himalaya. The geological setting in the region characterises lithological formations of varying age-groups such as recent deposits of Indo-Gangetic plains, Upper Siwalik formation to Precambrian in lesser Himalaya. The hilly and upper piedmont areas of watershed comprise the soils which are poorly developed, shallow, stony and excessively drained; on the other hand, the soils in plains have good to moderate profile development with medium permeability and higher productivity.

The stereo pairs from Cartosat-1; multispectral data from Resourcesat LISS-3 and LISS-4, and Landsat Thematic Mapper (TM); Survey of India (SoI) topographical maps besides the hydro-meteorological data from India Meteorological Department (IMD) and Water Data Collection Division, Karnal, Government of Haryana have been used in this study. The temporal changes in torrential regime is analysed with Landsat data available on Google Earth Engine (GEE) platform. Within GEE environment and using the Earth Engine Playground (EEP), the JavaScript based Application Programming Interface (API) was developed for temporal remote sensing data classification and analysing the vegetation characteristics. Land Use/Land Cover (LULC) was analysed with Classification and Regression Trees (CART) classifier and vegetation characteristics was assessed based on Enhanced Vegetation Index (EVI). It is observed that the LULC classes during the process of lateral migration and due to watershed inhabitants' intervention fall under four major categories in the watershed, namely cropland/fallow, orchard/plantation/forest, grass/scrub and dry river bed. Hence, these broad categories of LULC were used to classify multispectral data.

Differential Global Navigation Satellite System (DGNSS) based survey was conducted to acquire Ground Control Points (GCPs). Later, these GCPs were utilised to generate Digital Elevation Model (DEM) using Cartosat-1 stereo pairs for torrents'

vulnerability and hydrological risk assessment. During DEM generation, the block orientation was done utilising 43 GCPs, out of which 10 were selected as check points. After triangulation with 33 control points, the model's Root Mean Square Error (RMSE) was obtained as 0.105 pixel. The residuals for control points were 0.98 m (X) and 1.48 m (Y) whereas for check points were 1.869 m (X) and 1.843 m (Y). The torrents' vulnerability analysis was carried out using six parameters, viz. i) LULC, ii) Catchment's slope, iii) Soil characteristics, iv) Proximity to torrents' flood plain, v) Proximity to conservation measures and vi) Channel characteristics. The drainage maps were digitised with the conjugate use of SoI topographical maps and Indian Remote Sensing Satellite (IRS) data, and later used for preparing the drainage density map (stream length per km^2). The locations of various structural measures erected in watershed were captured through Global Navigation Satellite System (GNSS) device and later transferred to Geographic Information System (GIS) database. The stream width and torrents' meander angles were measured at various river sections while utilising satellite data and ground based measurements.

Revised Universal Soil Loss Equation (RUSLE) was utilised for soil loss estimation. The theme maps such as soil, slope and LULC were inferred using remote sensing data, brought as GIS layers and soil loss was estimated. The hourly rainfall data (1986-2013) obtained from IMD was analysed to assess the probability exceedance distribution function following the Intensity-Duration-Frequency (IDF) curve and Gumbel Type I distribution technique. The hydrologic and hydrodynamic modeling was done using Hydrologic Engineering Centre (HEC) Hydrologic Modeling System (HMS) and HEC's River Analysis System (RAS) tools. DEM derived from Cartosat-1 stereo data was pre-processed in HEC-HMS environment for catchment's hydrologic properties extraction. Curve Number (CN) technique of Natural Resources Conservation Service (NRCS) was used in the model. In the hydrodynamic modeling, the requisite information consisting of three primary elements, viz. plan, geometry and stream information were fed into the model. With Cartosat-1 DEM and Resourcesat LISS-3 data as background layers, the stream centre-line, banks, flow path and cross-sections were drawn. Using the geometry and peak flow information, the floodplain delineation was attempted and inundation modeling was done to evaluate the impact of peak flows on encompassing LULC based on rainfall of varying return periods.

It is observed that because of various conservation exercises adopted in watershed and also due to smaller land holdings and increasing pressure on land resources, some parts of the watershed are getting reclaimed. During the period from 1991 to 2018, the areas under bare torrents (dry river bed) have decreased from 701 ha to 407 ha. The torrential areas which were under grass/scrub have increased from 550 ha to 678 ha, and the land under agriculture (1478 ha to 1617 ha) and orchard/plantation/forest (533 ha to 560 ha) have also increased. Majorly, these developments are seen along the primary channel of Tangri (Dangri) river and at its downstream reaches, which is the meeting point of Thathar ki Nadi with main Tangri (Dangri) river. The monthly EVI values for March, September and December months for Tangri (Dangri) river sub-watershed were analysed. The monthly mean EVI values are continuously improving for the watershed with their values as -0.0626 (1991) to 0.297 (2018). The maximum values of EVI have also increased from 0.118 (1991) to 0.902 (2018). It is observed that though there are some data gaps in the GEE products but overall trend of monthly mean EVI is positive and continuously increasing which is owing to various soil and conservation activities implemented within watershed. The LULC and EVI based temporal assessment of watershed characteristics present a methodology for GEE based watershed monitoring to assess the impact of various treatment measures.

The torrents' vulnerability analysis was carried out using Multi-Criteria Decision Making (MCDM) based Analytical Hierarchy Process (AHP) model. The weights of various parameters and sub-parameters were derived and their cumulative effects were assessed for torrents' vulnerability assessment. These weightages were multiplied with feature class attributes to compute Composite Vulnerability Index (CVI). CVI layer was reclassified into five categories to prepare the torrent vulnerability classes, namely low, low to moderate, moderate, moderate to high and high. The torrent vulnerability map reveals that high and moderate to high vulnerable areas are noticed in proximity to settlements and cropland, slope transition zones, streams' confluence and also in proximity to meandering sections of the river. Areas under low to moderate vulnerability are mostly located in middle part of catchment due to moderate slope and low drainage density. It is observed that nearly 16% areas of watershed fall under moderate to high and high vulnerability classes whereas rest (nearly 84%) of the watershed fall under low, and low to moderate vulnerability towards settlements and various natural resources. The change analysis of torrential areas and multi-criteria based vulnerability analysis also present a methodology for the impact assessment of watershed treatment activity and to identify critical areas which still need attention.

RUSLE technique is a function of erosivity caused by rainfall, erodibility characteristics of soil, slope length and gradient, crop cover and management factor, and it estimates annual average soil loss. The soil loss in the watershed is relatively higher as its average value is 40.4 $t.ha^{-1}.yr^{-1}$. The annual average soil loss is highest (67.6 $t.ha^{-1}.yr^{-1}$) for mountain units. It is followed by Siwalik hills where the highest (59.4 $t.ha^{-1}.yr^{-1}$) soil loss is observed from H13 (Escarpments) followed by H12 (Fairly dense forest) (57.1 $t.ha^{-1}.yr^{-1}$) and H11 (Terraced cultivation) unit (46.7 $t.ha^{-1}.yr^{-1}$). In the piedmont region, the soil loss is varying from 15.7 $t.ha^{-1}.yr^{-1}$ to 17.8 $t.ha^{-1}.yr^{-1}$. The relationship between LULC classes with annual average soil loss has been plotted. The annual average soil loss is highest for forest scrub (61.5 $t.ha^{-1}.yr^{-1}$) trailed by open forest (49.5 $t.ha^{-1}.yr^{-1}$). The peak river discharge for varying return periods, namely two, five, ten, twenty-five, fifty, hundred and thousand years were estimated to vary from 591.07 cumecs to 2023.84 cumecs. The Nash–Sutcliffe model efficiency was obtained as 0.88 based on comparison between observed and simulated discharge. The Muskingum-Cunge routing method was utilised for flood routing. In HEC-RAS analysis, the river system schematics were defined in terms of reach, cross-sections, flow paths, ineffective areas, etc. Manning’s coefficient varied from 0.025 to 0.10 for Tangri (Dangri) river watershed. LULC layer along with Manning’s roughness variability was ingested into the HEC-RAS model. The river network, geometry and other cross-sectional details were transferred from HEC-GeoRAS to HEC-RAS model and model was executed for discharge values corresponding to varying return periods. Based on flood inundation modeling, it is observed that for two, five, ten, twenty-five, fifty, hundred and thousand years return periods; 1.42%, 2.76%, 4.84%, 8.43%, 12.58%, 16.14% and 24.32%, respectively areas of catchment are likely to get inundated.

Using the MCDM based techniques, following alternatives for the treatment of vulnerable sections of torrential regime were prioritised: i) Conservation structures (spurs, retaining walls, etc.) on torrents' bed and banks (A_{-1}), ii) Biological works (afforestation/plantation, grass cover, etc.) in valleys and flood plains (A_{-2}), iii) Biotechnical structures (wood dams, dried vegetative mat, etc.) in moderate slopes and lower order drainages (A_{-3}), iv) Agronomic measures (crop rotation, inter/mixed cropping, etc.) (A_{-4}), v) Channel desiltation (A_{-5}) and vi) Grazing reduction (A_{-6}). In consultation with experts, the prioritisation of these soil and water conservation measures were performed using two different MCDM models, viz. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and *ELimination Et Choix Traduisant la REalité* (ELimination and Choice Translating Reality, ELECTRE) where ELECTRE is an outranking type method which inspects whether an alternative outpaces another whereas TOPSIS is based on distance to ideal point for finding alternatives among choices. These alternatives were weighed with various criteria options, viz. i) Slope (C_{-1}), ii) LULC (C_{-2}), iii) Soil (C_{-3}), iv) Proximity to conservation structures (C_{-4}), v) Proximity to torrents (C_{-5}) and vi) Channel characteristics (C_{-6}). Based on AHP based MCDM technique, the criteria weights were obtained as follows: 0.028, 0.049, 0.085, 0.146, 0.253 and 0.439, respectively. The two MCDM based techniques, namely TOPSIS and ELECTRE have ranked various alternatives both the methods are identical. The alternative A_{-1} (Conservation structures) has scored highest among both the methods. The alternative with second highest score is yielded by A_{-2} (Biological works) followed by A_{-3} (Biotechnical structures), A_{-4} (Agronomic measures), A_{-5} (Channel desiltation) and A_{-6} (Grazing reduction) alternatives.

The methodology used and results obtained from this study has revealed multitude of problems faced by torrential systems. Large areas falling close to Tangri (Dangri) river flood-plain are highly vulnerable to floods and various hydrologic and hydraulic models have demonstrated to be very efficient modeling tools for flood hazard analysis and forecasting. The annual average soil loss in watershed is evaluated to be under extreme category. The methodology demonstrates its potential for adoption by conservation agencies to ascertain vulnerable zones and for efficient planning and management of torrential river systems.

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Pramod Kumar

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List of Acronyms

LAI	Leaf Area Index
IISWC	Indian Institute of Soil and Water Conservation
SWC	Soil and water conservation ()
3D	Three-dimensional
AGWA	Automated Geospatial Watershed Assessment
AHP	Analytical Hierarchy Process
ALI	Advanced Land Imager
AMC	Antecedent Moisture Condition
ANN	Artificial Neural Network
API	Application Programming Interface
ARS	Agricultural Research Service
ATE	Automatic Terrain Extraction
BF-TOPSIS	Belief Function-based TOPSIS
C	Crop management factor
CART	Classification and Regression Tree
CBA	Cost-Benefit Analysis
CI	Consistency Index
CN	Curve Number
CP	Compromise Programming
CR	Consistency Ratio
CVI	Composite Vulnerability Index
CVN	French Cevennes
DEM	Digital Elevation Model
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential Global Positioning System
DTM	Digital Terrain Model
EE	Earth Explorer
EEE	Google Earth Engine Explorer
EEP	Google Earth Engine Playground
ELECTRE	*ELimination Et Choix Traduisant la REalité* (ELimination and Choice Expressing Translating Reality)
ENE	East-Northeast
ERDAS	Earth Resource Development Assessment System
EROS	Earth Resources Observation and Science Centre,
ETM	Enhanced Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
EVI	Enhanced Vegetation Index
FAHP	Fuzzy Analytical Hierarchy Process
GCP	Ground Control Point
GDP	Gross Domestic Product
GEE	Google Earth Engine
GIS	Geographic Information System
GLONASS	*Globalnaya Navigatsionnaya Sputnikovaya Sistema*

GloVis	Global Visualisation Viewer
GLUE	Generalised Likelihood Uncertainty Estimation
GMS-5	Geostationary Meteorological Satellite-5
GNSS	Global Navigation Satellite System
GP	Goal Programming
GPS	Global Positioning System
GTA	Great Toronto Area
GUI	Graphical User Interface
HBV	*Hydrologiska Byr°ans Vattenbalansavdelning*
HEC	Hydrologic Engineering Centre
HEC-GeoHMS	HEC-Geospatial Hydrologic Modeling System
HEC-GeoRAS	HEC-Geospatial River Analysis System
HEC-HMS	HEC-Hydrologic Modeling System
HEC-RAS	HEC-River Analysis System
HMS	Hydrologic Modeling System
HP	Himachal Pradesh
HRU	Hydrologic Response Units
HSG	Hydrological Soil Group
IDE	Integrated Development Environment
IDF	Intensity-Duration-Frequency
IIRS	Indian Institute of Remote Sensing
IIST	Indian Institute of Space Science and Technology
IMD	India Meteorological Department
IRS	Indian Remote Sensing Satellite
ISRO	Indian Space Research Organisation
IWDP	Integrated Wasteland Development Program
IWMP	Integrated Watershed Management Programme
K	Soil erodibility factor
KINEROS	Kinematic Runoff and Erosion Model
L	Slope length factor
LISS	Linear Imaging Self-Scanning System
LPS	Leica Photogrammetry Suite
LR	Logistic Regression
LS	Slope length-gradient factor
LULC	Land Use/Land Cover
MADM	Multi-attribute Attribute Decision Making
MAUT	Multi-Attribute Utility Theory
MBT	Main Boundary Thrust
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
MCMC	Markov Chain Monte Carlo
MLC	Maximum Likelihood Classifier
MM5	Fifth-Generation Penn State/NCAR Mesoscale Model
MODM	Multi-Objective Decision Making
MSS	Multispectral Scanner
NBSS&LUP	National Bureau of Soil Survey and Land Utilisation Planning
NCAR	National Centre for Atmospheric Research

NCC	Natural Colour Composite
NDVI	Normalised Difference Vegetation Index
NDWI	Normalised Difference Water Index
NE	North-east
NEXRAD	Next-Generation Radar
NOAA	National Oceanic, Atmospheric Administration
NOEDA	National Remote Sensing Centre Open EO Data Archive
NRCC	National Research Council Canada
NRCS	Natural Resources Conservation Service
NRSC	National Remote Sensing Centre
NW	North-west
NWS	National Weather Service
OLI	Operational Land Imager
ORESTE	*Organísation, Rangement et Synthèse Dedonnées Relarionnelles*
P	Management practice factor
PCSWMM	Personal Computer Storm Water Management Model
PROMETHEE	Preference Ranking Organisation Method for Enrichment and Evaluation
Q	Discharge
R	Rainfall erosivity
RADAR	Radio Detection and Ranging
RAS	River Analysis System
RBV	Return Beam Vidicon
RF	Random Forest
RFA	Rainfall frequency analysis
RMSE	Root Mean Square Error
RPCs	Rational Polynomial Coefficients
RUSLE	Revised Universal Soil Loss Equation
S	Steepness factor
SCS	Soil Conservation Service
SE	Soth-east
SoI	Survey of India
SVM	Support Vector Machine
SW	South-west
SWMM	Storm Water Management Model
TBC	Trimble Business Centre
TIN	Triangulated Irregular Network
TIRS	Thermal Infrared Sensor
TLS	Terrestrial Laser Scan
TM	Thematic Mapper
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TR-55	Technical Release 55
TREX	Two-dimensionalDimensional-Runoff-Erosion-Export
UHF	Ultra High Frequency
UP	Uttar Pradesh
UPES	University of Petroleum and Energy Studies
US	United States

USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
WMO	World Meteorological Organisation
WRF	Weather Research and Forecasting
WSW	West-Southwest

Chapter 1

INTRODUCTION

Torrents are ephemeral mountainous streams emanating from outer Himalayas or Siwalik and usually carry heavy bed load and flash flows. As a result of frequent changes in course due to meandering and lateral migration, they cause extensive damage to environment in valley and alluvial land while scouring their beds, erode their banks and destroy precious arable lands. The torrential watersheds are of varying dimensions and experience an unexpected maximal discharge with high sediment volume (Ristić and Maloševi´c, 2011). Around Indian sub-continent, torrents are generally known as '*Choes*' (Punjab, India), '*Kholas*' (Himachal Pradesh, India; Nepal), '*Jhora*' (Sikkim and West Bengal, India) and '*Dong/Jhora*' (Assam, India; Bhutan). The riverine lands, however, are well-known as '*Bet*' (Haryana and Punjab, India), '*Khadar*' (Himachal, India), '*Char*' and '*Diara*' (Bihar and Uttar Pradesh, India) and '*Char*' and '*Beet*' (Assam and West Bengal, India) (Kumar et al. 2017; Yadav, 2005). The torrents are known as '*Torrenteras*' in Peru (Mazer, 2020); '*Torrentera*' and '*Riera*' in the Catalan countries; '*Yasa*' in Aragon; '*Clamor*' in the Aragon region of Monegros; '*Cárcava*', '*Barranco*', '*Rambla*', etc. in other parts of the world (Vidal-Abarca et al., 1992). Hence, the understanding of torrential streams, their hydrologic and hydraulic characteristics are essential to undertake conservation measures, and to minimise the adverse impact on surrounding environment. Some attempts to estimate the areas under torrents and the affected region have been made worldwide. Ministry of Agriculture, Govt. of India assessed the areas impacted by torrents in India as 2.73 million ha (Das, 1985). The areas under torrents and rivers were assessed in some states of northern India as 323 sq. km (Punjab), 400 sq. km (Himachal Pradesh), 238 sq. km (Haryana), 414 sq. km (Uttar Pradesh/Uttarakhand) and 140 sq. km (Jammu & Kashmir) by Tiwari et al. (2006). In Serbia, 9260 torrential watersheds were enlisted based on the analysis carried out from 1930 to 1974 (Ristić, 2012). Figure 1.1 shows the synoptic view of torrents emanating from Siwalik from Haridwar to Chandigarh as seen on natural colour composite (NCC) of satellite data.

Fig. 1.1. Synoptic view of torrents emanating from Siwalik from Haridwar to Chandigarh *(Source: Google Earth)*

The land degradation caused by torrents in upper reaches and its impact on economic activities in the plains call for their precise mapping and assessment of nature and extent of hazards. The systematic data acquisition of earth's surface through remote sensing technique provide opportunities for risks assessment caused due to torrential river systems, change detection of the river flow due to torrents (using temporal remote sensing data), physiography, land use/land cover (LULC) and erosional status, and also to monitor seasonal and year to year changes in land degradation due to torrential activities as well as planform analysis of river system wherein the different river reaches like straight, braided and meander can be identified. The torrential areas experience flashfloods as the river channel receives excess water and the water passage blocked by debris leads to overbank flooding and out onto the floodplain, especially at its lower reaches. This calls for torrential areas vulnerability analysis involving the study of variations in channel properties, hydraulic geometry parameters along the torrents, LULC, locations of existing soil and water conservation structures, etc. and their behaviour with respect to lateral migration. Thus, hydrological modeling of torrential ecosystem plays an important role in assessing impact of torrents with varying magnitude of peak flood. As the water leaves the torrential system and several torrents join together to form a larger river and braiding patterns with moderate slope, the river water overflow causes floods in downstream region. This overflow causes inundation in surrounding regions resulting into loss of agricultural land, forest produce and the

Fig. 1.2. Torrent beds and surroundings with some reclamation measures in Tangri (Dangri) river catchment

profound effects on human settlements. Thus, in torrential river systems, the upper reaches experience flashfloods whereas the lower reaches have floods due to moderate slopes and shallow banks. Figure 1.2 shows the torrent beds and surroundings with some reclamation measures adopted in Tangri (Dangri) river watershed located in Ambala district, Haryana.

1.1 RESEARCH MOTIVATION

In an application project to map the areas affected by torrents in Himalaya (Haridwar to Jammu), satellite data was used to assess extent of torrential streams and areas affected by torrents (Kumar et al., 2002). As the torrents have well known characteristics of lateral migration, remotely sensed information supersedes that available on topographical maps surveyed earlier. Information thus generated through remote sensing data raised further curiosity to address the issue of torrents' vulnerability analysis while considering the hydrological and physiological aspects of torrential regime. Therefore, present study is undertaken to address the issue of vulnerability analysis in upper reaches of torrential systems and inundation in downstream of torrential systems. Table 1.1 shows the area under torrents (*Choes*) in Haryana, Himachal Pradesh (HP), Uttarakhand and Uttar Pradesh (UP) states of India.

The hydrological models and applications are available in the literature for flood risk assessment. However, limited applications are available to comprehensively assess the hydrological risk from and within a torrential regime, especially in Ganga-Yamuna catchment. In a torrential regime, the upstream and downstream region experience hydrological risks differently due to varying hydrological-soil-cover-complex. While the upstream region under relatively higher slope, heavy sediment load and singular main stream experiences flashfloods; the downstream region has moderate slope but multiple channels and dominantly agricultural land use are susceptible to floods due to overbank flooding. The river piracy and river crisscrossing are prominent, making it difficult to distinctly demarcate catchment boundaries. Thus, the hydrological risks assessment associated with torrential areas needs extensive knowledge on its channel and upstream catchment characteristics, sediment pattern, routing techniques and events based modeling. The vulnerability analysis of torrential areas needs study of variations in hydrologic-physiographic parameters along the torrent and their behaviour with respect to lateral migration.

Table 1.1: Area under torrents (*Choes*) in Haryana, Himachal Pradesh, Uttarakhand and Uttar Pradesh states

Sl. No.	State	Area (km^2)
1.	Haryana	182.55
2.	Himachal Pradesh	63.33
3.	Uttarakhand and UP	282.65

Source: Kumar et al., 2002. Mapping of Choes (Torrents) in the South of Siwalik, Unpublished report, RRSSC, Dehradun.

The knowledge and understanding of torrents and its associated ecosystem is imperative as it shall help in assessing the impact of floods caused due to discharge with varying return periods. The satellite remote sensing and ancillary database is helpful in executing hydrological model for understanding flood risk and vulnerability analysis. The scope and deliverables of present research are as follows: i) Analysing the temporal behaviour of torrential systems demonstrated through time-series remote sensing data, ii) Understanding the efficacy of hydrological model(s) that work(s) well with fluvial regime of torrential streams and that carry flashfloods and have moderate slopes in upstream region and wide and relatively shallow river beds in the downstream regions, and iii) Hydrological hazard assessment from and within torrential river systems.

Flashfloods are frequent from torrential systems in Siwalik region. The Tangri (Dangri) river, Haryana state is one such torrential river system which causes flashfloods and heavy damage to crop land and infrastructure. Such high flood events are frequently reported from Tangri (Dangri) river and it floods Ambala city and surroundings, causing inconvenience to residents as nearly 9,300 cusec water was recorded on August 20, 2017, *(http://www.tribuneindia.com/news/haryana/tangri-river-floods-ambala-colonies-residents-suffer/454815.html).* High alert was sounded after heavy rains in Morni hills (July 23, 2016) and it caused swelling of Tangri river, and as a result flood water started entering into the houses built at or near banks of the river (*http://www.uniindia.com/high-alert-sounded-in-ambala-after-heavy-rains-flooded-tangri-markanda-rivers/states/news/565405.html#MBBU4HZBWCR0cwdM.99).* Figure 1.3 shows the water logged streets and flooding in downstream reaches of Tangri (Dangri) river. During year 2010, the study area and other parts of Haryana state witnessed unprecedented floods (https://sandrp.files.wordpress.com/2018/03/an_analysis_of_the_flood_disaster_in_ghaggar_basin_in_july_2010.pdf).

Fig. 1.3. Tangri (Dangri) river overflows and floods Ambala city (Source: *https://www.youtube.com/watch?v=ikqu8FH-rMc*)

1.2 RESEARCH QUESTIONS

The following research questions are envisaged in the present study-

a. How the remote sensing data can help in analysing spatio-temporal behaviour of torrents?
b. What are the effects of various channel attributes, physiographic and LULC parameters in causing vulnerability to the surrounding regions of a torrent?
c. How the soil loss in a torrential regime varies across different LULC and landforms?

d. How the hydrological hazards varies for rainfall of varying magnitudes?

e. What are the remedial measures for the treatment of torrential watersheds?

1.3 OBJECTIVES

The research objectives envisaged in this study are as follows:

a. To understand the temporal behaviour of torrential systems demonstrated through time-series remote sensing data,

b. Multi-criteria Decision Making (MCDM) based torrents vulnerability analysis,

c. Analyzing soil loss from varied LULC and landforms of a torrential regime,

d. To understand the hazards associated with varying flood magnitude using hydrological and hydrodynamic models in a torrential river system, and

e. To carry out MCDM based assessment of alternatives for the treatment of vulnerable sections in a torrential watershed.

1.4 OUTLINE OF THESIS CHAPTERS

The present thesis contains following chapters wherein the contents of each chapter are as follows-

- **Abstract**: contains the summary of study area, objectives, methodology and the results obtained from the study.
- **Introduction**: describes the research motivation, research questions, objectives and the rationale behind the study.
- **Study Area:** describes the study area and its drainage, physiographic, geological and meteorological characteristics,

- **Review of Literature**: contains record of studies carried out in the past related to the project objectives; sub-categorised into various research components.
- **Methodology**: discusses the data used (satellite remote sensing and ancillary), methodology flow chart and illustrations on models and their components used in the study.
- **Results & Discussions**: This chapter contains illustrative discussions on results obtained from the study through data inputs and outputs to the model demonstrated through tables and graphs.
- **Conclusions**: It includes the logical conclusions drawn from the study specific to the project area and its generalisation.
- **References**: Contain the list of references cited in the report.
- **Annexures**: Contain the record of ancillary data that has been used in the study.

Chapter 2

STUDY AREA

The present study is undertaken for Tangri (Dangri) river watershed, a tributary of Ghaggar river in Panchkula and Ambala districts of Haryana. The upper reaches of the catchment (denoted as ‘A’, sub-watershed in figure 2.1), is a torrential river system with diverse landforms, located in Panchkula district, Haryana, India. Therefore, the soil loss estimation and change dynamics of torrential system were carried out for the sub-watershed. The geographical area of sub-watershed (‘A’) is 99.3 sq. km and lies between 30^{o} 35’N to 30^{o} 42’N latitude and 77^{o} 00’E to 77^{o} 05’E longitude. It falls in Survey of India (SoI) topographical map no. 53 F/2 on 1:50,000 scale. The Ratta-tibbi and Thathar ki Nadi are the major tributaries of the sub-watershed, which ultimately offloads to Ghaggar, a tributary of river Yamuna. The north and north-east part of sub-watershed are under steep and dissected slope with a maximum elevation of 1160 m and bestowed with tropical dry deciduous and sub-tropical forests. The south and central part of the sub-watershed is under gently-sloping piedmont and alluvial areas and is intersected by broad beds of seasonal rivers. The lower reaches of torrential regime (denoted as ‘B’ in figure 2.1) has a larger and braided river network system and the watershed boundary was demarcated near Shahpur village, Ambala-Shahbad road crossing to understand the varying flow patterns in ‘A’ and ‘B’ (upstream sub-watershed and whole watershed, respectively). The study area lies between 30^{o}15’ to 30^{o}44’ N latitude and 76^{o}50’ to 77^{o}08’ E longitude with a catchment area of 482 sq. km. The entire catchment has an average slope of 7.1^{0}, ranging from nearly levelled surface in southern part to a maximum of 53.5^{0} in northern most part of watershed. The elevation in watershed varies from 208 m - 1160 m. It falls in Survey of India (SoI) topographical maps no. 53 B/9,10,11,12,13,14,15,16 and 53 F/1,2,3,4 on 1: 50,000 scale.

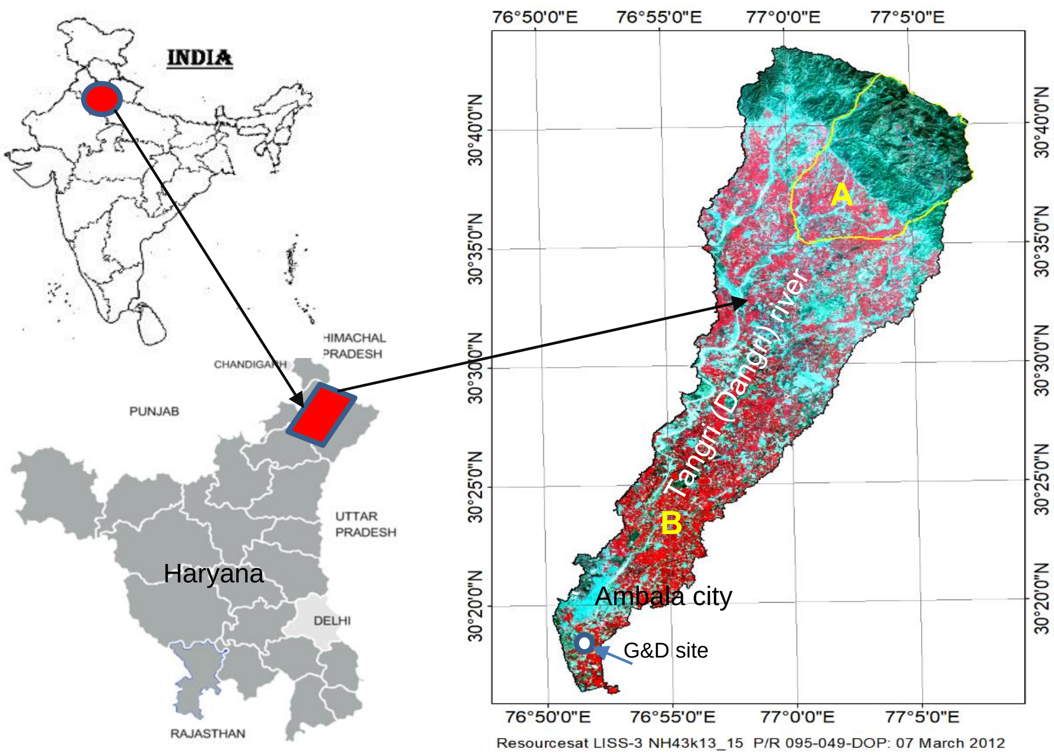


Fig. 2.1. Location map of Tangri (Dangri) river watershed

2.1 **SUB-ZONES IN TORRENTIAL AREAS**

As stated earlier, based on various physiographic and hydrological characteristics, a typical torrential system is typically divided among three zones (figure 2.2). The zone 'X' in figure 2.2 is mountainous, steep, runoff and soil loss contributory area. The zone 'Y' is the torrents' upstream zone having moderately steep to steep slope and the fluvial system carry higher sediment load and cause flashfloods in downstream zone. The soil loss is also higher due to poor hydrological-soil-cover complex. The rivers have tendency to broaden as they reach the downstream section. The lower part of the catchment (zone: 'Z') is gently sloping, extensively cultivated and have the phenomena of channel broadening and shallowing of river beds. The availability of fertile soil caused due to deposition in floodplains and surroundings tempts to encroach upon the floodplains and consequently, the narrowing of river beds and during high flood season, the probability of flood inundation increases. The sub-watershed denoted as "A" represents the zones "X" and "Y" whereas the whole watershed ('B') encompasses all the three zones of a typical torrential system.

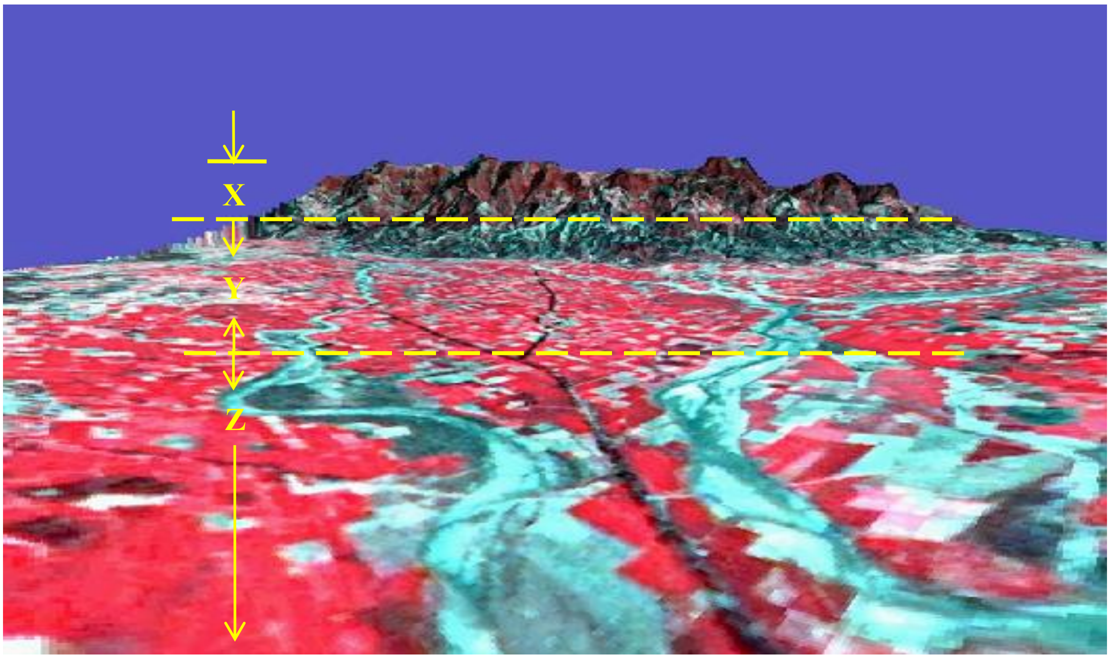


Fig. 2.2. Parts of torrential river system

2.2 PHYSIOGRAPHY

Physiographically, the Tangri (Dangri) watershed is divided into two distinct regions as northern region forming hilly terrain of outer and lesser Himalaya and the southern region consisting of gently sloping piedmont which merges into alluvial plain. The presence of steep scarps, sharp ridges, deep valley, landslides, and precarious slopes indicate active erosion processes in the hilly region. The region is broadly categorised into three physiographic units, namely hill/ mountain, piedmont and alluvial plains. The description of various physiographic units surrounding the watershed are as follows-

a. **Outer Himalayan hill tract:** This narrow tract (in the watershed) stretches along northern boundary of Tangri (Dangri) river watershed in north towards Nanakpur Nadi in south-west. The northern boundary of the study area in this section mostly follows the ridge crests, and the tract generally comprises of southern slopes of outermost Himalayan ridges.

b. **Siwalik hill tract:** It is essentially subdivided into three sections viz., the Chandigarh Siwalik tract, Morni tract and Kalesar tract. The study area mostly falls in Morni tract. The Morni slope tract is dissected by various streams forming deep narrow valleys. The level of dissection is considerably less when contrasted with the Chandigarh Siwalik tract. It is the result of thick vegetation cover and the comparatively consolidated nature of bed rocks. The slopes are moderately steep to steep. There are steep escarpments caused due to landslides and faults. In the south of Morni hills, there is plateau with two water bodies.

c. **Piedmont zone:** This is a transitional unit between the Siwalik hills and plains. It is traversed by number of seasonal streams, which are tributaries of Tangri (Dangri) river. It is undulating and contains large stretches of silt, sand and pebbles on the bed of these streams, which run down the slopes of highly dissected hills of Siwalik.

d. **Alluvial plain:** The alluvial plain forms the lower most part of the region. It stretches alongside the banks of river Tangri (Dangri) comprising mostly of deposited material like sand, silt and clay. It is fertile land and mostly used for cultivation.

e. **Other fluvial landforms:** The other fluvial landforms such as floodplains, sand bars, terraces, etc. are also present in the watershed. The Tangri (Dangri) river and its tributaries have built narrow terraces along their courses. These narrow flat surfaces are mostly cultivated. The rivers in hilly tract have narrow floodplains which meander at places. After entering the piedmont zone, the floodplains become wider and consists of rounded and sub-rounded boulders, pebbles, rock fragments, sands and gravels. The landforms observed are sand bars, braided channels, and channel bars.

2.3 DRAINAGE

The study area is mainly drained by ephemeral streams. Tangri (Dangri) is a major river of the area flowing towards south from north. The watershed has a drainage pattern that varies from dendritic to sub-dendritic and at some places sub-parallel too. The Tangri (Dangri) river ascends in the Morni hills and drains in south direction up to Chhajju Majra village where it is joined by the Baliali nadi. It takes after a south-westerly course running on the east direction of Ambala cantonment. In the wake of intersection with Ambala cantonment and Ambala-Jagadhri railroad line, it again takes south-westerly course heading close to Seta and Segti towns, where the Omla and Amri torrents (in the vicinity known as Shahazadpurwali or Gadri) join the Tangri (Dangri) river. It is here that the Narwana branch of Bhakra main canal crosses the Tangri (Dangri) stream. From that point, the Tangri (Dangri) takes a westerly course up to Niharsi town where it turns south and leaves the region to enter the Patiala region of Punjab. The Baliali nadi ascends in the southern slopes of Morni slopes and joins the Tangri (Dangri) stream near Chajju Majra town. The Amri (otherwise called

Shahazadpurwali or Gadri) is formed of water gathered in fields amid the monsoon season. It begins close to Raataur, drains south-west and takes the torrents emanating from Omla and joins the Tangri (Dangri) between the Segta and Segti settlements. While in its upper course, the waterway contains some water consistently, in its lower course it mostly remains dry in summer and conveys water just amid the monsoon season.

2.4 NATURAL VEGETATION

The region offers a favourable living space for the growth of rich and abundant vegetation because of good availability of rainfall and other bio-physical characteristics. Above 650 m elevation in the watershed, sub-tropical forests species viz., Chir (*Pinus roxburgii*), *Chhal/ Dhaura/ Dhauri/ Dhau/ Bakli/* Axle-wood tree (*Anogeissus/ Conocarpus latifolia*), *Khair* (*Acacia catechu*), Teak/ *Sagwan* (*Tectona grandis*), etc. are found. The tropical type of vegetation such as *Sisham* (*Dalbergia sissoo*), *Kikar* (*Acacia karroo*), Eucalyptus (*E. camaldulensis Dehnh.*), etc. are mainly found in foothills and plains.

2.5 SOCIO-ECONOMIC CHARACTERISTICS

Agriculture is the prime pursuit for the watershed inhabitants. The farmers of upstream region grow crops on terraces and on lower hill slopes, and have low income. Being the hilly tract, there are small villages which are not connected by roads. The watershed inhabitants go on-foot, or the mules are being used for transportation in uphill regions. In general, the health and education facilities in the upstream region is poor. Raipur Rani and Morni towns are the nearest places for marketing for the residents in upstream region of the catchment. The farmers in downstream region have in-general larger income due to fertile agricultural tracts and they grow crops twice in a year. The major *kharif* crops (autumn crops sown at the beginning of summer rains in South Asia) are sugarcane, paddy and maize while the minor ones or auxiliary crops are chilies, cotton, *bajra* (pearl millet), *jowar* (Sorghum), pulses (*arhar*, *moong* and *moth*), *til* (Sesame) and vegetables. The major *rabi* crops (crops harvested in spring season in South Asia) are wheat, gram and oilseeds (*sarson* and *toria*) while the minor ones are *masoor* (Red Lentils), berseem, *methi* (fenugreek), potato, onion and other winter vegetables. Sugarcane, cotton, chilies, potato, onion, vegetables and oilseeds are the major cash crops sown in the watershed.

2.6 GEOLOGY

Geologically, the study area consists of lithologies of Tertiary and Quaternary periods. Tertiaries are classified into two groups: (i) Subathus belonging to lower Tertiary (Eocene) and forming the high ridges in northern part of the watershed and (ii) Siwalik which form the low relief foothills and belonging to the upper Tertiary (Miocene-Pleistocene). Both of these formations trend NW-SE. Quaternary formation consists of the alluvium and colluvium occurring along the foothills and extending further down merging with the Indo-Gangetic alluvium. The stratigraphic-succession of geological units in the watershed and its surroundings are shown in Table 2.1.

a. **Subathus:** These are the oldest tertiary sequence exposed in Himalaya. Within study area, they are made up of olive green and purple shales with intercalated sandstone beds and limestone. The shales are thick bedded and splintery in nature while the sandstones are purple to grey coloured, medium to fine grained, hard, compact and quarzitic. Limestone are bluish to dark grey, hard and compact. Subathus form the NW-SE trending Morni ridge which form the north-eastern boundary of the watershed.

Table 2.1. General stratigraphic succession of geological units in watershed and surroundings

System	Geological Age	Unit	Lithology
Quaternary	Recent-Holocene	Alluvium	Pebbles, Sand, Silt, Clay, etc.
	Siwalik L. Pleistocene	Upper Siwalik	Boulder Conglomerate with thin clay bands and conglomerate with sandstone
Tertiary	Pliocene	Middle Siwalik	Soft sandstone with pebble and massive sandstone with clays
	Mid-Miocene to Upper Miocene	Lower Siwalik	Massive, buff coloured sandstone with red clays, sandstone, ash grey with silt-stone and red clays & sand stone
	Subathus Eocene		Olive green shale with thin sandstone & 1st bands

(Source: Gupta and Kanwar, 1969. *https://www.indiawaterportal.org/sites/indiawaterportal.org/files/report_haryana_state_geology_and_mineral_maps_geological_survey_of_india_0.pdf*)

b. **Siwalik:** This formation consists of fresh water sediments belonging to the upper Tertiary period. They are further categorised as Lower, Middle and Upper Siwalik.

- **Lower Siwalik** occur as a thrusted strip in between the Main Boundary Thrust (MBT) which separate it from the Subathus in north and Jansu thrust in south. The lithology comprises of alternate beds of sandstone and clay. The lower most unit is predominantly composed of purple to reddish coloured thick beds of clay with subordinate, medium to fine grained light yellowish sandstone. The middle unit consists of medium to fine grained, compact, ash-grey sandstone with thin clay bands, while the upper most unit is made up of coarse grained micaceous sandstone with few bands of clay.
- **Middle Siwalik** forms the highly dissected outermost foothill zone adjacent to the alluvial plain. The contact between the two is marked by a thrust, 'the foothill thrust'. The lithology consists dominantly of medium to coarse grained soft, friable brown to grey coloured sandstones interbedded with grey to purple red clay beds. They are highly susceptible to erosion resulting in deeply dissected terrain.
- **Upper Siwalik** overlies the Middle Siwalik and the contact between them is gradational. The northern farthest reach of upper Siwalik is set apart by the Jansu thrust which has brought lower Siwalik over upper Siwalik. Upper Siwalik comprises prevalently of conglomerate with sandstone and clay beds. The conglomerate is made-up of gravels, rounded pebbles and stones of sandstone, quartzite and clay stones. The sandstone is delicate, ineffectively stuffed, and dim to dark coloured and fine to medium grained while the clay is reddish, delicate and plastic.

c. **Quaternary alluvium:** The Siwalik formations are followed by the quaternary sediments of Holocene to recent. The alluvium is divided into older alluvium and younger alluvium. Older alluvium is composed of older form deposits consisting of coarse pebbles and cobbles with bands of silt and clay deposited along the foot of Siwalik forming piedmont zone, whereas the younger alluvium consisting of sand, silt and clay is confined to the floodplains of rivers which cut through the older alluvium.

2.6.1 Structure and Tectonics

The Tertiary sediments, the Subathus and Siwalik have a regional trend of NW-SE with gentle to moderate dips to either side indicating folded structure. These formations are separated by major thrusts. The MBT separates the Subathus and Lower Siwalik, while the Jansu thrust brings the lower Siwalik in juxtaposition with the upper Siwalik. The foothill thrust separates the Middle Siwalik from the alluvium. The Subathus show moderate to high angle dips due to SW and NE indicating repetitive folding. The Lower Siwalik formations which is bounded by the MBT and Jansu thrust in the NE and SW, respectively exhibit gentle to moderate dips to NE, while the middle and upper Siwalik between Jansu thrust and foothill thrust are folded into a number of anticlines and synclines as indicated by their varying dip directions. Apart from the major thrusts, there are a few faults and lineaments traced in the area. The well-developed joints are developed in the compact sandstones of Subathus and Lower Siwalik. Main joint directions are NE-SW, ENE-WSW, and NW-SE.

2.6.2 Mineral Potential

The area is not known to have any notable mineral potential. However, the Tangri (Dangri) river bed is reported to contain sonic placer-gold, which the local people used to extract by panning the river sand during ancient times. Subathus formation contains the bands of good quality limestone. Apart from this, the massive sandstones of Subathus and gravels and sands in the river beds are used for building purposes.

2.6.3 Hydrogeomorphology

The ground water characteristics of a region is governed by relief, landform, lithology, structure, state of weathering, etc. Various zones of runoff, groundwater recharge, groundwater storage and discharge are observed in the watershed on the basis of these parameters.

a. **Runoff zones:** The structural hills of Subathus and Siwalik form the main runoff zone in the Tangri (Dangri) watershed. Though, the lithology in these geomorphic units (such as sandstone and limestone in Subathus, and sandstone and conglomerates in Siwalik) have primary porosity, the predominance of shales and clays render them less permeable. The high relief and steep slopes together with the less permeable lithology results in loss of a major portion of the rainfall as surface runoff. Since, these formations are highly faulted, jointed and folded, some water infiltrates through these weaker planes and comes out as springs along slopes.
b. **Recharge or infiltration zones**: The major recharge zones in the Tangri (Dangri) watershed include the piedmont zones, alluvial plain, floodplain, river terraces, and

river beds. The piedmont zones bordering the Siwalik foothills consisting of unconsolidated materials such as coarse elastics, reworked pebbles, boulders, sands, gravels, silt, clays etc. form the most important infiltration zone in the area. A major part of this percolated water moves southwest or southwards as sub-surface flow because of the pressure driven flow of the order of 8 m/ km. The ground water mostly is normally exploited through open wells or tube wells in this region. Open wells give limited discharge for domestic purpose and are of 5 m to 15 m in depth. The water occurs in submerged table conditions and water level extends from 2 m - 10 m. The tube wells are drilled up to 200 m and they tap deeper aquifers which occur under confined or semiconfined conditions. The water level in the tube wells ranges from 25 m - 40 m with discharge varying from 50 lpm to 1700 lpm (*http://cgwb.gov.in/District_Profile/Haryana/Panchkula.pdf*). The river beds, floodplains, alluvial plain, and terraces also form good recharge zones. They consist mostly of sand, silt and having high infiltration characteristics. The ground water mostly occurs in unconfined to semi-confined conditions within study area. The water level is shallow in river beds and floodplains, but deeper in terraces and alluvial plains.

c. **Groundwater zone:** The ground-water investigation zone occurs under confined and semi-confined conditions. The water level changes essentially across north and south region of watershed. It goes between 2 m and 47 m, most extreme being towards higher slopes. The water level in the zone towards south ranges between 1.5 m and 12 m. The shallow wells are typically built down to a depth of 10 m to 45 m. At a few spots, as in Nagla-Mullana belt, the tube wells have been bored to a depth of 90 m. The shallow tube wells generally tap groundwater from single aquifer. The depth of deep tube wells by and large ranges between 91 m and 185 m, yet at places, the tube wells down to 445 m have been built (*http://cgwb.gov.in/AQM/NAQUIM_REPORT/Haryan_NCR/Ambala.pdf*). The quality of groundwater majorly is fresh and good for human consumption and other purposes.

2.7 WEATHER AND CLIMATE

The study area experiences hot summer (beginning from April till June), cool winter, and has high variation in precipitation and diurnal temperature exhibiting sub-tropical continental monsoon climate. The relative humidity is relatively higher at about 70 per cent during monsoon, otherwise atmosphere is generally dry during other time of the year. The temperature varies rapidly from March as the May and June are hottest months with about 41^{o}C as mean-daily maximum-temperature and from 14^{o}C to 25^{o}C as the mean-daily minimum temperature. The discomfort is also caused by scorching dust-laden winds which are fairly common feature in later part of the summer season. When the monsoon propels during second fortnight of June, it leads to decrement in day time temperature but the night-times stay warm. It later leads to oppressive weather due to higher humidity level in air. By the mid-September when the monsoon withdraws, the day-time temperature slightly increases but the nights turn gradually cooler. January is by and large, the coldest-month when maximum daily average temperature is nearly 21^{o}C and the minimum daily average temperature is at 7 ^{o}C. Amid winter season, the cold-waves sweep the region caused by western-disturbances and the minimum temperature declines considerably. During such events, frosts are an imaginable phenomenon in the region. The relative humidity is high, about 70 percent amid the monsoon. The late spring season is driest part of the year during which the day hours have least relative humidity to about 25 percent. The driest and wettest months of the year have a difference of about 250 mm of precipitation. Table 2.2 and figure 2.3 show the rainfall and temperature characteristics of the Ambala district.

Table: 2.2. Meteorological characteristics of Ambala district

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Average Temp. (°C)	13.70	16.20	21.70	27.70	32.70	33.80	30.50	29.40	29.30	24.70	19.30	15.20
Minimum Temp. (°C)	6.80	8.60	14.00	19.50	24.80	27.20	26.00	25.30	23.80	16.70	10.30	7.20
Maximum Temp. (°C)	20.70	23.80	29.50	36.00	40.60	40.40	35.00	33.60	34.90	32.80	28.40	23.20
Rainfall (mm)	44.0	31.0	29.0	6.0	16.0	57.0	258.0	248.0	178.0	31.0	8.0	13.0

Source: https://en.climate-data.org/location/19415/

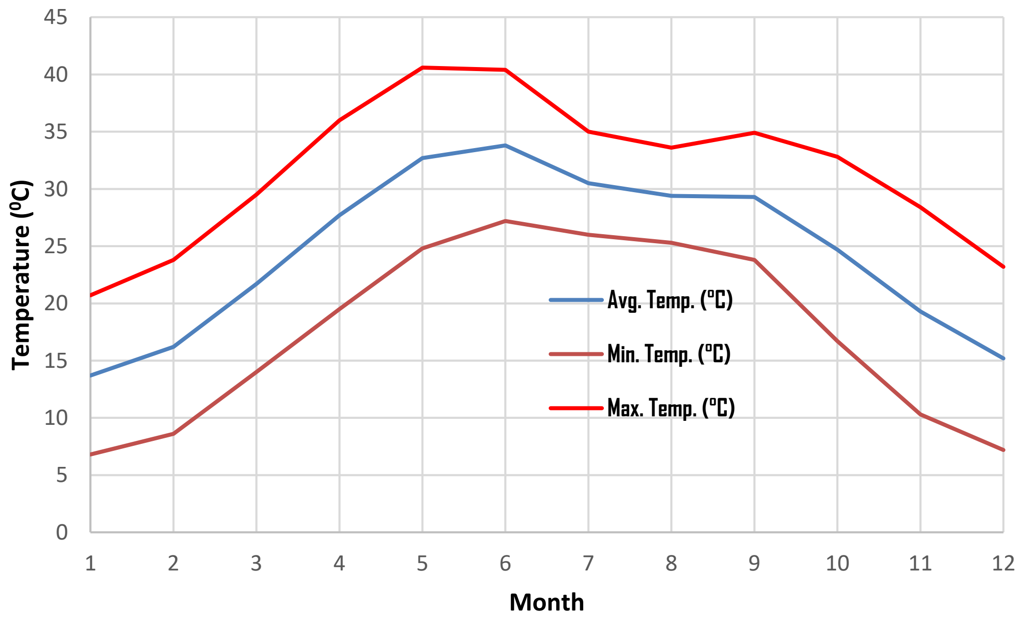


Fig. 2.3. Annual temperature characteristics in study area (° C)

Chapter 3

REVIEW OF LITERATURE

The present study on '**Hydrological Risk Assessment from and within a Torrential Watershed'** has been undertaken for Tangri (Dangri) river, which is primarily a torrential river system. The literature on hydrological risks associated with torrential river systems have been cited in the present chapter in following sections- i) Torrents' genesis and effects on ecosystem, ii) Understanding fluvial regime of torrential streams, iii) Spatial modeling to understand torrential regime, iv) Understanding hydrology of ungauged catchments, v) Geographical Information System (GIS) based hydrological modeling, vi) Torrents' vulnerability analysis, vii) Methods for treating torrential watersheds, viii) Watershed monitoring and evaluation ix) Understanding uncertainty in flood risk modeling, and x) Summary & research gaps.

3.1 TORRENTS' GENESIS AND EFFECTS ON ECOSYSTEM

The torrential rivers exhibit extreme discharge fluctuation and bed load movement especially in upper reaches of the river. Kaul and Dohru (1995) stated that anthropogenic events especially on the southern slopes of Siwalik have highest influence on biophysical assets of a torrential ecosystem. World Meteorological Organisation (WMO, 2012) provided a comparison between riverine and flashfloods, and illustrated mitigation actions that can be adopted to minimise the potential impacts of flashfloods. It was reported that flashfloods occur more often in mountainous terrain or foothills as compared to riverine floods owing to the limited capacity of hydrologic-soil-cover complex to accumulate water. They expressed that in contrast to riverine floods, flashfloods regularly happen in hilly tracts or in the foothills because of steep slopes and sometimes, thin surface soil layers. Additionally, they reported that in hilly landscape, there are very constrained spaces for maintenance supplies or building levees. Gao et al. (2006) attempted a study to analyse the effects of torrents on surrounding ecosystem. It was concluded that in a torrential system, if they were facing a) floods alone, then the losses were minimal but occurrences were of high frequency; b) debris then, disaster caused is of low frequency and high losses; c) floods and debris, then losses were higher than the debris flow; and (iv) flood, debris flow and landslips, then the disasters caused by the torrents were of lowermost periodicity, highest order and the losses were highest among all. While examining the relationship between recurrence and the losses, Gao et al. (2006) observed that lower the recurrence, higher the losses that may happen. The effects of various anthropogenic activities as well as mechanical-cum-vegetative measures for soil and water conservation under Integrated Watershed Management Programme (IWMP) in Siwalik area was evaluated by Samra and Agnihotri (1995). They stated that the IWMP project helped to gain new insights and the concepts of developing farms and forest areas with people's participation. WMO (2009) stated that both structural and non-structural measures were advisable to lessen the effects of flashfloods and it is difficult to contain them with traditional approaches.

3.2 UNDERSTANDING FLUVIAL REGIME OF TORRENTIAL STREAMS

Mazari (1995) stated that the torrents' fluvial system depends on variations in river discharge, tectonic uplift and denudational characteristics. Vandine (1985) observed that the sediment budget estimation has high importance especially in mountainous terrain. The debris flow hazard is governed by geomorphologic characteristics and dictated by indicators such as slope instability, channel scouring and rate of sediment deposition in alluvial fans. Mudd (2006) carried out runoff and infiltration analysis during flashfloods in ephemeral channels based on numerical experiments. He found a strong relationship between momentum losses due to transmission during flashfloods to channel friction through the scaling of governing flow equations which significantly affect the flow velocity. Berti and Simoni (2007) developed the DflowZ module as an implementation of empirically based approach for debris flow prediction. From a user perspective, the DflowZ module within AdB toolbox was seen as a 'standalone-module' which can be utilised for a first-cut assessment of potentially affected areas. Rickenmann et al. (2006) developed SETRAC as a sediment routing model for high gradient torrent channels. SETRAC is based on utilisation of correction processes to compute roughness losses. Through this model, rational agreement was obtained between simulated and observed sediment loads. Braud et al. (2010) demonstrated the distributed hydrological models i.e., French Cevennes (CVN) built within LIQUID hydrological platform and MARINE for flash flood modelling and concluded that rainfall is important controlling factor for flash flood dynamics. They observed that there is a direct relationship between peak flow and high rainfall events. It was also observed that the roughness of river beds and soil characteristics have high influence on stream flow and hydrograph. The simulation of soil saturation was observed to be intensely interrelated with soil depth and initial storage deficit. Tsanakas et al. (2016) carried out flood-discharge analysis while utilising the GIS coupled hydrological model for a torrential watershed based on its geomorphological and drainage characteristics. They observed that anthropogenic activities were the most influential factors responsible for flashfloods. Petrović, et al. (2014) carried out the inventory and analysis of torrential floods in Serbia to understand their spatio-temporal distribution and for their further characterisation.

Hydrodynamic models are by and large classified as one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D) models and depict the progression of liquids, particularly incompressible liquids in movement. They reproduced the water movements in the light of physical laws and frequently combined with water quality models. As per general guidelines, one-dimensional can be used if the length-to-width proportion is higher than 3:1. The two-dimensional models are especially useful for narrow bridge crossing with significant expansion/ contraction around hydraulic structure. However, if only the water surface profile illustration is desirable in such case then both 1D and 2D models can be used (Néelz and Pender, 2009).

3.3 SPATIAL MODELING TO UNDERSTAND TORRENTIAL REGIME

Tang and Zhu (2005) carried out risk zonation in upstream region of torrents in red river basin using a GIS. Population census and Gross Domestic Product (GDP) were used for torrent hazards and vulnerability mapping. Various channel and morphological characteristics and hydro-meteorological inputs were analysed to produce the torrent risk map. Guan and Cheng (2007) carried out regional torrent risk zonation in Jiangxi Province in China. Population densities, GDP and area under agriculture were utilised as indicators to analyse the susceptibility to erosion. Renyi and Nan (2002) carried out flood risk zone mapping and damage estimation in Zhejiang, China. The flood damage estimation was done by overlaying the affected areas onto socio-economic layers. Vinet (2008) carried out damage area analysis due to flashfloods in southern France. It was observed that rural areas experienced substantial losses caused by prevailing poor socio-economic status. It was concluded that land use planning should be carried out and flood warning systems should be developed for watersheds encompassing rural settlements, especially for those which were located in proximity to vulnerable river sections. Williams and Archer (2002) utilised past flood data for English Midlands to improve risk assessment. Tang and Shi (2006) carried out torrent vulnerability analysis via geomorphologic and the numerical simulation method in a GIS domain. The hazard prone regions were identified for better land use planning and decision making. It was also suggested that public awareness is desirable to identify risk prone areas coinciding with urban settlements. Phillips (2002) assessed the geomorphic influences of flashfloods in a forested catchment based on the relationships between stream features and frequency of river discharge. Sunkar and Tonbul (2011) used GIS and digital maps to carry out morphometric and hydrographic analyses for Iluh River, Batman in relation to flashfloods and torrential activities. It was concluded that the rivers within city have migrated and owing to various hydrographic characteristics, the city experiences floods and other torrential events of high magnitude and frequency. Munir and Iqbal (2016) studied the flashflood mitigation measures in Wador hill torrent, Dera Ghazi Khan, Pakistan. They have utilised the Storm Water Management Model (SWMM) for designing of water conveyance system in downstream region and potential sites for water retention in upstream region. It was assessed that 27 million m^3 of water can be stored through such measures.

Hydrologic Engineering Centre (HEC)-Hydrologic Modeling System (HEC-HMS) is an open source software package of United States Army Corps of Engineers (USACE). HEC is an organisation under Institute for Water Resources, USACE, which has developed expertise in water resources systems studies. HEC has a set of software packages to analyse surface and sub-surface hydrological characteristics, river hydraulics, sediment transport, reservoir planning, etc. The hydrological components of a watershed are assumed to be associated in a dendritic system to re-enact overflow processes. HEC-HMS uses various hydrological models for analysing different mechanisms of runoff processes based infiltration and unit hydrograph theory and flood routing techniques (USACE-HEC, 2006). The Natural Resources Conservation Service (NRCS) Curve Number (CN) method [earlier known as the Soil Conservation Service (SCS), United States Department of Agriculture (USDA) [USDA, 1986)] is utilised to assess the infiltration capacity and runoff characteristics built on hydrologic-soil-cover-complex characteristics. Yasin et al. (2015) carried out HEC- Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) based rainfall-runoff modeling in Mithawan watershed, Punjab province, Pakistan. They studied the damage assessment based on peak flow for varying return periods.

3.4 UNDERSTANDING HYDROLOGY OF UNGAUGED CATCHMENTS

Norbiato et al. (2008) demonstrated flashflood warning system in view of rainfall characteristics and Antecedent Moisture Conditions (AMC) in ungauged as well as gauged catchments. A semi-distributed conceptual hydrological model was used to compute the probability based distributed moisture condition and later the runoff depth was estimated. A good comparison was obtained between real-time measured and predicted rainfall of same duration. Norbiato et al. (2009) used flashflood guidance method with model driven runoff threshold to improve flashflood forecasts accuracy at ungauged locations. A lumped hydrological modeling was attempted to understand the flood incidences at the outlet of ungauged basin. They have achieved nearly 12% and 31% correspondence between observed and estimated discharge for gauged and ungauged basins, respectively.

Javelle et al. (2010) recommended a technique for the assessment of AMC to increase accuracy of flashflood predictions at ungauged catchments. The indices, namely climatic temporal index and a spatial statistical index were estimated based on soil moisture accounting scheme. It was observed that improved warnings were forecasted by the distributed model based on different discharge thresholds (2, 10 and 50 years return periods). Ballesteros et al. (2011) estimated peak discharge of a flashflood event in an ungauged mountainous catchment based on dendrogeomorphic palaeostage indicators using 2D hydraulic model and height measurements done from a Terrestrial Laser Scanner (TLS). Moretti and Montanari (2008) carried out continuous and distributed hydrological modelling to deduce flood frequency distribution of Riarbero Torrent. Using the principles of hydrological similarity, the peak river flow estimates were verified and the analysis highlighted the applications of spatially distributed models to ungauged catchments. Foody et al. (2004) predicted the sites sensitive to flashfloods in an arid region. The land cover and soil properties were ingested into a hydrological model to predict areas at risk due to high peak flows for some rivers in Egypt. The model was proven to be useful in a data scarce region. Gaume et al. (2010) found that the Markov Chain Monte Carlo (MCMC) algorithm for regional flood frequency analyses for peak flows at ungauged catchments is uniform within an identical region. The study followed the standard regionalisation methods with an assumption that peak flows were rescalable by a site-specific index flood. Moretti and Montanari (2004) stated that distributed hydrological models can be helpful to mimic the peak flow event from a watershed. The continuous and distributed hydrological model was utilised for Riarbero Torrent to assess peak flow for a given likelihood of exceedance. The 100-year hourly event at Secchia site was simulated and compared with observed frequency distribution. The goodness of fit delivered by the model was encouraging to simulate the flood frequency distribution for an ungauged watershed. Koutroulis and Tsanis (2010) proposed an empirical equation based method for assessing peak river flow from an ungauged watershed. The hydrologic and hydraulic models were used for watershed delineation, flood simulation and inundation modeling. Omran (2020) carried out the hazard mapping and risk assessments due to torrents in Aswan Governorate, Egypt and reported that lower elevation is at greater risk than the highest. Mazer et al. (2020) used hydrologic and hydraulic models to assess flash flood hazards caused by Torrenteras, the ephemeral streams in Arequipa city, Peru.

3.5 GIS BASED HYDROLOGICAL MODELING

Hydrological models are generally classified as i) lumped models, where catchment is taken care of as a homogeneous unit and model parameters are applied to the entire zone, and ii) distributed models which depend on spatial characteristics of various network parameters e.g., LULC, soil, elevation, etc. The hydrological modeling using GIS based methodology has been conducted to evaluate the impact of flood water in surrounding landscape. Liou (2007) presented the advanced automated and GIS-based modeling techniques and methods to integrate the flood forecasting methods and emergency response for an urban area. Skotner et al. (2010) presented GIS based flood forecasting system for Songhua river catchment, China utilising 1D and 2D hydrological and hydraulic forecast models. The forecast results were overlaid with spatial data to recognise and publish evacuation routes, hydraulic structure operation rules and others. Huijun et al. (2010) demonstrated a flood model based on GIS and the relevant mesh generation and model parameters derivation algorithm for the lower Huanghe River using topography, land use, and water conservation engineering data. Snell and Gregory (2002) carried out a distributed hydrological modelling to estimate river discharge from a high-intensity short-duration rainfall-events. The modified kinematic-wave method was used to compute overland flow and travel time from watershed to the basin outlet. Grillakis et al. (2010) simulated conceptual and distributed hydrological model *Hydrologiska Byr°ans Vattenbalansavdelning* (HBV) for analysing flashfloods. A satisfactory Nash-Sutcliffe coefficient of 0.82 was obtained after calibrating model based on past rainfall-runoff events. Deckers (2009) carried out GIS based flood risk modelling (LATIS) using LULC and socio-economic data. LATIS produced promising results to estimate the loss of life and property during flood simulation modelling.

The River Analysis System (RAS) is a popular software package useful for assessing hydraulic characteristics of a river system for flood modeling and floodplain regulation developed by the USACE’s Hydrologic Engineering Centre (HEC-RAS). The HEC-RAS software has evolved from HEC-2 version with the advancements in computational capabilities as windows based version, useful for hydraulic modelling with user friendly GUI. Fig. 3.1 shows the schematic diagram for HEC-RAS modeling. The initial versions of HEC-RAS had only the capability to perform 1D water surface profile estimations for steady and gradually varied flow in natural or artificial channels. The recent versions have facilities to analyse storage area, hydraulic networks, boundary conditions, velocity estimation and RAS Mapper editing tools which is based on finite volume approach and can improve model stability. The cells can begin totally dry, improved from earlier finite element technique and takes into account the larger time stages than previously available. The framework involves a GUI, data storage and administration abilities, analysis segments, and illustrations facilities. The 2D capabilities has shapeless network flexibility and the cells do not necessarily have levelled bottom. It allows larger computational cells without loss of terrain details and the cells can be sized according to terrain features. The energy losses due to friction is computed using the Manning's equation and shrinkage/ enlargement is resolved through a product of coefficient and changes in velocity head. The momentum equation is beneficial in mixed flow regime e.g., hydraulic-jumps, river hydraulics at bridge locations, and at stream junctions.

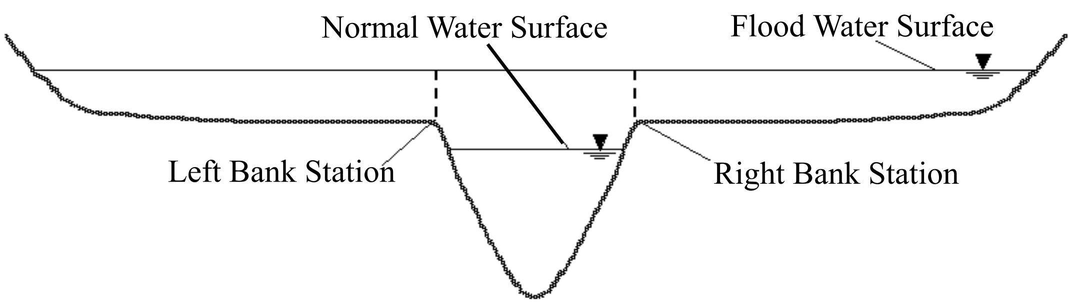


Fig. 3.1. Schematic diagram for HEC-RAS modeling

Solaimani (2009) attempted the flood hazard modelling from Hydrologic Engineering Centre's River Analysis System (HEC-RAS)/ Hydrologic Engineering Centre's Geographic River Analysis system (HEC-GeoRAS) tools with promising results obtained for effective floodplain management. HEC-GeoRAS and HEC-RAS are widely utilised for flood inundation mapping and hydrodynamic modeling or river systems analysis (Alaghmand et al., 2012). Smemoe (2004) carried out spatial data driven study to minimise the losses caused by floods. Monte Carlo-style stochastic simulation was done by means of HEC-RAS and Digital Terrain Model (DTM) for evaluating probability of annual exceedance for varying intensity of rainfall for inundation area modeling. A series of curves were used to identify the hazard-prone areas. Pistocchi et al. (2002) used the HEC-HMS and HEC-RAS models coupled with ArcView GIS software for hydrological risk assessment.

Simonovic (1993) developed a decision support system for urban flood control system. Semmens et al. (2008) used Automated Geospatial Watershed Assessment (AGWA) and Kinematic Runoff and Erosion Model (KINEROS2) models to evaluate the impacts of urbanisation and conservation activities (near reservoirs and river channels) on flood hydrographs and sediment yield. Martı´n-Vide et al. (1999) studied runoff and sediment transport for a torrential stream in Mediterranean coast. It was observed that HEC-1 based rainfall-runoff modeling produced satisfactory results with respect to field measurements. The modeling exercise conducted has taken into account the high transmission losses whilst the volume of bed load was four times greater as compared to estimates using the Meyer-Peter and Mu¨ller equations. Sangati and Borga (2009) analysed the effects of rainfall data in terms of spatial distribution and grid size on flashfloods. Distributed hydrologic models were used along with Radio Detection and Ranging (RADAR) based rainfall measurements for flashflood simulations.

Cook and Merwade (2009) carried out flood inundation mapping to assess the impact of topography, channel geometry and modeling approaches. The study was carried out for Strouds Creek in North Carolina and Brazos River in Texas, which showed that for similar hydro-meteorological characteristics, the inundation area got reduced with fine horizontal resolution and improved vertical accuracy of topographic data. It was observed that the deviations in flood inundation maps were smaller as produced by varying the factors in FESWMS, as compared to HEC-RAS based modeling.

Yang et al. (2006) applied the GIS techniques and HEC-RAS model for river network floodplain delineation for parts of South Nation River system, situated in eastern side of Ottawa, Ontario. The river floodplain was plotted in 2D and 3D by combining the hydraulic model with GIS. Sinnakaudan et al. (2003) carried out flood risk mapping while including sediment transport and HEC-6 hydraulic model. Shipeng (1996) evaluated the effects of simulation parameters such as fluvial and soil properties for determining intensity of disasters in mountainous torrents. Merwade et al. (2008) carried out GIS based hydrologic and hydrodynamic modeling for flood inundation analysis. They demonstrated the advantages of 2D and 3D hydrodynamic models instead of 1D hydraulic models. An improved topographic mapping based on 3D mesh for main channel system was integrated in hydrodynamic modeling. Knebl et al. (2005) carried out regional scale flood modeling while utilising the Next-Generation Radar (NEXRAD) rainfall data, HEC-HMS and HEC-RAS tools in GIS environment for San

Antonio River catchment. HEC-HMS was utilised to assess the magnitude of rainfall excess that is likely to cause overland flow and channel runoff. The hydraulic modeling was done for unsteady state flow analysis through river channel network arranged in view of the HEC-HMS-determined hydrographs.

Markwood (2008) carried out floodplain delineation and modeling using HEC-GeoRAS and HEC-RAS hydrological models. The geographic representations of floodplain depths, velocities, and extents provided good insights into model response and the behaviour of natural system. Tomassetti et al. (2005) carried out distributed hydrological model coupled with National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) meteorological model for flood hazard analysis. It was demonstrated that such coupling produced encouraging results for flood early warning system analysis. Ackerman et al. (2009) demonstrated HEC-RAS capability for floodplain delineation, water surface profile generation and inundation modeling. These capabilities provided an efficient environment for hydraulic modeling. National Oceanic, Atmospheric Administration (NOAA) (1997) of United States (US) demonstrated the automated flood warning system developed from a flood forecast table and useful to generate flash floods alarm system.

Badoux et al. (2005) proposed a hydrological model (PREVAH) that used a set of calibrated model parameters yielding stable results with linear efficiency of 0.80 and 0.73 for daily and hourly hydrograph, respectively. Wardah et al. (2008) established a rainfall assessment algorithm based on infrared data from Geostationary Meteorological Satellite-5 (GMS-5) for flood early warning system development. Using the back-propagation neural network, the radar based rainfall rate estimation was conducted. The technique adopted helped in establishment of Artificial Neural Network (ANN) based technique and satellite-based rainfall estimation with a gain of two-hour for flash-flood forecasting. Schmitz and Cullman (2008) proposed process modeling and artificial intelligence based online flood forecast concept while combining physically based hydrologic and hydraulic model. This concept and the methodology proposed helped in simulating flashflood events based on meteorological data analysis. Sahoo et al. (2006) used MIKE-SHE to forecast variations in river discharge from a hilly Hawaii stream. The resultant outputs were calibrated and validated with observed measurements. Rozalis et al. (2010) carried out flash-flood modeling and simulations by utilising a non-calibrated hydrologic model and radar technique based rainfall data for a Mediterranean catchment. USDA SCS-CN technique was utilised for hydrological modeling with kinematic wave based method for flow routing. It was reported that model well predicted the flashfloods produced from strong and short-duration convective storm event whereas the prediction was weak for low and moderate flows. Reed et al. (2007) utilised a distributed hydrological model blended with threshold frequencies for accuracy improvement of flashflood forecasts at ungauged catchments. It was observed that both non-calibrated and calibrated distributed models yielded improved results as compared to lumped hydrological modeling for flashfloods.

Hsu et al. (2003) carried out flashflood forecasting by utilising the dynamic wave hypothesis for unsteady flow in Tanshui river, Taiwan with flood routing and real-time stage correction strategy. A four-point finite difference method was utilised for flashflood prediction. Hong et al. (2009) carried out assessment of Weather Research and Forecasting (WRF) model for the prediction of flashfloods caused due to heavy rainfall in Korea. It was observed that orographic effects were accountable for about 20% rise in precipitation in high-rainfall region. Georgakakos (2006) documented the guidelines for operational flash-flood mitigation technique. Sacramento soil moisture accounting model was utilised for some streams in United States for flashflood modeling. Carrara et al. (1992) demonstrated a model for the prediction of flashfloods with 10-12 hours of lead time in Arno river, Tuscany, Italy using hydro-meteorological data. The model developed has a utility for the safe evacuation of inhabitants in case of flashfloods. Carpenter et al. (1999) estimated the runoff thresholds which can cause flashfloods for many streams in United States. The study outputs were used for US National Weather Service (NWS) flashflood watch and warning programmes.

Cao and Yue (2007) commented on the study carried out by Mudd (2006) on hydrodynamics of flashfloods in ephemeral streams. They stated that infiltration contribution in momentum conservation of main channel flow is insignificant. Blo¨schl et al. (2008) presented a distributed flashflood forecasting model. They have utilised Ensemble Kalman Filtering and model updation using the observed runoff data with lumped routing in the river reaches. Abderrezzak et al. (2009) carried out 2D flashflood propagation modelling in urban areas for high-rainfall event or dam/ dyke break-wave using a 2D depth-averaged shallow water topographic model for urban areas. The simulation modelling showed that flow depths and wave velocity were strongly affected by urban structures as compared to natural floodplain. England et al. (2007) utilised the Two-Dimensional-Runoff-Erosion-Export (TREX) model to simulate flashfloods based on probability based designed rainfall event for large catchments in semi-arid regions of USA. The model sufficiently captured the after-effects of spatio-temporal variability of extreme events for dam safety reasons and found to be a substitute to unit-hydrograph based rainfall-runoff modeling. Chiang et al. (2007) demonstrated the strength of data assimilation techniques for flashflood forecasting. Two assumptions were made in the study, viz., i) rainfall measurements made were non-bias and ii) rainfall measurements made were bias and accordingly the bias and gain factors were computed. Chen and Yu (2007) demonstrated the real-time probabilistic-forecasting of flood-stages resulting from support vector regression based on fuzzy inference modeling. The resultant hydrographs produced at 95% confidence interval indicated the efficacy of suggested methodology. Gaume et al. (2004) carried out SCS method and kinematic wave equation based hydrological modeling. They observed that nearly 200 mm of rainfall were retained in depressions or water bodies in the catchment which did not contribute to runoff or floods.

The hydrodynamic models are generally categorised as 1D, 2D and 3D models and describe the dynamics of fluids, especially the incompressible fluids in motion. One-dimensional hydrodynamic model is suitable under following conditions: a) river basins where stream flow does not spread significantly, b) river/ channel network having steep gradient and flow does not expand laterally, c) floodplains with well-connected drainage network with uni-directional flow, and d) high-resolution topographic data is unavailable. Two-dimensional hydrodynamic models were found to be particularly suited where the a) flow was predicted to spread in omni-direction, b) river channel/ stream passing through urbanised regions, c) wide and shallow floodplains, d) downstream of levee breaks, e) areas with wetlands or lakes, and f) regions under estuary/ alluvial fans (*http://hecrasmodel.blogspot.com/*). Munir et al.

(2020) analysed flash flood response of Vidor/Wadore hill torrent in Pakistan using Personal Computer Storm Water Management Model (PCSWMM) and HEC-RAS models. They observed that simulated flood extent showed 76% accuracy with historic flood extent with highest impact on agriculture in piedmont areas affecting the wheat and maize crops and fruit orchards. Nassima et al. (2020) carried out spatial analysis of erosion and deposition in Nekor river basin, Northern Morocco with dense hydrographic network and dynamic torrents using Revised Universal Soil Loss Equation (RUSLE) for complex terrain and unit stream power based erosion deposition models. The investigation revealed that average annual soil erosion and deposition rate were 60 - 65 $t.ha^{-1}.yr^{-1}$ and 38 $t.ha^{-1}.yr^{-1}$, respectively. Nikolaos et al. (2019) did the hydrologic and hydraulic modeling using HEC-HMS/RAS models for Sperchios river basin, Greece with torrential characteristics, high flood peaks and intense sediment yield. The flood extents simulated for an extreme flood event and as observed from Sentinel-1 images were found to be nearly 90% comparable.

The Universal Soil Loss Equation (USLE) is established by USDA (1986) Agricultural Research Service (ARS) [Wischmeier and Smith (1965 and 1978)] and is widely acknowledged and utilised soil loss estimation method for over 50 years. USLE equation was developed based on erosion trials on plots for over 20 years in 10 states of United States. Wischmeier was a statistician with USDA and he collated over 10000 annual records of data on soil erosion characteristics and for 46 stations to derive the equations. The USLE method can assess long-term annual soil loss and guides Engineers and Soil Conservationists for prioritising the watershed areas for efficient cropping management and adopting the conservation practices. The Agriculture

Handbook (No. 537) (Wischmeier and Smith, 1978) portraying USLE got published in 1965 and further revised during 1978. USLE has turned into a significant tool for conservationists and is extensively utilised worldwide for soil loss computation for variety of landscapes.

USLE method was later revised as Revised Universal Soil Loss Equation (RUSLE); an enhanced version which was established with additional research, experiments, data, and resources. RUSLE has some indistinguishable similarities from USLE, yet has a few changes in deciding variables. Some modifications and updates to original USLE equation include improved iso-erodent maps, time-dependent methodology for soil-erodibility-factor, improved strategy to compute slope length and gradient, and revised values for conservation practice factor (Renard, 1997).

3.6 TORRENTS' VULNERABILITY ANALYSIS

The torrents' vulnerability analysis is a combination of various subjective as well as objective criteria and consequently, it is a complex act. Hence, the Multi-Criteria Decision Analysis (MCDA) can be proficiently utilised to address such issues in watershed management. MCDA techniques are usually categorised as Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM). MADM technique are efficiently utilised to handle limited number of options whereas MODM is relevant for unending choices. It is usually regarded as a four-stage non-linear recursive procedure which comprises of: (i) Organising the choices (alternatives), (ii) Articulating and demonstrating their inclinations, (iii) Assessments (preferences) of alternatives and (iv) Finalising the alternatives (Guitouni and Martel, 1998). The

MADM technique is categorised as follows: i) Singular strategy based methodology while considering the parameter dominance such as Technique for Order Preference by Simulation of Ideal Solution (TOPSIS) (Hwang and Yoon, 1981) and Analytical Hierarchy Process (AHP) (Saaty, 1980), etc., ii) The outranking integration approach such as "*ELimination Et Choix Traduisant la REalité*" or "Elimination and Choice Translating Reality" (ELECTRE) (Roy, 2013), *Organísation, rangement et Synthèse de données relarionnelles* (ORESTE) (Roubens, 1982), etc., and iii) The intuitive local judgments with experimentation technique. The MODM technique handles the synchronous optimisation of various objective functions under a progression of restrictions. Generally, MODM techniques are applicable for design and optimisation issues whereas the MADM strategies are utilised for choosing the best elective among different choices and acquiring an alternative amongst choices.

Different investigations have been done for risk and hazard examination on watershed basis in diverse hydrological and climatological regimes. Anane et al. (2012) conducted an experiment in Tunisia to prioritise areas for irrigation with treated wastewater. Potential locations were identified based on land suitability, environmental characteristics, resources conflicts, cost adequacy, and social acceptance. Minatour et al. (2015) attempted a study in western Iran utilising the AHP method for siting earthen dams. They considered nine criteria and eleven sub-criteria dependent on their relative significance i.e., annual discharge, river flow regime, annual sediment volume, probable maximum flood, reservoir volume, annual average evaporation, water quality, topographic characteristics, dam site characteristics, probable dam break, overall cost, availability of construction material and facilities, and various environmental and sociopolitical characteristics, etc. Based on the analysis, four feasible alternatives were projected and ranked based on AHP technique. Özcan et al. (2017) used AHP and TOPSIS methods for upkeep and maintenance policy determination using nine critical elements and a Goal Programming (GP) model for hydroelectric power plants in Turkey. The study outcomes demonstrated an improvement of 77.1% in failure recurrence of power plant, which was primarily occurring due to wrong maintenance strategy selection. Esavi et al. (2012) analysed AHP and Fuzzy-AHP methods for sub-surface dam site selection in parts of Iran. They found that the Fuzzy-AHP technique performed better in the analysis. Vulević et al. (2015) utilised AHP and TOPSIS techniques for ranking sub-watersheds as indicated by their vulnerability to erosion using slope gradient, land use, and soil type factors. The study outcomes demonstrated a strong relationship between the rankings proposed by AHP as well as TOPSIS techniques. It was seen that most vulnerable sub-watersheds were portrayed with strong existence of arable land with extreme slopes and subsequently have desirable prerequisites for protection.

Le Cozannet et al. (2013) evaluated the usefulness of AHP based MCDA for physical coastal vulnerability to erosion and flooding in two areas of France. The study outcome demonstrated more prominent susceptibility of estuaries, sand spits and low-lying zones close to beach front tidal ponds. Carladous et al. (2016) compared Cost-Benefit Analysis (CBA), AHP and Belief Function-based TOPSIS (BF-TOPSIS) techniques for natural risks assessment in mountainous terrain. They found that BF-TOPSIS technique remarkably showed its strength to rank reversal problems with a manageable intricacy. Jozaghi et al. (2018) opined that AHP and TOPSIS techniques are amongst the extensively utilised MCDM based techniques equipped for settling issues in water resources. They carried out comparative analysis of these two methods for dam site selection based on various environmental and water quality criteria. It was observed that the TOPSIS method was better suited for dam site selection in the study area (Néelz et al., 2018). Aher et al. (2013) studied various morphological characteristics using Fuzzy Analytical Hierarchy Process (FAHP) technique to prioritise sub-watersheds located in transition zones among hilly and water shortage regions in Western Part of India. The study resulted into the identification of vulnerability zones categorised into five categories ranging from low-risk to very high-risk classes. Néelz et al. (2018) demonstrated the use of group fuzzy TOPSIS model for the ideal positioning of Kandoleh dam site in Kermanshah province, Iran while including eighteen input criteria. Rahman et al. (2015) showed the effectiveness of MCDA technique for ranking best options to recreate and restore the inland conduit structure on River Ilmenau in Germany. Rincón et al. (2018) conducted an experiment in Don River Watershed, Great Toronto Area (GTA) for flood hazard analysis with four scenarios. Besides the inferences drawn from flood hazard analysis, the socio-economic vulnerability was also included for overall flood-risk analysis.

3.7 METHODS FOR TREATING TORRENTIAL WATERSHEDS

Sheng (1999) underscored the exercises for the treatment of torrential watersheds in European Countries which mostly focused on flood and debris control while in North America, the emphasis is on managing the river discharge and quality, and flood mitigation measures whereas the developed countries focused on effective land management, erosion control, sediment reduction and flood control. In recent times however, emphasis is laid on "Integrated Watershed Management". Thus, the concept of Integrated Watershed Management has gained importance for improving the regime of torrential watersheds. Mandal (2018) mentioned that following measures are needed towards Integrated Watershed Management- i) Safe dissipation of raindrop energy, ii) Reduction in sediment yield, iii) Localised storage of rain water, iv) Safe disposal of excess water, v) In-situ soil and water conservation, vi) Ground water recharge through various structures and practices, vii) Rejuvenation of surface water bodies and efficient water utilisation, viii) Improving the time of concentration in drainage networks, ix) Restoration of degraded land, x) Prevention of flood and drought, xi) Overall conservation and restoration of watershed environment, xii) Biodiversity conservation, xiii) Flora and fauna conservation and xiv) Improving the soil fertility status, etc. These measures can be broadly categorised as follows: (i) Mechanical measures to intercept runoff and safe disposal of excess water, (ii) Vegetative measures by raising grasses and plantation, and (iii) Cultural practices while adopting various agronomic practices. Gerstgraser (1998) emphasized on the soil bioengineering methods for stabilising slopes, reduction in soil erosion and protecting the riverbanks. The entire method rests on bio-technical structures supported with vegetative growth which together can stabilise the torrential rivers and banks. This method was demonstrated in alpine regions of Italy and Austria.

Kamboj (2010) analysed the survival percentage of different species as effective vegetative barriers in the torrential watersheds of Siwalik region near Sabhawala in Doon valley. The identified plant species effectively served as vegetative barrier and had better soil binding capacity, underground water recharges, improve soil moisture level, conserved maximum runoff and also provided fodder to livestock and fuel to the villagers. McDowell (2011) laid the importance of *Carex nudata* which is also known as torrent sedge and the cattle grazing has caused its depletion near Middle Fork John Day River in north-eastern Oregon. Its rejuvenation exercise is helping towards re-stabilising the river and its associated landforms. However, it is also causing the narrowing of channels while making them rough and more stable with reduced sediment transport conditions. Tudose et al. (2013) described the importance of desiltation of existing hydro-technical works and channels besides the proper maintenance of structures built for flood mitigation, regularisation/ recalibration of riverbeds (desilting existing hydro-technical works and channels), etc.

Kostadinov et al. (2018) assessed the impact of various biotechnical works and found a general decreasing trend in soil erosion processes with specific annual gross erosion reducing from 1920.34 $m^3/km^{-2}/year^{-1}$ (year 1953) to 492.42 $m^3/km^{-2}/year^{-1}$ (year 2016) in Grdelica Gorge, Serbia. Blinkov et al. (2013) mentioned that erosion control measures can be classified in following groups: i) technical-ameliorative measures, ii) biological-ameliorative measures, iii) hydraulic structures, iv) administrative measures and v) educative measures. They later described the importance of biological works (afforestation, grass management as well as agricultural production) on steep slopes, rehabilitation of small gullies, etc. Dragović et al. (2007) assessed the performance of biological works in torrential watersheds and bio-technical works in the riverbed. Biological works mostly consisted of afforestation and grass management with an increase of forest covered areas in Bulgaria from 10% in early twentieth century to 35% in 1995. Evette et al. (2009) mentioned the benefits of biological engineering as compared to structural measures for increasing the channel capacity as plants form integral part of bio-technical structures after maturity and spread over the soil, thus make the system as erosion resistant.

3.8 WATERSHED MONITORING AND EVALUATION

Kumar et al. (2000) described the watershed management as an effective mechanism for sustainable rural development. They also emphasized the need for remote sensing data driven watershed monitoring and evaluation following the implementation of watershed development programmes. During such exercise, the conventional remote sensing data classification approaches and the method of post-classification comparison of pre- and post-implementation of watershed development programmes have their limitations as they account for overall changes not alone due to various interventions specifically intended for watershed development. Therefore, a method based on control area approach was devised to minimise the biases caused due to other interventions. The study area consisting of four clusters in Vidarbha region, Maharashtra exhibited positive changes due to various interventions specifically implemented under watershed development programmes. Thakkar et al. (2017) carried out the impact evaluation of watershed development activities for Khan-Kali watershed, Anas River, Gujarat. Different government and non-government institutions have adopted watershed treatment measures in the watershed. The temporal remote sensing data was used to understand the LULC and vegetation cover dynamics in agricultural areas. Remote sensing data based Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI) were used for analysing the changes. Major changes were observed in the study area. The ground water level has also improved. Overall, the positive impact of watershed management was observed within study area. Sharma et al. (2001) carried out a study for the Jasdan taluka (district) of Rajkot in Gujarat, India with an objective to assess the impact of watershed development programmes. The watershed prioritisation was carried out based on runoff yield, land use characteristics and hydrological response from the watershed. It was observed that the runoff is likely to decrease by nearly 43% due to various soil and water conservation measures. Shanwad et al. (2008) made an attempt to examine the utility of remote sensing data for pre- and post-treatment period for the impact assessment of Integrated Wasteland Development Program (IWDP), which was carried out in the Katangidda Nala watershed, Gulbarga, Karnataka. The overall changes in LULC and biomass over five years (1997-2002) were analysed. A positive impact of watershed development activities was observed with good changes in agricultural areas and forest land due to the conversion of wastelands and fallow lands mainly attributed to improved utilisation of available water resources, soil and water conservation measures adopted and improved agronomic practices. A benefit-cost analysis of remote sensing data based watershed monitoring and evaluation led to the conclusion that the technique is nearly 2.2 times cheaper than conventional methods.

3.9 UNDERSTANDING UNCERTAINTY IN FLOOD RISK MODELING

Pappenberger et al. (2006) utilised Generalised Likelihood Uncertainty Estimation (GLUE) technique towards analysing the effects of undefined boundary-conditions on flood-inundation modeling. It was observed that such uncertain conditions can exceed the significance of model parameters for some regions of the watershed. Morss et al. (2005) carried out flood risk uncertainty modeling for an informed decision making. Their study included the effects of climate variability, scientific uncertainty, and hydro-meteorological information in risk modelling. García-Pintado et al. (2009) demonstrated a distributed hydrological modeling for a semi-arid flashflood to understand the dynamics of surface-storage and channel-roughness. They have utilised GLUE model with conditions to observe nested hydrographs for improved simulations.

3.10 SUMMARY & RESEARCH GAPS

Some hydrological models and applications are available in the literature for flood risk assessment from a torrential watershed. However, limited applications are available to comprehensively assess the hydrological risk from and within a torrential regime, especially in Ganga-Yamuna catchment. In a torrential regime, the upstream and downstream region experience hydrological risks differently due to varying hydrological-soil-cover-complex. While the upstream region under relatively higher slope, heavy sediment load and singular main stream experiences flashfloods; the downstream region has moderate slope but multiple channels and dominantly agricultural land use susceptible to overbank flooding. The river piracy and river crisscrossing are prominent while making it difficult to distinctly demarcate catchment boundaries. Thus, the hydrological hazard assessment for torrential areas needs extensive knowledge on its channel and upstream catchment characteristics, sediment pattern, routing techniques and events based modeling. The vulnerability analysis of torrential areas needs the study of variations in hydrologic-physiographic parameters along with the temporal behaviour of torrents with respect to lateral migration and land use alternations.

The torrential systems emanating from Siwalik and lesser Himalaya bear unique characteristics. The torrents originate from these regions with high velocity due to steep bed gradient which get further perpetuated by heavy bed material detached from loose conglomerate formations of Siwalik. Such a system causes flash floods in upstream region and river overflow in downstream reaches. Thus, an attempt has been made in the present study for hazard assessment in a torrential watershed while differentially considering the upstream and downstream characteristics. The hazard characteristics of the sub-watershed in upstream region is compared with respect to the whole watershed in the present study. The upstream sub-watershed consists of varied landforms but dominantly have areas under Siwalik and lesser Himalaya from where the torrents emanate whereas the large areas under whole watershed are under alluvial plains and river flood plains.

In the present study, therefore hydrologic and hydrodynamic, and soil loss estimation models have been used to assess and demonstrate such characteristics of a torrential river. Besides, temporal satellite data has also been used to assess the LULC and vegetation changes as a measure of remote sensing data driven watershed monitoring and evaluation of watershed treatment activities, as several agencies have undertaken development activities in the study area. MCDM based vulnerability assessment has also been attempted to identify vulnerable reaches in the watershed.

Chapter 4

DATA USED & METHODOLOGY ADOPTED

The present study on '**Hydrological Risk Assessment from and within a Torrential Watershed'** has been carried out using remote sensing and ancillary data, and GIS coupled hydrological models. The data used and methodology followed in this study are elaborated in this chapter.

4.1 DATA USED

In the present study, multi-sensor remote sensing data were geo-referenced and various theme maps were derived. These theme maps were used as inputs in hydrological models to assess hydrological hazard from and within the torrential watershed of Tangri (Dangri) river. Following data are used in the present study-

4.1.1 Ancillary Data

The ancillary data utilised in this study are as follows-

- SoI topographical maps at 1:50,000 scale (53B09 to 16 and 53F01 to 08),
- Soil map published by National Bureau of Soil Survey and Land Utilisation Planning (NBSS&LUP),
- Rainfall data (IMD) for the period 1986-2013,
- Gauge and discharge data from Water Data Collection Division, Karnal, Government of Haryana and
- Published reports and research papers.

Table 4.1. List of satellite data utilised in present study

Sl. No.	Satellite-Sensor	Date of Imaging	Scene specifications	Resolution (m)	Bands (spectral range, µm)
1	IRS-P5 (Cartosat-1) stereo kit	11-12-2010	519-258	2.5	PAN (0.5 - 0.85)
		09-02-2011	520-256, 257, 258, 259		
		04-06-2011	521-256, 257, 258, 259		
		18-01-2011	522-257		
2	IRS-P6 LISS-4	11-03-2010	102-19, 20	5.8	3 (0.52-0.59, 0.62-0.68, 0.77-0.86)
3	IRS-P6 LISS-3	07-03-2012	NH-43K09-095-049 (K09-K016)*, NH43L01-095-049 (L01-08)*	23	4 (0.52-0.59, 0.62-0.68, 0.77-0.86, 1.55-1.70)
5	Landsat TM	17-02-1991, 30-01-1996, 04-02-2001, 08-02-2011, 06-02-2016, 27-02-2018	LT05_L1TP_147039_19910217_20170127_01_T1+, LT05_L1TP_147039_19960130_20170106_01_T1+, LE07_L1TP_147039_20010204_20170207_01_T1+, LT05_L1TP_147039_20110208_20161010_01_T1+, LC08_L1TP_147039_20160206_20170405_01_T1+, LC08_L1TP_147039_20180227_20180308_01_T1+	30	Landsat 4-5: 7 bands (0.45-0.52, 0.52-0.60, 0.63-0.69, 0.76-0.90, 1.55-1.75, 10.40-12.50, 2.08-2.35) Landsat 7: 8 bands (0.45-0.52, 0.52-0.60, 0.63-0.69, 0.77-0.90, 1.55-1.75, 10.40-12.50, 2.09-2.35, 0.52-.90) Landsat 8-9: 11 bands (0.43-0.45, 0.45-0.51, 0.53-0.59, 0.64-0.67, 0.85-0.88, 1.57-1.65, 2.11-2.29, 0.50-0.68, 1.36-1.38, 10.6-11.19, 11.50-12.51) **

* Open source, downloaded from **N**ational Remote Sensing Centre (NRSC) **O**pen **E**arth **O**bservation (EO) **D**ata **A**rchive (NOEDA), *Bhuvan* (https://bhuvan-app3.nrsc.gov.in/data/download/index.php)

+ Open source (downloaded from Earth Explorer, also analysed in GEE)

**https://www.usgs.gov/faqs/what-are-band-designations-landsat-satellites?qt-news_science_products=0#qt-news_science_products

4.1.2 Satellite Data

In the present study, IRS-P6/ RESOURCESAT-1 LISS-3 and LISS-4 multispectral, and IRS-P5 (Cartosat-1) stereo data were used for deriving various thematic layers for hydrologic and hydrodynamic modeling, and Landsat TM data available on Google Earth Engine (GEE) were used for analysing the temporal behaviour of torrential rivers in the Dangri (Tangri) river watershed. The details of satellite data as utilised in the present study are given in Table 4.1.

4.2 MODELS AND SOFTWARE USED

The model essentially represents the reality. Models *per se* are not entirely the substitute of ground based measurements. The selection of an appropriate model is important and the effective modelling depends upon data used. The models are generally categorised as follows- a) Physical/ Numerical/ Mathematical, b) Empirical/ Mathematical, c) Deterministic/ Conceptual/ Stochastic, d) Steady/ Unsteady, e) Perspective/ Descriptive, f) White box/ Black box/ Gray box, and g) Lumped/ Distributed. Models are also classified based on biological or hydrologic assumptions underlying the processes being studied.

Following software were used in the present study- i) ArcGIS 10.1, iii) HEC-HMS and HEC-GeoHMS 10.1, iii) HEC-RAS and HEC-GeoRAS 10.1, iv) ERDAS Imagine 14 and v) Leica Photogrammetry Suite 2010. The models and software as utilised in the present study are given in Table 4.2 and described in following paragraphs.

4.2.1 Models for Vulnerability Assessment

MCDM techniques help to resolve a decision making task using various choices or alternatives. It ensures that the process of decision making relies upon various feasible options rather than a single criterion. MCDM strategies are characterised into six fundamental classes (Hajkowicz et al., 2000) as follows- i) Outranking type which inspects whether an alternative outpaces another such as Preference Ranking Organisation Method for Enrichment and Evaluation (PROMETHEE) and '*ELimination Et Choix Traduisant la REalité*' or 'Elimination and Choice Translating Reality' (ELECTRE), ii) Distance to ideal point such as Compromise Programming (CP) and Technique for Order Preference by Similarity to Identical Solution (TOPSIS), iii) Multi-criteria value functions or Multi-Attribute Utility Theory (MAUT) that depends on specified weights and usefulness or scoring functions for each decision criteria, iv) Pairwise comparisons such as Analytical Hierarchy Process (AHP), v) Fuzzy set analysis that depends on issues having uncertainty governed with absence of well-defined criteria and possess randomness, and vi) Tailored methods which usually extends or adapts a fundamental methodology to a particular application.

In the present study, the AHP method introduced by Saaty (1980) was utilised to evaluate criteria weights and the ELECTRE and TOPSIS methods were used for finding alternatives for the treatment of torrential areas. The blend of two strategies is a good arrangement because on one hand we can define the criteria weights and also, we can use a consistency index (CI) using AHP method. We can also set the criteria values and the optimisation types using TOPSIS and ELECTRE methods. This reduces subjectivity during decision making process (Önüt and Soner 2008; Żak and Kruszyński 2015). The difference between AHP and TOPSIS methods are as follows- i) AHP strategy depends on hierarchical principle whereas TOPSIS method uses the distance principle, ii) AHP is based on pairwise comparison between criteria and pairwise comparison between alternatives for each criterion by applying Saaty's scale and CI whereas TOPSIS method fixes the criteria weights and ranks the alternatives, iii) With AHP method, the criteria weights are not set (are not necessary) but the alternatives are evaluated using Saaty's scale whereas in TOPSIS method, the type of optimisation is set for each of criteria (maximum or minimum), and iv) With TOPSIS method, all the parameters are taken at a time as alternatives and they would be given score on the basis of criteria, which is called the decision matrix whereas in AHP method, pairwise comparison matrix helps to determine weights for various parameters. The best alternatives are thus ascertained from the decision matrix built using the TOPSIS method. The calculation part is lessened as we can compute the best alternative from the decision matrix. But one problem encountered in TOPSIS or other MCDM method is the computation of the weightage of the criteria. This problem is tackled by various methods like AHP, cross-entropy, fuzzy preference programming, etc. Later, we can compute the weightages of the criteria by forming a comparison matrix and following AHP technique.

4.2.1.1 AHP method

Analytical Hierarchy Process (AHP) is an extensively utilised strategy for scaling the weights of parameters by developing a pair-wise correlation framework of parameters whose entries show the eminence with which one component overwhelms another opposite the criteria under investigation. In the present study, the Saaty's AHP system was utilised to allocate weightages to different parameters for the preparation of torrents' vulnerability map. AHP was established by Prof. Thomas L. Saaty in 1977. It is executed as a matrix, giving relative weightages to each component.

The AHP tool acts as a measure of judgmental consistency, helps to derive priorities among criteria and its alternatives, and also helps in simplifying the preference ratings among the decision making criteria by making use of pair-wise comparisons. Table 4.3 shows the importance matrix explained by Saaty (1980). The process is depicted by Eq. 4.1 to 4.11 (Malczewski, 1999; Saaty, 1980) for a matrix of pair-wise elements and the steps in the estimation of weights through AHP method is as given in Eq. 4.1.

a. $$A = (C_{ij)} = \begin{pmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{pmatrix} \quad where\ i, j = n \qquad \ldots\ldots.4.1$$

b. The numerical values in various columns of matrix is summed-up as given in Eq. 4.2.

$$A = \sum_{i=1}^{n} C_{ij} \qquad \ldots\ldots.4.2$$

c. Later, every component of matrix is divided by columns total values to produce a normalised matrix as given in Eq. 4.3.

Table 4.2 List of models and software used in the present study

Sl. No.	Activity	Model	Advantage	Disadvantage	Outputs
1	Vulnerability Analysis	AHP	Simplicity by using pair-wise comparison, consistency in evaluation	Inconsistencies imposed by 1 to 9 scale	Weights under multi-criteria decision modeling
2	-do-	TOPSIS & ELECTRE	Determines criteria weights and ranks alternatives	Requires computation weightages	Best alternative from decision matrix
3	Hydrological Analysis	HEC-HMS	Open source, runoff modeling, channel routing, water control structure	Events based modeling, lacks long-term hydrologic simulations	Annual yield, peak flow, water erosion, water quality
4	Hydrodynamic modeling	HEC-RAS	Open source, extensive support by USACE, add-on packages available	Numerical instability during unsteady analyses	Flood management, bridge/culvert modeling
5	Soil Loss	RUSLE	Assessment of hill slope configuration	Incapable for routing sediment through channels, applicable for small areas	Soil loss estimation

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}} \qquad \text{.......4.3}$$

d. The aggregate sum of normalised matrix is divided by criteria used (n) to produce weighted matrix as given in Eq. 4.4.

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n} \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} \qquad \text{.......4.4}$$

e. Later, the consistency vector is computed by multiplying pair-wise matrix by weights of vector as given in Eq. 4.5.

$$\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{21} \\ W_{31} \end{bmatrix} = \begin{bmatrix} Cv_{11} \\ Cv_{21} \\ Cv_{31} \end{bmatrix} \qquad \text{.......4.5}$$

f. The consistency vector is produced by dividing weighted sum vector with weight of each criterion as given in Eq. 4.6 to Eq. 4.8.

$$Cv_{11} = \frac{1}{W_{11}} [C_{11}W_{11} + C_{12}W_{21} + C_{13}W_{31}] \qquad \text{.......4.6}$$

$$Cv_{21} = \frac{1}{W_{21}} [C_{21}W_{11} + C_{22}W_{21} + C_{23}W_{31}] \qquad \text{.......4.7}$$

$$Cv_{31} = \frac{1}{W_{31}} [C_{31}W_{11} + C_{32}W_{21} + C_{33}W_{31}] \qquad \text{.......4.8}$$

g. Later, the Eigen value (λ) is estimated by averaging values of consistency vector as given in Eq. 4.9.

$$\lambda = \sum_{i=1}^{n} Cv_{ij} \qquad \text{.......4.9}$$

h. CI measures the deviation as given in Eq. 4.10.

$$CI = \frac{\lambda - n}{n - 1} \qquad \text{.......4.10}$$

i. The Consistency Ratio is calculated as given in Eq. 4.11.

$$C_r = \frac{CI}{RI} \qquad \text{.......4.11}$$

Where C_r is Consistency Ratio, RI is random consistency index and λ is principal eigenvalue.

Table 4.3. Importance matrix defined by Saaty (1980)

Importance Level	Classification	Description
1	Equally important	Two factors have equal significance
3	Slightly higher importance	Factor *i* has marginally higher significance than *j*
5	Higher important	Factor *i* has higher significance than *j*
7	Strong importance	Factor *i* has strong significance than *j*
9	Absolutely higher importance	Factor *i* has absolute greater significance than *j*
2,4,6,8	Intermediate importance	Transitional category of importance

In the event that the importance matrix and the weights derived thereupon ideally prioritises the importance of various criteria, the consistency measures will rise to n and in this way, the CIs will be equivalent to zero. In the event, where this proportion is substantial (Saaty recommends > 0.10), at that point, it is not sufficiently reliable and the best action is to reconsider the correlations. AHP is used in cost-benefit analysis, investment priorities, strategic planning, evaluation of alternatives, etc. (Ho, 2008; Malczewski, 2006).

4.2.1.2 TOPSIS method

Hwang and Yoon (1981) brought forward the MCDA based Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) which is an improved form of technique earlier introduced by Zelany (1974). This technique is useful to distinguish solutions from a limited number of choices while concurrently maximising distance with nadir point and decreasing distance with ideal point (Olson, 2004). It is assumed that ideal solution is an alternative with highest suitability for all rules considered, then again the negative ideal solution relates to a choice with poorest values. It follows an ideal MCDM technique which relies on function aggregation and tends to derive solution closest to positive ideal solution and most remote from negative ideal solution but it doesn't

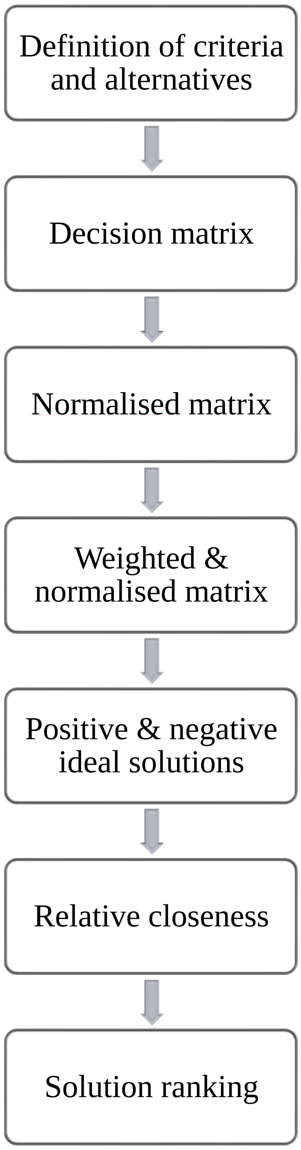


Figure 4.1. TOPSIS methodology

take into account the relative significance of these distances (Opricovic and Tzeng, 2004). TOPSIS procedure incorporates following six progressive stages (Hwang and Yoon, 1981): a) Establishing decision matrix, b) Normalising decision matrix estimation, c) Weighted decision matrix determination, d) Identifying positive and negative ideal solutions, e) Calculation of separation distance, f) Measuring the relative closeness, and g) Ranking of preference order. Using the TOPSIS method, the most preferred alternative or option can be quickly discerned (Parkan and Wu, 1997). TOPSIS technique alike other MCDA tools helps to derive linear transformation parameters based on normalisation and simplification (Hejazi and Saghafian, 2005). Fig. 4.1 describes the TOPSIS methodology. The steps followed in TOPSIS methodology are as follows-

a. **Establishing decision matrix**: It is the initial step under TOPSIS strategy which includes the development of a Decision Matrix.

b. **Decision matrix estimation normalisation**: The decision matrix normalisation denote relative performance of generated design alternatives as given in Eq. 4.12 for *i* = 1… m; *j* = 1… n.

$$R_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \quad \text{…….4.12}$$

Where R_{ij} and X_{ij} are actual and normalised scores of decision matrix, respectively.

c. **Weighted decision matrix determination:** Based on relative importance of various parameters, the weights are obtained from AHP method to evaluate the general significance of various criteria. It is developed by increasing every component of normalised decision matrix using irregular weights.

$$V_{ij} = w_j * R_{ij} \qquad \ldots\ldots.4.13$$

Where w_j is weight of j criterion and V_{ij} is weighted normalised value.

d. **Identifying Negative and Positive Ideal Solutions**: The negative (A^-) and positive (A^+) ideal arrangements are perceived by weighted decision matrix using following conditions: $A^+ = \{V_1^+, V_2^+ \ldots \ldots V_n^+\}$, where $V_j^+ = \{(maxi\ (v_{ij})$ if j ε J); (mini (v_{ij}) if j ε J')} and $A^- = \{V_1^-, V_2^- \ldots \ldots V_n^-\}$, where $V_j^- = \{(mini\ (v_{ij})$ if j ε J); (maxi (v_{ij}) if j ε J')} and J is connected with beneficial attributes and J' is connected with non-beneficial attributes.

e. **Calculation of separation distance**: It is resolved for each competitive option using the ideal and non-ideal solutions as given in Eq. 4.14 and Eq. 4.15.

$$S^+ = \sqrt{\sum_{i=1}^{n} (V_j^+ - V_{ij})^2} \ \{i = 1,2, \ldots m\} \qquad \ldots\ldots.4.14$$

$$S^- = \sqrt{\sum_{i=1}^{n} (V_j^- - V_{ij})^2} \ \{i = 1,2, \ldots m\} \qquad \ldots\ldots.4.15$$

Where, *i* = criterion index, *j* = alternative index.

f. **Measuring the relative closeness**: It is evaluated for each position for attaining ideal solution as given in Eq. 4.16. It describes the relative closeness of potential criteria as given for ideal solution.

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}, \qquad 0 \le C_i \le 1 \qquad \text{.......4.16}$$

g. **Ranking of preference order:** According to estimations of relative closeness, the rankings are characterised, where higher the positioning, better the options exercised. Thus, the preference ranking in descending order enables better monitoring of performances.

4.2.1.3 ELECTRE method

ELimination Et Choix Traduisant la REalité (ELimination and Choice Translating Reality, ELECTRE) assessment technique is broadly perceived as superior approach for MCDM analysis while considering both subjective as well as quantitative criteria. ELECTRE was introduced by Roy (1991) because of insufficiencies in existing decision making approaches. In this approach, the discordance matrix is utilised to define the criticalness of adjusted values (Huang and Chen, 2005). ELECTRE has progressed through various adjustments (I, II, III, IV, V, IS, A, etc.), and all rely upon some comparably significant processes, and yet are operationally somewhat similar (Huang and Chen, 2005). The steps in ELECTRE strategy are as follows:

a. **Step 1:** Calculation of normalised decision matrix N_{ij} as given in Eq. 4.17.

$$N_{ij} = \frac{R_{ij}}{\sum_{i=1}^{n} R_{ij}^2} \{i = 1,2 \dots m; j = 1,2 \dots n\} \qquad \text{.......4.17}$$

Where R_{ij} represents the decision matrix, m denotes an alternative whereas n denotes the criteria under consideration.

b. **Step 2:** Derivation of weighted normalised decision matrix as given in Eq. 4.18.

$$V_{ij} = N_{ij} * W_{ij} \quad \text{.......4.18}$$

With the presumption that W is a diagonal matrix (n * n) and its diagonal elements are $w_{1...n}$ and other quantities are null, it is estimated as given in Eq. 4.19).

$$W= \begin{pmatrix} w_1 & 0 & 0 & \dots & 0 & 0 \\ 0 & w_2 & 0 & \dots & 0 & 0 \\ 0 & 0 & w_3 & \dots & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 & w_n \end{pmatrix} \quad \text{.......4.19}$$

c. **Step 3:** Determination of concordance and discordance sets are done as given in Eq. 4.20.

$$S_{ki} = \{J \mid N_{kj} \leq N_{ij}\}; \{k, l = 1, 2, 3 \dots \mathrm{m}, \mathrm{k} \neq 1\} \quad \text{.......4.20}$$

When this condition is true then 1 otherwise 0. Later, the discordance set is computed as follows:

$$D_{kl} = \{J \mid N_{kj} < N_{ij}\}; \{k, l = 1, 2, 3 \dots \mathrm{m}, \mathrm{k} \neq 1\} \quad \text{.......4.21}$$

Wherever, S_{kl} and D_{kl} are found as opposites then go to step 4.

d. **Step 4:** Calculation of concordance matrix (Eq. 4.22)

$$I_{kl} = \sum_{j=S_{k,l}} W_{j;} \sum_{j=1}^{n} W_j = 1 \quad \text{.......4.22}$$

Wherein the matrix (I) has elements {k, l = 1, 2, 3...m, k≠1}, and with the end goal that matrix elements incorporate aggregate of element(s) W, they rely upon $S_{k,l}$. In this manner, every component of $S_{k,l}$ will be such that $0 \leq I_{k,l} \leq 1$.

e. **Step 5:** Discordance matrix calculation

In order to estimate the matrix NI, it is essential that {k, l = 1, 2, 3...m, k≠1}, to such an extent that elements of matrix will be registered as follows in numerator and denominator, separately:

$$NI_{k,l} = \frac{\max|V_{kj} - V_{Ij}|}{\max|V_{kj} - V_{Ij}|}; +j€J \qquad \text{.......4.23}$$

f. **Step 6:** Concordance dominance matrix determination

The dimensions of matrix F and I (in step 4) are equivalent yet for discovering matrix F, it is required to process threshold values as given hereunder:

$$\bar{I} = \sum_{k=1}^{m} \sum_{I=1}^{m} \frac{I_{k,l}}{m(m-1)} \qquad \text{.......4.24}$$

Where, m is matrix dimension. The matrix F is estimated by utilising matrix I, such that each component of matrix I are partitioned to arrive at threshold values.

$$f_{kl} = 1 \overset{if}{\rightarrow} I_{kl} \geq \bar{I}, \qquad \text{.......4.25}$$

$$f_{kl} = 0 \overset{if}{\rightarrow} I_{kl} < \bar{I}, \qquad \text{.......4.26}$$

Above disparities imply that if every component of matrix I is more important than or equivalent to, at that point *l* would be set in matrix F, which is a relating component.

g. **Step 7:** Discordance dominance matrix determination

$$N\bar{I} = \sum_{k=1}^{m} \sum_{I=1}^{m} \frac{NI_{k,l}}{m(m-1)} \; (m \; is \; dimension \; of \; matrix) \qquad \text{.......4.27}$$

The matrix G is processed by utilising matrix NI, if each comparable components of matrix NI are separated to arrive at threshold values to such an extent that-

$$g_{kl} = 1 \overset{if}{\rightarrow} NI_{kl} \geq \overline{NI} \qquad \text{.......4.28}$$

$$g_{kl} = 0 \overset{if}{\rightarrow} NI_{kl} < \overline{NI} \qquad \text{.......4.29}$$

Additionally, the above imbalances imply that given the chance that every component of matrix NI is not exactly or equivalent to, at that point 'I' would be set in matrix G.

h. **Step 8:** Aggregate dominance matrix determination

$$h_{k,l} = f_{k,l} * g_{k,l} \qquad \text{.......4.30}$$

Subsequently, the matrix H is processed by duplicating the relating components of F and G matrices.

i. **Step 9:** Elimination of less favourable alternatives and ranking

Finally, the columns of matrix H are determined such that the column which has least value of *I* should be chosen as the best one.

4.2.2 HEC-HMS

HEC-HMS is an open source software package of USACE which has facility to recreate the hydrologic processes of a watershed. It can simulate the precipitation-runoff relationships and provide outputs which are helpful to understand various processes of a watershed such as infiltration characteristics, river channel flow, urban drainage system, flow forecasting, impact of urbanisation on hydrological behaviour of a watershed, protection through flood damages, floodplain regulation, reservoir systems operation, etc. HEC-GeoHMS provides an interface for feeding data over ArcGIS software. It enables an interface for database creation, data entry and computation engine facility. The user can define the drainage and watershed boundary, meteorological characteristics, hydrological-soil-cover-complex and various control specifications using HEC-GeoHMS interface. The user is required to define hydrological elements of a watershed such as sub-basin, reach, junction, reservoir, diversion, etc. as hydrological elements. The meteorological information such as precipitation and evapo-transpiration is fed into the model. The simulation requires various control specifications, which include simulation timings and computation sequences. The program enables the user for building strategies, simulate processes and to define parameters while utilising a graphical user interface (GUI). In the present study, the HEC-HMS and its HEC-GeoHMS interface was used for hydrological modeling of Tangri (Dangri) river watershed. Later, the model output was calibrated with respect to the discharge of Tangri (Dangri) river measured at Gauge and Discharge (G&D) site no.5 on the river near Ambala-Shahbad road crossing near Shahpur town.

4.2.3 HEC-RAS

HEC-RAS can perform one and two-dimensional simulations for a natural and manmade channel. It provides an integrated environment and useful for understanding the river system hydraulics and associated effects on surrounding ecosystems. The model has following added proficiencies in addition to unsteady and steady-flow analysis: a) hydrodynamic modelling of open channel and their networks based on unsteady and steady flow options, b) hydrodynamic modeling for bridges, weirs, and culverts (unsteady and steady-flow options), iii) retention area modelling, navigation dam, tunnel, pumping station, and levee failures (only unsteady flow option), and iv) subcritical, supercritical, and mixed-flow regimes handling (steady-flow option only) (Brunner, 1995).

The HEC-RAS program outputs are useful in delineating floodplain boundary and flood depth, which later can be used to estimate flood damage losses, analyse severe flood events, flood insurance rate maps, identify risk and vulnerable sections and evaluate habitat restoration alternatives. In the present study, the HEC-RAS along with its HEC-GeoRAS interface have been used for hydrodynamic modeling of the Tangri (Dangri) river watershed.

4.2.4 RUSLE

In the present study, the RUSLE method is used for varying soil loss from varied landforms, LULC and slope regions of the watershed. RUSLE utilises following four parameters to process the soil loss from watershed: rainfall, soil erodibility, topography and LULC. The amount and intensity of rainfall is used in this model. The soils have contrast in their inherent erodibility, which is based on their properties such as texture, structure, porosity, chemistry, etc. The topographic parameter is represented by slope and slope-length factor. The cropping and conservation practice factors are obtained from LULC map.

4.3 STEREO DATA PROCESSING

In this study, following Cartosat-1 satellite stereo data were utilised to produce Digital Elevation Model (DEM) and ortho-products for Tangri (Dangri) river watershed and its surroundings- Path/ Row (P/R) 519/258 (11 December 2010), 520/256, 257, 258, 259 (09 February 2011), 521/256, 257, 258, 259 (04 June 2011) and 522/257 (18 January 2011). After setting-up project definition and data downloading, Leica Photogrammetry Suite (LPS) was utilised for interior and exterior orientation based on tie-points and Ground Control Points (GCPs). Differential Global Navigation Satellite System (DGNSS) based survey was conducted to acquire GCPs. DEM was generated using Rational Polynomial Coefficients (RPCs) and then updated using GCPs. In order to acquire GCPs, the Cartosat-1 image chips were extracted for the navigation purpose. GCPs planning was done based on the following criteria: i) Identifiable on both bandA and bandF of stereo images, based on image contrast and features association, ii) Well-distributed throughout block as well as in each stereo pair, iii) Accessibility and iv) Provision for acquiring a GCP among multiple choices given in vicinity in view of field conditions. Tie-points were generated with both automatic and manual processes. A careful scrutiny of all the points were done to eliminate wild points (mis-matched points). Manual points were kept at shadow regions, low contrast regions and at forest patches. DEM was generated from the mass points derived from the control points and tie-points. These mass points made up the Triangulated Irregular Network (TIN) which represent a surface constituting a set of contiguous, non-overlapping triangles. The grid size was kept as 10 m considering the terrain undulation.

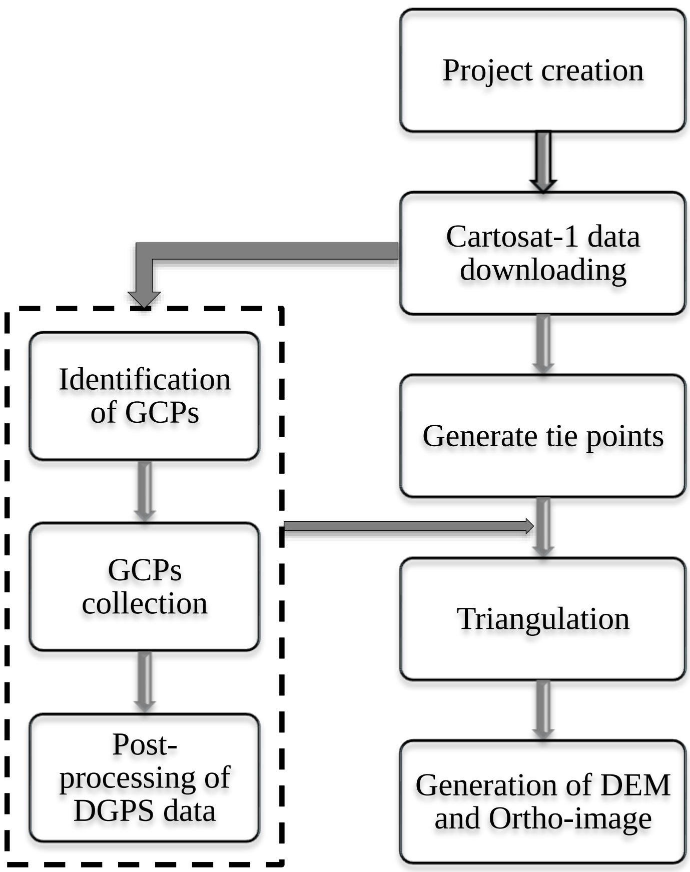


Figure 4.2. Flow of operations for generating DEM and Ortho-image for GPS survey

LPS software provides GCP and tie-point identification tool through which all the GCPs and tie-points have been identified. DGPS based GCPs were assigned and Cartosat-1 data was triangulated subsequent to creating tie-points. Initially, the ground coordinates of tie-points were unknown and they were distinguished in image overlap areas. Triangulation is the technique towards setting up a mathematical correlation amongst images, ground and sensor model. The triangulation process yields data useful for ortho-rectification of stereo images. Triangulation has been performed with control points to verify the model correctness for each tie-point. LPS software identifies tie points in overlap region of stereo images in all ideal cases. Some more tie-points were added manually in the zones where automatic triangulation failed in order to fill-up the gaps. DEM was produced while utilising the LPS Automatic Terrain Extraction (ATE) following the achievement of agreeable model precision. Figure 4.2 shows the flow of operations for generating DEM and Ortho-image based on DGPS survey.

4.3.1 GCPs Collection

DGNSS based survey was done to acquire GCPs. In the present study, Trimble R7 GNSS System was utilised for DGNSS survey. It is a high-precision GNSS receiver with Ultra High Frequency (UHF) radio consolidated as an integrated unit. It supports the L2C and L5 GPS, in addition to *Globalnaya Navigatsionnaya Sputnikovaya Sistema* (GLONASS) inputs. L2C (1227 MHz) and L5 (1176 MHz) are second and third civilian GPS frequencies, respectively which are intended for non-military use and for various high-performance applications.

In order to carry out the GCPs survey, the Cartosat-1 image chips were extracted for the navigation purpose. The names of urban settlements (and encompassing towns) were additionally appended with the GCP chips. Figure 4.3 demonstrates an example GCP chip, which was utilised during GPS survey. A base station was established in the area during rover readings.

Sl. No.	GCP_id	Scene no.	District/ block	Village/ town	Feature type	Scene based lat./ long.	Route plan
1	175315191_a_1	175315191_a	Kurukshetra/ Thanesar	Mundhri	Village road intersection	76°44'6,686"E 30°9'40,434"N	Ambala-Dharkora-Jhansa road

Figure 4.3. A typical chip used in GCP survey

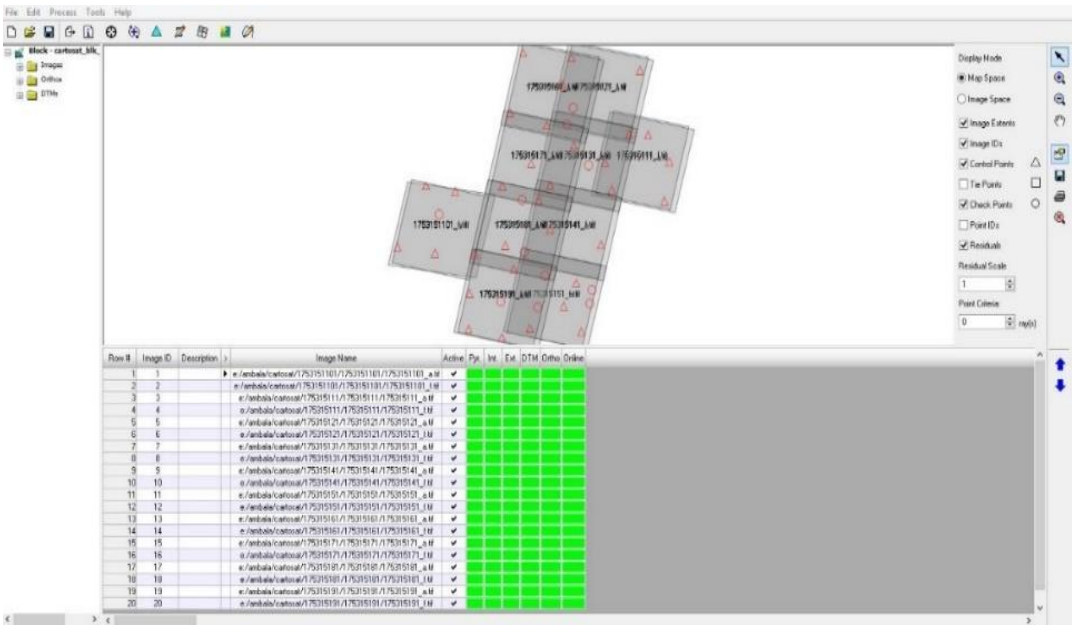


Figure 4.4. Distribution of GCPs in photogrammetry block

4.3.2 Post-processing of GPS data

Post-processing of observed rover points was done with base station point as reference while utilising Trimble Business Centre (TBC) software. It was utilised to perform least squares adjustments on rover point network with respect to base station points to distinguish any intrinsic errors within the survey data. Those points reporting higher errors were eliminated and finally DEM and ortho-products were generated for Tangri (Dangri) catchment and surroundings. Figure 4.4 demonstrates the distribution of accepted GCPs in the photogrammetry block.

4.3.3 DEM Generation

LPS software provides GCP and tie point identification tool through which all the tie points and GCPs are distinguished. The block orientation was done utilising 43 GCPs, out of which 10 were selected as check points. DGPS based GCPs were assigned and the Cartosat-1 data was triangulated subsequent to generating tie-points. After triangulation with 33 control points, the model's RMSE was observed as 0.105 pixel. With 33 GCPs, the image X and Y residuals were obtained as follows: 0.148 and 0.145 pixels, respectively whereas the residuals for control points were 0.98 m (X) and 1.48 m (Y), respectively. Similarly, the residuals for check points were as follows- i) Image points X and Y were 0.165 and 0.00006, respectively, and ii) Residuals for ground coordinates of check points were 1.869 m and 1.843 m, respectively. Figure 4.5 shows the triangulation results obtained from photogrammetry block based on 33 control points, 10 check points and 26,546 tie points. Using LPS Automatic Terrain Extraction (ATE) tool, the DEM was created after the agreeable model accuracy as above was accomplished. DEM for Tangri (Dangri) catchment and surroundings is shown in figure 4.6. Once the DEM was successfully extracted after utilising ATE tool, the subsequent stage was intensive confirmation of quality of the output DEM by viewing it overlaid over the stereo model. The stereo model fills in as a kind of reference source for ensuring the correctness of the DEM. Wherever the mass points associated with a raster terrain dataset did not 'sit' on the surface of the model, explicit DEM editing tools accessible in Terrain Editor has been utilised to ensure that the terrain dataset conforms to model's surface.

4.3.4 Ortho-image Generation

Orthoimage is an image with orthogonal projection, whose each point looks as though an observer is seeing straight down at it as a nadir pixel, along an observable pathway that is orthogonal (perpendicular) to the earth. Orthorectification is a process of correcting the remote sensing images to a planar, map-like form by precisely eliminating the sensor, camera and terrain related distortions while using the camera/ sensor and terrain models, and GCPs. The AFT image due to its near nadir acquisition angle alongside DEM was utilised for orthorectification with 2.5 m resolution.

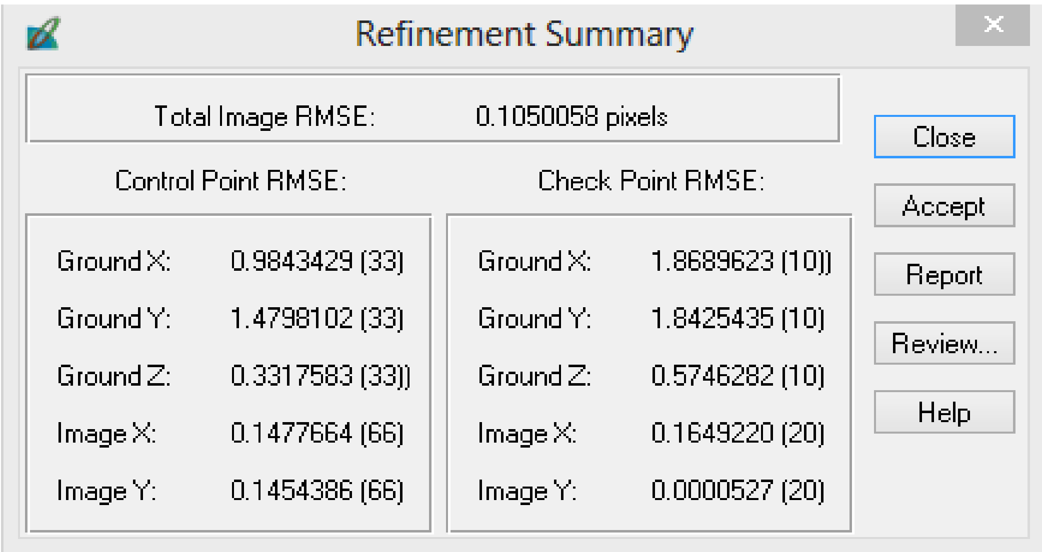


Figure 4.5. Triangulation results obtained from photogrammetry block

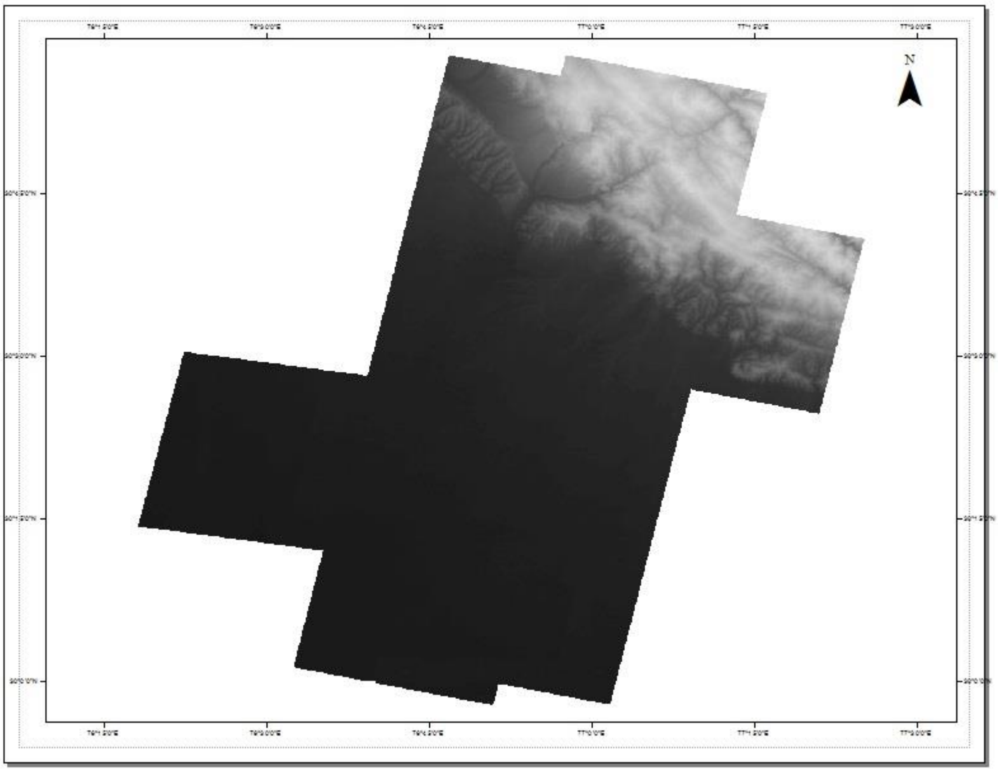


Figure 4.6. DEM for Tangri (Dangri) catchment and surroundings

4.4 TORRENTS' CHANGE DYNAMICS

The change dynamics of torrential regime in the Dangri (Tangri) river sub-watershed (marked as "A", figure 2.1) of Himalayan region was carried out using temporal Landsat satellite data. Landsat data acquired during last four decades are archived by Earth Resources Observation and Science (EROS) Centre, U.S. Geological Survey (USGS) (Woodcock et al., 2008). This vast data made available from Landsat series of satellites can be arranged into four groups as per their sensors' characteristics and is accessible through websites, namely Earth Explorer (EE) and Global Visualisation Viewer (GloVis). Landsat-1, 2 and 3 satellites with Multispectral Scanner (MSS) sensor and Return Beam Vidicon (RBV) camera onboard are part of first group. Landsat-4 and 5 satellites having Thematic Mapper (TM) sensor and MSS sensors are the part of second group. This era of Landsat satellites denoted the beginning of higher technological development with automated processing facility. Landsat-6 and 7 satellites with Enhanced Thematic Mapper (ETM) and Enhanced Thematic Mapper Plus (ETM+) sensors onboard form the third group. Landsat-8 satellite with sensors onboard, namely Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) launched in February, 2013 form the fourth group.

The radiometric calibration of image data acquired from multi-sensors is important for understanding the land surface change dynamics. It essentially involves computation of at-sensor spectral radiance. The time-series grey values (Q) of Landsat images made available from multi-sensors, namely MSS, TM, ETM+, and Advanced Land Imager (ALI) are radiometrically calibrated (Q_{cal}) and disseminated through web portals such that time-series images have equivalent radiometric scaling. In this process, the digital numbers (Q) are transformed to 32-bit absolute spectral radiance and later rescaled (Q_{cal}) to 7-bit for MSS, 8-bit for TM and ETM+, and 16-bit for products delivery through web portals. The Q_{cal} values are later transformed to at-sensor spectral radiance (L_λ) based on highest and lowest values based on following equations (Eq. 4.31 to Eq. 4.34):

$$L_\lambda = \frac{LMAX_\lambda - \mathrm{LMIN}_\lambda}{Q_{calmax} - Q_{calmin}} (Q_{cal} - Q_{calmin}) + \mathrm{LMIN}_\lambda \qquad \text{.......4.31}$$

Or,

$$L_\lambda = G_{rescale} * Q_{cal} * \mathrm{B}_{rescale} \qquad \text{.......4.32}$$

$$G_{rescale} = \frac{LMAX_\lambda - \mathrm{LMIN}_\lambda}{Q_{calmax} - Q_{calmin}} \qquad \text{.......4.33}$$

$$B_{rescale} = \mathrm{LMIN}_\lambda - \left(\frac{LMAX_\lambda - \mathrm{LMIN}_\lambda}{Q_{calmax} - Q_{calmin}}\right) Q_{calmin} \qquad \text{.......4.34}$$

Where, L_λ= radiance recorded at sensor's aperture [W/(m^2 sr µm)], Q_{cal}= calibrated value of a pixel [DN], Q_{calmin}= Minimum calibrated pixel value corresponding to $LMIN_\lambda$ [DN], Q_{calmax}= Maximum calibrated pixel value corresponding to $LMAX_\lambda$ [DN], $LMIN_\lambda$= Spectral at-sensor radiance scaled to Q_{calmin} [W/(m^2 sr µm)], $LMAX_\lambda$= Spectral at-sensor radiance scaled to Q_{calmax} [W/(m^2 sr µm)], $G_{rescale}$= Band-specific rescaling gain factor [(W/(m^2 sr µm))/DN] and $B_{rescale}$= Band-specific rescaling bias factor [W/(m^2 sr µm)] (Chander et al., 2009).

GEE contains voluminous information for temporal investigation and visualisation of Earth's natural resources. After the Landsat images are made openly accessible in 2008, Google blended and associated it to distributed computing resources i.e., GEE for analysing the Earth's resources. GEE incorporates satellite datasets from different platforms including numerous vector-based datasets. GEE's front-end provides a convenient platform for intuitive information extraction and algorithm advancement. It is also possible to include and process users' own data, while utilising Google's cloud assets. GEE permits to mine this huge information of last four decades for change detection and to measure and visualise Earth's resources (Google Earth Engine, 2012) (*https://earthengine.google.org/#intro*). It empowers to upload and downloading of worldwide satellite images just as enabling them to perform complex computations. It includes two primary components, namely Google Earth Engine Explorer (EEE) and Google Earth Engine Playground (EEP) which work in consonance. EEE is a data viewer and provides an interface to GEE data catalogue whereas EEP is a JavaScript Application Programming Interface (API) which helps in doing raster, vector and array operations (*https://code.earthengine.google.com/*).

The GEE platform contains vast repository of analysis ready data from Landsat series of satellites. This data and GEE platform was utilised in the present study to analyse temporal LULC and vegetation changes in the Tangri (Dangri) river and its surroundings. Within GEE, the Enhanced Vegetation Index (EVI) product can also be generated while utilising the Level L1 ortho-rectified product. The EVI is signified as (Eq. 4.35)-

$$EVI = \frac{2.5*(\rho_{nir} - \rho_{red})}{\rho_{nir} + 6*\rho_{red} - 7.5*\rho_{blue} + 1} \quad \text{.......4.35}$$

Where, ρ = atmospherically and cloud cover corrected surface reflectance for blue, red and near infrared bands. The EVI values range from -1 to 1 and help in measuring greenness over a terrain (Mokarram et al. 2015) where higher the values, better the quality of vegetation.

The Earth Engine (EE) Code Editor is an online Integrated Development Environment (IDE) tool for the EE JavaScript API. It is intended to make complex geospatial work processes into a quick and simple procedure. In the present study, using EE Code Editor, the API was coded and executed to analyse the temporal aspects of Tangri (Dangri) river watershed. Annexure-1 shows the API codes for analysing the LULC and vegetation change characteristics. The temporal satellite data was classified into four LULC categories following the supervised classification technique and using Classification and Regression Trees (CART) classifier. CART follows an analytical algorithm and is reported as highly useful to predict variables' values based on similarity from assigned samples. Shelestov et al. (2017) presented comparison of pixel-based approaches and investigated the proficiency of GEE based cloud platform for crop classification and mapping. They reported that the best performance was accomplished for CART at 75%, though Random Forest (RF) produced nearly 68%, Logistic Regression (LR) gave 72% accuracy and Multi Class Perceptron and Winnow, gave up to 60% accuracy, while an option of Support Vector Machine (SVM) yielded a modest accuracy of 57%.

Therefore, in the present study, the CART classifier was used for LULC classification of torrential environment. Typically in any torrential system, the LULC classes during the process of lateral migration and consequent watershed inhabitants' intervention fall under four major LULC categories, namely cropland/ fallow, orchard/plantation/forest, grass/scrub and dry-river-bed. Hence, these broad categories of LULC were used to classify multispectral data. As in the study area, the torrents migration was found to be contained within 200 m from river's centre line and several conservation measures are undertaken by various agencies within this reach, therefore, a buffer zone surrounding the torrents was generated with 200 m as distance value for torrents' change dynamics. The classified output was overlaid to assess the temporal changes in torrential regime. The methodology followed for change detection is described as figure 4.7.

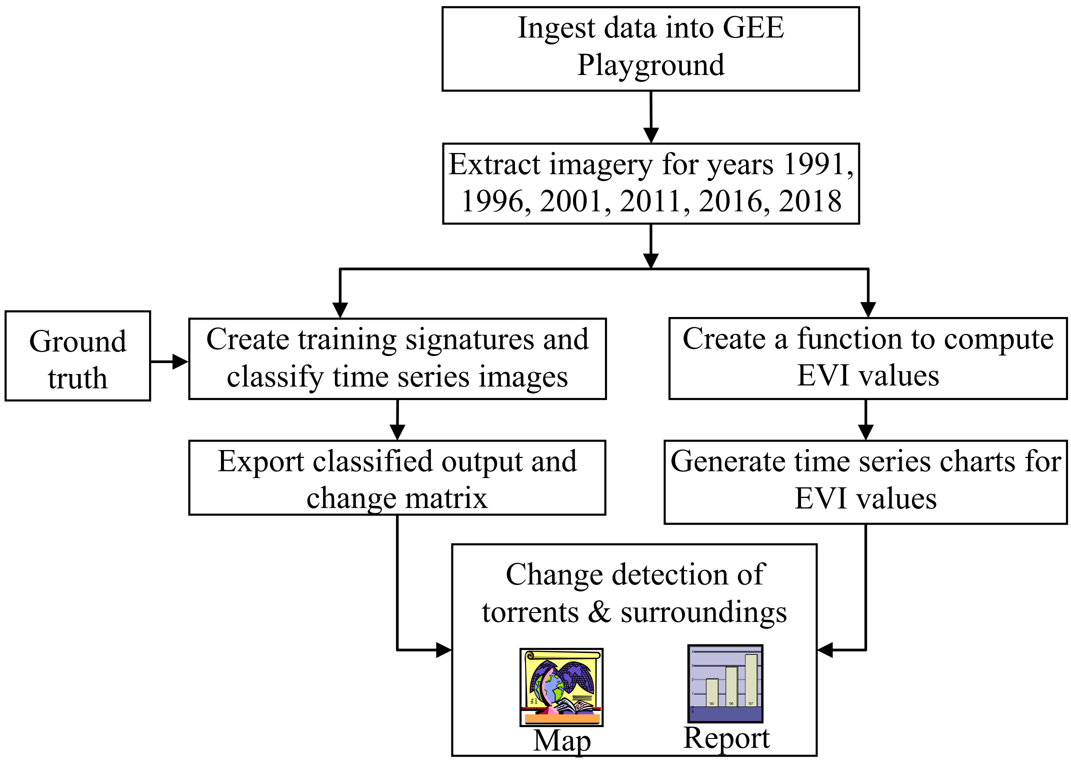


Fig. 4.7. Methodological framework within Google Earth Engine Playground using Javascript API

4.5 TORRENTS' VULNERABILITY ANALYSIS

The torrents' vulnerability analysis has been carried out using Saaty's AHP by developing a pair-wise comparison of parameters that affect the torrential regime. In a torrential regime the multitude of parameters, namely soil-cover complex, terrain, channel characteristics, proximity to river system, soil and water conservation measures, etc. play their role in understanding the vulnerability aspects to man and environment. Therefore, in the present study following six parameters, namely i) Catchment's Slope, ii) Soil characteristics, iii) LULC, iv) Proximity to torrents' flood plain, v) Proximity to conservation measures and vi) Channel characteristics were used for vulnerability analysis. Various kinds of conservation activities have been implemented by the development agencies in the watershed e.g., retaining walls, spurs, rejuvenation of water bodies, plantation of grasses and plants, etc. Along the Thathar ki Nadi, near its confluence with Tangri (Dangri), 36 spurs and retaining walls have been constructed. At other places too, some conservation measures were noticed. The locations of these conservation measures were collected using handheld GPS device and transferred to GIS database to carry out torrents' vulnerability analysis. Fig. 4.8 shows the overall methodology for torrents' vulnerability analysis.

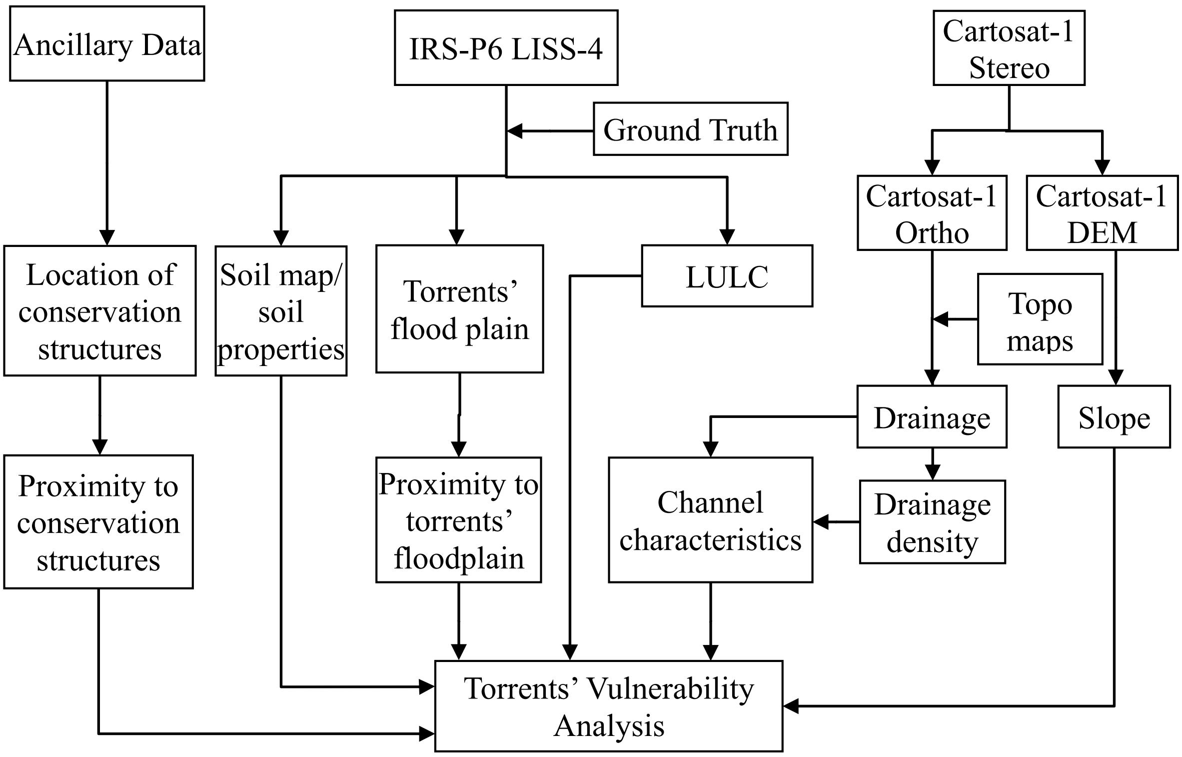


Fig 4.8. Methodology for torrents' vulnerability analysis

4.5.1 Parameters for Vulnerability Analysis

Six parameters, namely i) Catchment's Slope, ii) Soil characteristics, iii) LULC, iv) Proximity to torrents' flood plain, v) Proximity to conservation measures and vi) Channel characteristics were used for vulnerability analysis. The slope map was produced based on standard slope classification (NRCC, 1998). This classification scheme has methodically proven the association between runoff characteristics and slope of a given region. The slope layer was categorised into ten classes as leveled (0^{o} - 0.3^{o}), nearly leveled (>0.3^{o} - 1.1^{o}), very gentle sloping (>1.1^{o} - 3.0^{o}), gentle sloping (>3.0^{o} - 5.0^{o}), moderate sloping (>5.0^{o} - 8.5^{o}), strong sloping (>8.5^{o} - 16.5^{o}), very strong sloping (>16.5^{o} - 24^{o}), extreme sloping (>24^{o} - 35^{o}), steep sloping (>35^{o} - 45^{o}), and very steep sloping (>45^{o} -

90^o) with least weightage given to leveled and gentle slope, and higher weightages were given to acute slopes in upstream region of the catchment or the steep slopes along valleys. The physiographic-cum-soil association map was classified into 16 classes, namely A1, A2, P11, P12, P13, P21, P22, T, H11, H12, H13, H21, H22, M1, M2 and V. The description of these classes have been provided under section 5.3.1.1.

The drainage density was categorised into five classes as 0.04-2.13, >2.13-4.21, >4.21-6.30, >6.30-8.38 and >8.38-10.47 km/ sq. km and used for describing the channel characteristics. The torrential channel characteristics were also described as bed-width (m) and meander (degree). These properties were obtained with measurements from satellite data and during field visits. The channel bed-width was categorised into five classes, namely 0 - 15 m, >15 - 30 m, >30- 45 m, >45 - 60 m and >60 - 75 m. The torrents' meander angles have been estimated interactively using the satellite data at numerous river sections. The channels' meander angle was expressed in degrees as follows: i) 0^o-30^o/ >330^o-360^o, ii) >30^o-60^o/ >300^o-330^o, iii) >60^o-90^o/ >270^o-300^o, iv) >90^o-120^o/ >240^o-270^o, v) >120^o-150^o/ >210^o-240^o and vi) >150^o-210^o. Towards understanding the channel characteristics of torrential system, the stream width has been measured at several places on the ground.

Table 4.4. Importance matrix for torrents' vulnerability analysis

Parameter	Importance
Channel characteristics	- Slightly more significant than proximity to torrents' flood plain - Slight to more significant than proximity to conservation measures - More significant than soil characteristics - Strongly more significant than LULC - Absolutely more significant than catchment's slope
Proximity to torrents' flood plain	- Slightly more significant than proximity to conservation measures - Slight to more significant than soil characteristics - More significant than LULC - Strongly more significant than catchment's slope
Proximity to conservation measures	- Slightly more significant than soil characteristics - Slight to more significant than LULC - More significant than catchment's slope
Soil characteristics	- Slightly more significant than LULC - Slight to more significant than catchment's slope
LULC	- Slightly more important than catchment's slope

Table 4.5. Pairwise comparison matrix and weights derived for various parameters influencing the vulnerability of torrential surfaces

Parameters	1	2	3	4	5	6
1	1	3	4	5	7	9
2	0.33	1	3	4	5	7
3	0.25	0.33	1	3	4	5
4	0.20	0.25	0.33	1	3	4
5	0.14	0.20	0.25	0.33	1	3
6	0.11	0.14	0.20	0.25	0.33	1
Weights	**0.439**	**0.253**	**0.146**	**0.085**	**0.049**	**0.028**

1: Channel characteristics, 2: Proximity to torrents' flood plain, 3: Proximity to conservation measures, 4: Soil characteristics, 5: LULC, and 6: Catchment's Slope.

Various agencies have laid conservation structures in proximity to torrential areas such as retaining walls and spurs (attractive and deflective type). The weights were assigned to each category. The upstream LULC characteristics were identified using multispectral satellite data into following classes in the whole watershed region: cropland, fallow, terrace cultivation, plantation, dense forest, open forest, scrub land, water body and settlements. The weights were apportioned to each LULC class based on their sensitivity to erosion and surface runoff. The buffers were generated surrounding the torrents and the proximity to current torrent floodplain (m) was put into five buffer regions as 200 m, 400 m, 600 m, 800 m and 1000 m. Using importance matrix for torrent vulnerability analysis (Table 4.4), weights for six parameters based on Eigen vector method were derived. These weightages were multiplied with feature class attributes to compute Composite Vulnerability Index (CVI). The CVI coverage was reclassified into five categories to prepare the torrent vulnerability classes. Table 4.4 shows the importance matrix for torrents' vulnerability analysis based on Saaty's principle and table 4.5 shows the weights derived for various parameters which influence the vulnerability of torrential surfaces.

As could be seen from the Table 4.5 that highest weightage was obtained for channel characteristics (43.9%) whereas the least weightage was obtained for catchment's slope (2.8%). C_r was obtained as 6.2% with Principal Eigen value as 6.387 and the number of comparisons as 15. As the C_r value is less than 10%, the analysis showed an acceptable consistency. Principal Eigenvector bears highest eigenvalue of matrix and signifies importance extracted from a positive reciprocal near consistent pairwise comparison matrix. It was also found to be within reasonable limits.

4.5.2 Weights of Sub-parameters

The weights of various sub-parameters were similarly derived using the Saaty's importance matrix and used for vulnerability analysis. The relative importance of various sub-parameters was set in discussion with experts and two-dimensional importance matrices were built for each parameter. After deriving the weights, the consistency ratio was analysed.

a. Channel characteristics

The channel characteristics were determined based on the cumulative effect of three sub-parameters, namely torrents' width, meander angle and drainage density. The importance matrices were built to derive the weightages of various sub-features. Table 4.6 shows the importance matrix and weights derived for various sub-classes defined based on torrential stream width. The channel bed-width was categorised into five classes, namely 0 - 15 m, >15 - 30 m, >30 - 45 m, >45 - 60 m and >60 - 75 m.

Table 4.6. Importance matrix and weights derived for torrents' width

Sub-parameter	**0 – 15 m**	**>15 – 30 m**	**>30 – 45 m**	**>45 – 60 m**	**>60 – 75 m**
0 – 15 m	1	3	5	7	9
>15 - 30 m	0.33	1	3	5	7
>30 – 45 m	0.20	0.33	1	3	5
>45 – 60 m	0.14	0.20	0.33	1	3
>60 – 75 m	0.11	0.14	0.20	0.33	1
Sub-weights	0.51	0.26	0.13	0.06	0.03

As could be seen from the Table 4.6 that highest weightage is obtained for sub-class 0 - 15 m (0.51) whereas the least weightage is obtained for sub-class >60 m - 75 m (0.03). C_r is obtained as 5.3% with Principal Eigen value as 5.237 and the number of comparisons as 10. As the C_r value was less than 10%, the analysis showed an acceptable consistency. The Principal Eigenvector was also found to be within reasonable limits.

Table 4.7. Importance matrix and weights derived for torrents' meander angle

Parameters	>150º-210º	>120º-150º/ >210º-240º	>90º-120º/ >240º-270º	>60º-90º/ >270º-300º	>30º-60º/ >300º-330º	0º-30º/> 330º-360º
>150º-210º	1	0.33	0.25	0.2	0.14	0.11
>120º-150º/ >210º-240º	3	1	0.5	0.25	0.17	0.12
>90º-120º/ >240º-270º	4	2	1	0.33	0.2	0.14
>60º-90º/ >270º-300º	5	4	3	1	0.33	0.2
>30º-60º/ >300º-330º	7	6	5	3	1	0.33
0º-30º/ >330º-360º	9	8	7	5	3	1
Sub-weights	0.028	0.047	0.068	0.132	0.255	0.471

The torrents' meander angle was sub-categorised into six classes as i) 0º-30º/ >330º-360º, ii) >30º-60º/ >300º-330º, iii) >60º-90º/ >270º-300º, iv) >90º-120º/ >240º-270º, v) >120º-150º/ >210º-240º and vi) >150º-210º, wherein the torrents meandering at acute angles were assigned higher weightages whereas the straight sections were considered to be less vulnerable. As could be seen from the Table 4.7 that highest weightage was obtained for sub-class 0º-30º/ 330º-360º (47.10%) whereas the least weightage is obtained for sub-class >150º-210º (2.80%). C_r was obtained as 5.8% with Principal Eigen value as 6.365 and the number of comparisons as 15. As the C_r value was less than 10%, the analysis showed an acceptable consistency. The Principal Eigenvector was also found to be within reasonable limits.

Similarly, the torrents' drainage density was sub-categorised into five classes as i) 0.04 - 2.13, ii) >2.13 - 4.21, iii) >4.21 - 6.30, iv) >6.30 - 8.38 and v) >8.38 - 10.47 km/ sq. km, wherein the lower drainage density was assigned less weightages whereas the torrential sections having higher density was considered to be highly vulnerable. As could be seen from the Table 4.8 that highest weightage was obtained for sub-class >8.38-10.47 km/ sq. km (0.51) whereas the least weightage was obtained for sub-class 0.04-2.13 km/ sq. km (0.03). C_r was obtained as 5.3% with Principal Eigen value as 5.237 and the number of comparisons as 10. As the C_r value was less than 10%, the analysis showed an acceptable consistency. The Principal Eigenvector was also found to be within reasonable limits.

Table 4.8. Importance matrix and weights derived for drainage density

Parameters	**0.04-2.13**	**>2.13-4.21**	**>4.21-6.30**	**>6.30-8.38**	**>8.38-10.47**
0.04-2.13	1	3	5	7	9
>2.13-4.21	0.33	1	3	5	7
>4.21-6.30	0.20	0.33	1	3	5
>6.30-8.38	0.14	0.20	0.33	1	3
>8.38-10.47	0.11	0.14	0.20	0.33	1
Sub-weights	**0.03**	**0.06**	**0.13**	**0.26**	**0.51**

b. Proximity to torrents' flood plain

In order to assess the weights based on proximity to torrents' flood plain, the buffers were generated surrounding the torrents and proximity to current torrent floodplain (m) were classified into five buffer regions as 200 m, 400 m, 600 m, 800 m and 1000 m. Subsequently, the importance matrix was generated to compute weights for various sub-parameters. As could be seen from Table 4.9 that highest weightage was obtained for sub-class 200 m (0.51) whereas the least weightage was obtained for sub-class 1000 m (0.03). C_r was obtained as 5.3% with Principal Eigen value as 5.237 and the number of comparisons as 10. As the C_r value was less than 10%, analysis showed an acceptable consistency. Principal Eigenvector was also found to be within reasonable limits.

Table 4.9. Importance matrix and weights based on proximity to torrents' floodplain

Parameters	200 m	400 m	600 m	800 m	1000 m
200 m	1	3	5	7	9
400 m	0.33	1	3	5	7
600 m	0.20	0.33	1	3	5
800 m	0.14	0.20	0.33	1	3
1000 m	0.11	0.14	0.20	0.33	1
Sub-weights	**0.51**	**0.26**	**0.13**	**0.06**	**0.03**

c.   Proximity to conservation measures

Various agencies have laid conservation structures in proximity to torrential areas such as retaining walls and spurs (attractive and deflective type), etc. The importance was assigned to each category - i) Biological works in valleys and flood plains, ii) Attractive type spur, iii) Deflective type spur and iii) Retaining walls. Subsequently, the relative importance matrix was generated to compute weights for various sub-parameters. As could be seen from the Table 4.10 that highest weightage was obtained for sub-class 'Retaining walls' (0.33) whereas the least weightage was obtained for sub-class 'Biological works' (0.19). C_r was obtained as 5.7% with Principal Eigen value as 4.154 and the number of comparisons as 6. As the C_r value was less than 10%, the analysis showed an acceptable consistency. The Principal Eigenvector was also found to be within reasonable limits.

Table 4.10. Importance matrix and weights derived based on conservation measures

Parameters	**1**	**2**	**3**	**4**
1	1	1	1	3
2	1.00	1	1	1
3	1.00	1.00	1	1
4	0.33	1.00	1.00	1
Sub-weights	**0.19**	**0.24**	**0.24**	**0.33**

1: Biological works, 2: Attractive type spur, 3: Deflective type spur and 4: Retaining walls.

d. Soil characteristics

The physiographic-cum-soil association map was classified into following 16 classes, namely A1, A2, P11, P12, P13, P21, P22, T, H11, H12, H13, H21, H22, M1, M2 and V. The description of these classes are given in section 5.3.1.1. The weights were assigned to each category based on their vulnerability characteristics. Subsequently, the relative importance matrix was generated to compute weights for various sub-parameters. As could be seen from the Table 4.11 that highest weightage was obtained for sub-class 'A2' (0.1881) whereas the least weightage was obtained for sub-class 'M1' (0.0097). C_r was obtained as 4.8% with Principal Eigen value as 17.156 and the number of comparisons as 120. As the C_r value was less than 10%, the analysis showed an acceptable consistency. The Principal Eigenvector was also found to be within reasonable limits.

e. Slope characteristics

The slope layer was categorised into ten classes as leveled (0^o - 0.3^o), nearly leveled (>0.3^o - 1.1^o), very gentle sloping (>1.1^o - 3.0^o), gentle sloping (>3.0^o - 5.0^o), moderate sloping (>5.0^o - 8.5^o), strong sloping (>8.5^o - 16.5^o), very strong sloping (>16.5^o - 24^o), extreme sloping (>24^o - 35^o), steep sloping (>35^o - 45^o), and very steep sloping (>45^o - 90^o) with least weightage given to leveled and gentle slope, and higher weightage given to acute slopes in upstream region of the catchment or the steep slopes along valleys. The weights were assigned to each category based on their vulnerability characteristics. Subsequently, the relative importance matrix was generated to compute weights for various sub-parameters. As could be seen from the Table 4.12 that highest weightage was obtained for sub-class '>45° - 90°' (0.272) whereas the least weightage was obtained for sub-class '>0.3° - 1.1°' (0.018). C_r was obtained as 1.9% with Principal Eigen value as 10.252 and the number of comparisons as 120. As the C_r value was less than 10%, the analysis showed an acceptable consistency. The Principal Eigenvector was also found to be within reasonable limits.

f. LULC characteristics

Following LULC classes were identified in the whole watershed region: crop land, fallow, terrace cultivation, plantation, dense forest, open forest, scrub, water body and settlements. The weights were apportioned to each LULC class based on their sensitivity to erosion and surface runoff. Subsequently, the relative importance matrix was generated to compute weights for various sub-parameters. As could be seen from the Table 4.13 that highest weightage was obtained for sub-class 'Settlements' (0.290) whereas the least weightage was obtained for sub-class 'Dense forest' (0.020). C_r was obtained as 1.8% with Principal Eigen value as 10.234 and the number of comparisons as 45. As the C_r value was less than 10%, the analysis showed an acceptable consistency. Principal Eigenvector was also found to be within reasonable limits.

Table 4.11. Importance matrix and weights derived based on soil characteristics

	M1	H12	H22	P21	M2	H13	P11	H11	H21	P12	P22	T	A1	P13	V	A2
M1	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20	0.20	0.17	0.17	0.14	0.14	0.13	0.11	0.11
H12	2	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20	0.20	0.17	0.17	0.14	0.14	0.13	0.11
H22	2	2	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20	0.20	0.17	0.17	0.14	0.14	0.13
P21	3	2	2	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20	0.20	0.17	0.17	0.14	0.14
M2	4	3	2	2	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20	0.20	0.17	0.17	0.14
H13	4	4	3	2	2	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20	0.20	0.17	0.17
P11	4	4	4	3	2	2	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20	0.20	0.17
H11	5	4	4	4	3	2	2	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20	0.20
H21	5	5	4	4	4	3	2	2	1	0.50	0.50	0.33	0.25	0.25	0.25	0.20
P12	6	5	5	4	4	4	3	2	2	1	0.50	0.50	0.33	0.25	0.25	0.25
P22	6	6	5	5	4	4	4	3	2	2	1	0.50	0.50	0.33	0.25	0.25
T	7	6	6	5	5	4	4	4	3	2	2	1	0.50	0.50	0.33	0.25
A1	7	7	6	6	5	5	4	4	4	3	2	2	1	0.50	0.50	0.33
P13	8	7	7	6	6	5	5	4	4	4	3	2	2	1	0.50	0.50
V	9	8	7	7	6	6	5	5	4	4	4	3	2	2	1	0.50
A2	9	9	8	7	7	6	6	5	5	4	4	4	3	2	2	1
Weights	0.0097	0.0114	0.0135	0.0165	0.0204	0.0251	0.0305	0.0377	0.0461	0.0570	0.0695	0.0855	0.1051	0.1285	0.1554	0.1881

Table 4.12. Importance matrix and weights derived based on slope characteristics

	0 - 0.3	>0.3 - 1.1	>1.1 - 3.0	>3.0 - 5.0	>5.0 - 8.5	>8.5-16.5	>16.5-24.0	>24.0-35.0	>35.0-45.0	>45.0-90.0
0 - 0.3	1	0.5	0.5	0.33	0.25	0.2	0.17	0.14	0.12	0.11
>0.3 - 1.1	2	1	0.5	0.5	0.33	0.25	0.2	0.17	0.14	0.12
>1.1 - 3.0	2	2	1	0.5	0.5	0.33	0.25	0.2	0.17	0.14
>3.0 - 5.0	3	2	2	1	0.5	0.5	0.33	0.25	0.2	0.17
>5.0 - 8.5	4	3	2	2	1	0.5	0.5	0.33	0.25	0.2
>8.5-16.5	5	4	3	2	2	1	0.5	0.5	0.33	0.25
>16.5-24.0	6	5	4	3	2	2	1	0.5	0.5	0.33
>24.0-35.0	7	6	5	4	3	2	2	1	0.5	0.5
>35.0-45.0	8	7	6	5	4	3	2	2	1	0.5
>45.0-90.0	9	8	7	6	5	4	3	2	2	1
Weights	**0.018**	**0.024**	**0.032**	**0.043**	**0.06**	**0.082**	**0.113**	**0.153**	**0.203**	**0.272**

Table 4.13. Importance matrix and weights derived based on LULC characteristics

Sub-classes	Dense forest	Open forest	Scrub forest	Scrub land	Fallow	Orch./Plnt.	Terrace cultivation	Waterbody	Cropland	Settlement
Dense forest	1	1	0.5	0.33	0.25	0.2	0.17	0.14	0.12	0.11
Open forest	1	1	1	0.5	0.33	0.25	0.2	0.17	0.14	0.12
Scrub forest	2	1	1	1	0.5	0.33	0.25	0.2	0.17	0.14
Scrub land	3	2	1	1	1	0.5	0.33	0.25	0.2	0.17
Fallow	4	3	2	1	1	1	0.5	0.33	0.25	0.2
Orch./Plnt.	5	4	3	2	1	1	1	0.5	0.33	0.25
Terrace cultivation	6	5	4	3	2	1	1	1	0.5	0.33
Waterbody	7	6	5	4	3	2	1	1	1	0.5
Cropland	8	7	6	5	4	3	2	1	1	0.33
Settlements	9	8	7	6	5	4	3	2	3	1
Weights	**0.020**	**0.024**	**0.032**	**0.043**	**0.060**	**0.082**	**0.113**	**0.152**	**0.184**	**0.290**

4.6 HYDROLOGICAL HAZARD ASSESSMENT

Usually, the hydrological risks (such as floods) in time-space domain occur whenever the incoming events equal or exceed their return period and channel carrying capacity and thus, the risk assessment requires computational hydraulic-hydrologic models. This phenomenon is far more dynamic in a torrential watershed and the catchment's physical characteristics could better be understood using satellite remote sensing database. In the present study, the data from following sources were used to draw information required for hydrological risk modeling: a) remote sensing data to analyse the physical characteristics of torrential watershed and hydrodynamic properties of torrential river, b) DEM of study area, c) hydro-meteorological characteristics, and d) software to analyse the hydrologic and hydrodynamic properties of the channel and the watershed. This section further describes the data and models used in the present study for hydrological hazard assessment.

4.6.1 Rainfall Frequency Analysis (RFA)

The goal of rainfall frequency analysis (RFA) in precipitation-runoff relationship is to relate resultant rainfall intensity with different probabilities of exceedance. The RFA assumes crucial part in giving information on likely recurrence of flood events which is utilised as a part of planning structures like dams, levees, expressways, sewage plants, waterworks and other hydraulic structures. The statistical tools assist in flood frequency estimates and are highly useful to draw ideal plans suitable for hydraulic structures, and to avert over-planning or under outlining. Such appraisals are also helpful in giving an estimation of parameters to assess the likely damages relating to specific flows amid floods. Alongside the hydraulic design, RFA are additionally helpful in flood insurance and flood zoning exercises. The strategies utilised for flood recurrence investigation ranges from the analysis of statistical distribution to simulation approaches. The popular statistical methods are Gumbel, Normal, Log-normal, Exponential, Weibull, Pearson and Log-Pearson. The precise RFA analysis is desirable for designing of hydraulic structures and for prevention and maintenance during and post flood hazards. The RFA analysis has got a strong linkage with rainfall return period. Generally, the return period, which is additionally considered as recurrence interval, also represents the probability of any occasion such as floods or drought in the given time interval (Reed, 1994).

4.6.1.1 Intensity-Duration-Frequency curves (IDF curves)

RFA, which is required for hydrological risk assessment and also for designing of various hydraulic structures is usually assessed based on Intensity-Duration-Frequency (IDF) curve which portrays the probability of exceedance of a given intensity of rainfall and derived after building the relationship between rainfall intensity and duration, and its frequency. It represents the extreme rainfall characteristics of a region for varying return periods. In flood risk analysis, this information helps to understand that when an area will get flooded and the probable peak flow that will occur from the watershed.

IDF curves are typically estimated with annual maxima analysis of historical precipitation data, assuming there is no change in climate or other factors. Usually, the RFA is conducted for analysing probability exceedance distribution function using rainfall data with either i) building an empirical plot of observed data to analyse exceedance probabilities or ii) After fitting a hypothetical Extreme Value (EV) distribution (e.g., Gumbel Type I) to evaluate rainfall data associated with varying exceedance probabilities. In the present study, the Gumbel Type I distribution was used to analyse the rainfall characteristics.

4.6.1.2 Gumbel distribution

Gumbel distribution is a statistical strategy frequently utilised for modeling extreme hydrological events, for example, floods. Gumbel distribution which depends on extreme value theory and popularly used to determine design parameters of hydraulic structures has been applied in the present study to examine the rainfall pattern as the river is less regulated, consequently isn't essentially influenced by reservoir operations or major extent of urbanisation in the catchment. Gumbel distribution also knows as Extreme Value Type-I distribution is unbounded when defined on real axis (Koutsoyiannis, 2004). Gumbel’s distribution with a return period, T is given as Eq. 4.36.

$$X_T = \bar{X} + K_T \, \sigma_x \qquad \text{........ 4.36}$$

Where $\bar{X}$ and σ_x are mean and standard deviation of hydrological observations. The frequency factor associated with return period T, K_T is given by

$$K_T = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left(\ln\left(\frac{T}{T-1}\right)\right)\right] \qquad \text{........ 4.37}$$

4.6.2 Soil Loss Estimates

The soil loss from a torrential regime has been computed in the present study using RUSLE technique with the assumption that stream contributes to major flow or a deposition. RUSLE technique computes the average erosion rate from a catchment which can vary depending on the rainfall, slope and soil characteristics. RUSLE method doesn't evaluate the amount of sediment released from a watershed but it assesses the soil movement from a land parcel (Agassi, 1996). The RUSLE and USLE techniques alike are articulated as given hereunder-

$$A = R * K * LS * C * P \qquad \text{.......4.38}$$

Where, A= average annual soil loss in tons/ ha/ year, R= rainfall-runoff erosivity factor, K= soil erodibility factor, L= slope length factor, S= slope steepness factor, C= cover-management factor, and P= support practice factor.

Figure 4.9 describes the methodology followed for soil erosion modelling in Tangri (Dangri) river sub-watershed in the present study. LULC information (please refer section 5.2.2) was produced by utilising the IRS LISS-4 data with supervised classification approach and maximum likelihood technique. R-factor was estimated using the rainfall information of study area. The physiography-cum-soil-association map was used to analyse K-factor. LULC data was utilised to infer the C and P factor of RUSLE model. LS factor is a resultant product of DEM produced from the Cartosat-1 stereo data. The detailed methodology for deriving various factors are given in subsequent sections of this chapter.

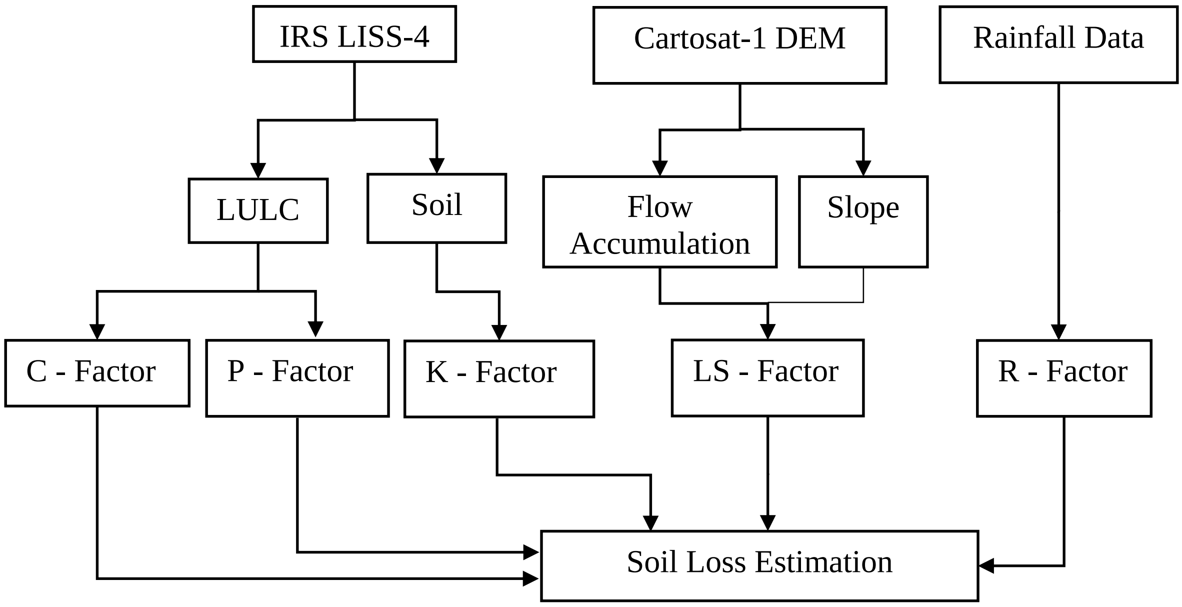


Fig. 4.9. Methodology for soil erosion modelling in Tangri (Dangri) river sub-watershed

4.6.2.1 Rainfall erosivity (R) factor

Rainfall erosivity (R) factor is a long-term yearly average and a derivative of kinetic-energy and intensity of rainfall (for 30 minutes and expressed in mm/ hour). It represents the strength of rainfall to cause erosion and detachment of soil particles (Wischmeier and Smith, 1978). The empirical formulae are available to assess R factor for various catchments in the world. Singh et al. (1981) have built association between R factor and annual/ seasonal rainfall (X) using rainfall data collected from 45 stations across the country. Using this method and based on regression analysis, the correlation coefficient was observed as 0.83 for yearly and 0.88 for seasonal regression equations, respectively. The relationship is articulated as given hereunder-

$$R_a = 79 + 0.363*X_a \qquad \text{…….4.39}$$

$$R_s = 50 + 0.389 * X_s \quad \text{........4.40}$$

Where, R_a and R_s are annual average and seasonal erosivity index, respectively and X_a and X_s are normal yearly and seasonal rainfall (mm), respectively. The information from meteorological station at Ambala which received normal yearly precipitation of 919 mm per year and normal seasonal rainfall of 741 mm/ year (June - September) was used in this study. Accordingly, rainfall-erosivity index was evaluated as 412.6 MJ mm ha^{-1} hr^{-1} per year using Eq. 4.39.

4.6.2.2 Soil erodibility (K) factor

It reflects feebleness of soils to erosion which is governed by parent material, texture, structure, organic matter content, porosity, and so forth (Wischmeier and Smith, 1978). The K factor for various soil types are computed as defined in Eq. 4.41.

$$K = [(2.1 * 10^{-4} * M^{1.14}(12 - OM) + 3.25 * (s - 2) + 2.5 * (p - 3))/100] * 0.1317 \quad \text{....4.41}$$

where M represents textural factor [(m_{silt} + m_{vfs}) * (100 - m_c)], m_c (%) is clay fraction (<0.002 mm), m_{silt} (%) is silt fraction (0.002 – 0.05 mm) and m_{vfs} (%) is very fine sand fraction (0.05 – 0.1 mm); OM (%) is organic matter content; s represents soil structure (1: very fine granular, 2: fine granular, 3: medium or coarse granular, and 4: blocky, platy or massive); and p is permeability class (1: very rapid, …, 6: very slow).

4.6.2.3 Slope length (L) and steepness (S) factors

As stated in section 4.3, the DEM was produced from Cartosat-1 stereo data with raster cell-size of 10 m using LPS. This DEM information was utilised to produce land surface gradient, slope length (L) and steepness (S) factors. The average percentage slope was also computed based on difference of its elevation and surrounding eight neighboring pixels. LS factor is a derivative of L and S factors, in which L factor governs detachment and S factor controls the movement of soil particles. L factor was substituted with A(r) ($m^2\ m^{-1}$) factor which governs upslope contributing area per unit width (Mitasova et al., 1996) and defined as follows:

$$L * S_{(r)} = (m+1) * \left[\frac{A_{(r)}}{22.13}\right]^{m} * \left[\frac{sin\beta_{(r)}}{0.09}\right]^{n} \qquad \text{.......4.42}$$

Where, $\beta_{(r)}$ = land surface slope (degrees), and m, n are constants with values as 0.6 and 1.3, respectively.

4.6.2.4 Crop management (C) and management practice (P) factors

C and P factors were estimated while considering a progression of sub-factors that include LULC, vegetation characteristics and surface roughness in RUSLE technique (Renard, 1991). Some information as related to the conservation practices and its linkages with LULC types were gathered from field and assigned to each LULC class.

4.6.3 Hydrologic and Hydrodynamic Modeling

GIS based flood modeling is a blend of four components, i.e. geospatial information, a tool for floodplain mapping and visualisation, hydrologic and hydraulic model. In this study, DEM data was pre-processed to produce fill-sink, flow direction, flow accumulation, stream segment processing and finally, the watershed delineation (Jenson, 1988) was done. The longest flow path was computed and used for computing the time of travel. The centroidal flow path was determined, which is distance/ path along longest flow length connected with watershed centroid and pour point of a sub-catchment. Later, the DEM was utilised to set-up model for flood progression. The peak flow determination is essential in disaster management and also for flood mitigation structures design. Hence, in this study, the peak discharge estimation was done for rainfall frequencies of different return periods. The peak flows for two, five, ten, twenty-five, fifty, hundred and thousand years' average recurrence intervals were obtained by conducting rainfall frequency analysis, as explained earlier. The steps followed with the hydraulics modeling to translate the discharges into water levels, and finally the inundated areas for river discharge of varying return periods are given in subsequent sections.

4.6.3.1 Hydrologic modelling

a. Watershed and drainage delineation

The DEM derived from Cartosat-1 stereo pairs was pre-processed in HEC-HMS environment for catchment's hydrologic properties extraction. Initially, the DEM with depression-filled was created. Later, the flow direction for each pixel with a binary sequence (1, 2, 4, 8, 16, 32, 64 and 128) was computed. These binary sequence represent the flow direction starting from north-east to north in clock-wise direction. The flow accumulation dataset was built with flow direction layer as input. The cells with flow accumulation value as zero represents the ridge. It is feasible to form the drainage pattern based on flow accumulation values and as its threshold increases, the density of drainage decreases (higher threshold represents higher order drainage system) (Jenson, 1988). Later, the watersheds were delineated using flow accumulation data with a user defined catchment size threshold either automatically for whole area or interactively with seed points defined. Figure 4.10 shows the broad methodology demonstrating the watershed and drainage delineation (Jenson and Domingue, 1988).

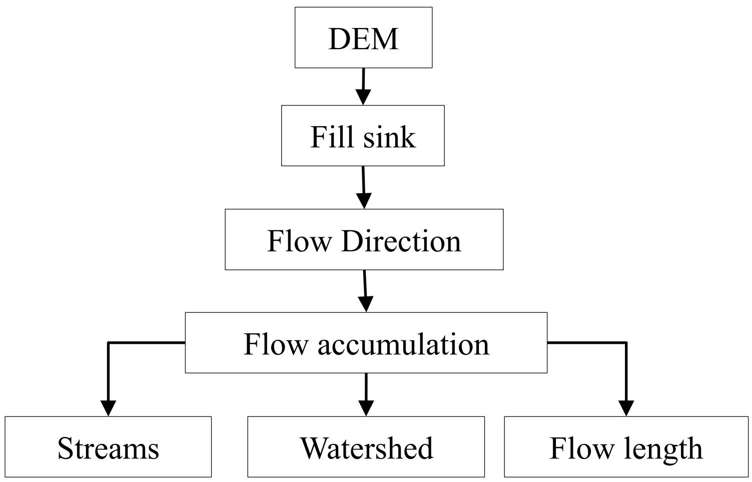


Fig. 4.10. Broad methodology demonstrating the watershed and drainage delineation

b. Runoff Curve Number (CN)

SCS runoff CN technique is established by USDA-SCS and widely used to compute the depth of runoff emanating from a catchment (Hjelmfelt, 1991). The runoff CN is a dimensionless entity that ranges between 0 and 100 and depends on soil type, LULC and AMC of catchment area. Subramanya (2013) emphasised on the simplicity of SCS method as it depends only on one parameter, i.e. CN. The value of CN is dictated by the AMC, hydrologic conditions and soil characteristics. SCS method with its several advantages has some disadvantage as well as with regard to assessing the initial abstraction ratio, which depends on the AMC conditions. This method was initially established for agricultural watersheds but has found usage world-wide far beyond its original developers would have imagined (Hjelmfelt, 1991). Kumar et al. (1991) established the SCS runoff CN from IRS-1A LISS-II for Kaliaghai watershed, Midnapore district, West Bengal. This method is proven to be useful, dependable and yields results with lesser inputs (Mishra & Singh 2004). Since 1994, SCS method is known as NRCS method and is computed as follows:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad \text{......4.43}$$

Where S is a function of CN as given in Eq. 4.44.

$$S = \left(\frac{25400}{CN}\right) - 254 \quad \text{......4.44}$$

Where, CN = runoff curve number; Q = direct runoff, mm; P = storm event rainfall, mm; and S = potential maximum retention of water by soil, mm. SCS unit hydrograph technique is chosen for this investigation for runoff analysis based on effective rainfall. The peak flow hydrograph (Q_P) and time to peak of unit hydrograph (t_P) are predicted based on following equations:

$$Q_p = \frac{0.208A}{t_p}$$ ……4.45

Where t_p is defined as given in Eq. 4.45.

$$t_p = \frac{D}{2} + t_l$$ ……4.46

Where t_l is defined as given in Eq. 4.46.

$$t_l = \frac{L^{0.8}(S+1)^{0.7}}{(1900)Y^{0.5}}$$ ……4.47

Where, Q_p = peak flow of unit hydrograph, A = watershed area, t_p = time to peak of unit hydrograph, D = time interval, t_l = lag time between centre of mass of excess rainfall, L = hydraulic length, S = potential maximum retention of water by soil, and Y = average slope (Chen and Liew, 2002).

Table 4.14. Hydrological soil groups (HSG) classification

HSG	Soil texture	Runoff potential	Water transmission	Infiltration
A	Deep, well drained sands and gravels	Low	High rate	> 7.5
B	Moderately deep, well drained with Moderate texture	Moderate	Moderate rate	3.8–7.5
C	Clay loam, shallow sandy loam soils with moderate to fine textures	Moderate	Moderate rate	1.3–3.8
D	Clay soils that swell significantly when wet	High	Low rate	< 1.3

Source: *https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/texas/TX453/0/Travis.pdf*

Table 4.15. Antecedent moisture condition (AMC)

AMC Group	Soil characteristics	Five-day antecedent rainfall in mm	
		Dormant season	Growing season
I	Wet condition	Less than 13	Less than 36
II	Average condition	13–28	36–53
III	Heavy rainfalls	Over 28	Over 53

Source: National Engineering Handbook 4 (USDA, 1985)

Table 4.16. NRCS Curve number (CN) values for hydrologic-soil-cover complex

Sl. No.	LULC class	Hydrologic soil group			
		A	B	C	D
1	Cropland	76	86	90	93
2	Fallow	68	79	86	89
3	Orchard/ Plantation	39	55	67	71
4	Dense forest	26	40	58	61
5	Open forest	28	44	60	64
6	Scrub forest	33	47	64	67
7	Land with/ without scrub	71	80	85	88
9	Settlement	98	98	98	98
10	Road	98	98	98	98

Table 4.14 describes characteristics of various Hydrological Soil Groups (HSGs) that governs the CN values. "HSG 'A' is deep, well drained sands and gravels having low runoff potential and high rate of water transmission (>7.5 mm). HSG 'B' is moderately deep, well drained with moderate runoff potential and moderate rate of water transmission (3.8 mm - 7.5 mm). HSG 'C' has clay loam, shallow sandy loam soils with moderate to fine textures having moderate runoff potential and moderate rate of water transmission (1.3 mm - 3.8 mm). HSG 'D' has clay soils that swell significantly when wet and having high runoff potential and low rate of water transmission (< 1.3 mm) (*https://directives.sc.egov.usda.gov/OpenNonWeb Content.aspx? content=17757.wba*)".

Table 4.15 lists the AMC characteristics of various soils. The AMC group is decided based on five-day antecedent rainfall for growing or wet season. Table 4.16 shows the NRCS CN values as used for various hydrologic-soil-cover-complex of catchment. As could be seen from the table 4.16, CN for various hydrologic-soil-cover-complex of Tangri (Dangri) river catchment varied from 26 to 98. The lowest value pertains to dense forest with HSG 'A' class whereas the highest value is for impervious surfaces.

c. Channel Routing Methods

HEC-HMS has six channel routing methods for simulating flow in open channels, namely Kinematic wave routing, Lag routing, Modified Puls routing, Muskingum routing, Muskingum-cunge routing, and Straddle Stagger routing. The routing with no constriction can be demonstrated with lag technique. Muskingum strategy is incorporated alongside the straddle stagger method for better approximations of constrictions in the flow path. Modified Puls method is utilised to exhibit the movement of falling, level pools with a user-defined storage-discharge association. Channels with trapezoidal, rectangular, triangular, or circular cross sections can be modeled with the kinematic wave or Muskingum-Cunge strategies. The channels with overbank zones can be routed and modeled with Muskingum-Cunge method and an eight-point cross-section. Moreover, channel losses can likewise be incorporated into the routing. The constant loss method can be added to any routing strategy while the percolation strategy can be utilised only with the modified Puls or Muskingum-Cunge methods (Chen and Liew, 2002). Muskingum-Cunge routing was chosen in this study (Cunge, 1969; Ponce 2014). The continuity equation is expressed as follows in this method:

$$(\frac{\Delta t-2KX}{2K(1-X)+\Delta t})I_t + (\frac{\Delta t-2KX}{2K(1-X)+\Delta t})I_{t-1} + (\frac{2K(1-X)-\Delta t}{2K(1-X)+\Delta t}Q_{t-1} \quad \ldots\ldots 4.48$$

Where, Q = outflow, I = inflow, t = time, and K, X are parameters that depend on the channel and streamflow characteristics.

4.6.3.2 HEC-RAS modeling

A schematic geometry model that comprises of waterway cross-section profile and banks is required in a HEC-RAS display set-up. The hydraulic parameters require Manning's n coefficient for various LULC classes. Afterwards, the boundary conditions are set-up for a state of the stream and the floodplain is recreated for inundation modeling. In HEC-RAS, the prerequisite input comprises of three primary parts, viz. plan, geometry and stream information. The plan information will recognise geometry and stream information to be utilised and also gives a depiction and short identifier for the simulation. The cross-sections need to be defined on stream wherever changes are likely to happen in the discharge, slope, shape, and roughness parameters. Figure 4.11 demonstrates the technique followed for flood inundation modelling in Tangri (Dangri) stream watershed.

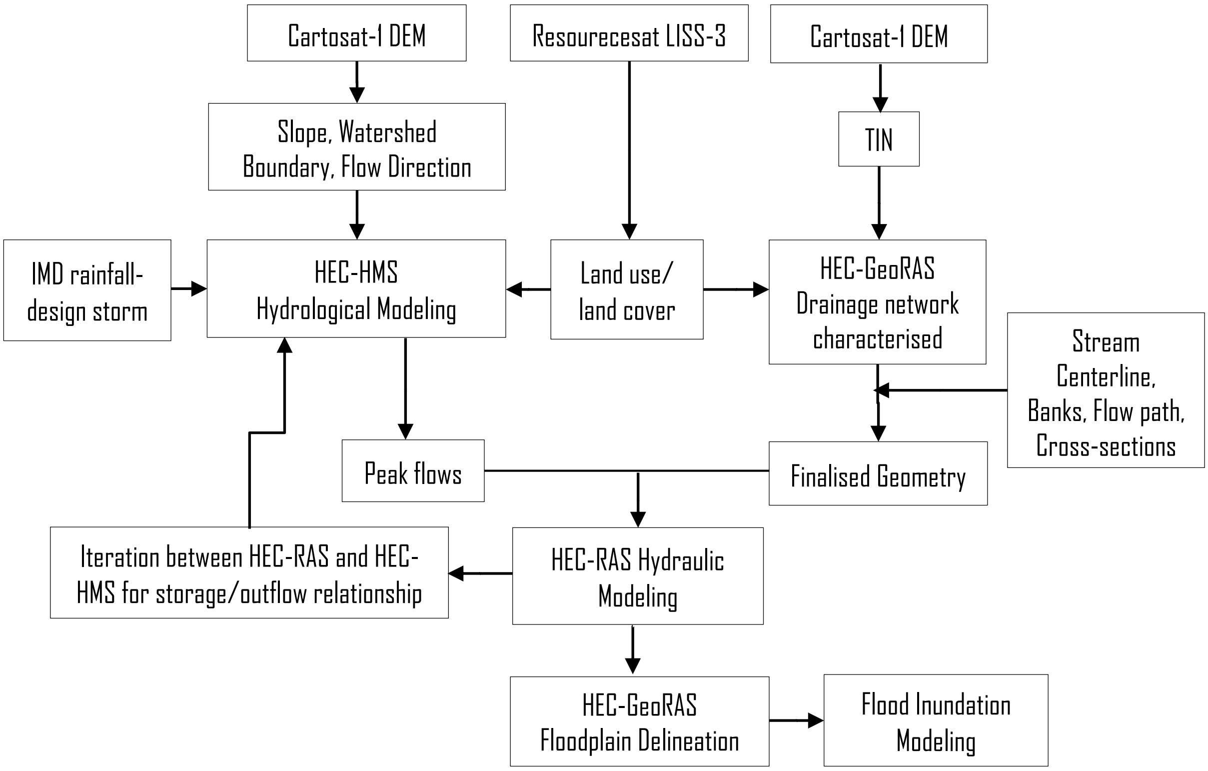


Fig. 4.11. Methodology for flood inundation modelling in Tangri (Dangri) river watershed

The DEM created from Cartosat-1 stereo data was utilised to infer flow direction and flow accumulation layers utilising HEC-HMS software. The slope data was additionally obtained from DEM. Resourcesat LISS-3 data was used to prepare LULC information. The hydrological modeling was carried in HEC-HMS to assess the peak flows for rainfall of varying return periods. With Cartosat-1 DEM and Resourcesat LISS-3 data as background layers, the stream centre-line, banks, flow path and cross-sections were drawn. The data on hydraulic structures within the catchment boundary was also ingested in the HEC-RAS module. Using the geometry and peak flow information, the floodplain delineation was attempted and inundation modeling was done to evaluate the impact of peak flows on encompassing LULC based on rainfall of varying return periods.

a. Manning's Coefficients

The Manning's roughness coefficient signifies resistance to flow of water in streams and floodplains. This method is an indirect estimation of streamflow, and have applications in floodplain administration, insurance, and in designing of various hydraulic structures. Manning's equation is defined as follows:

$$v = (k_n/n)*R^{2/3}*S^{1/2} \qquad \text{……4.49}$$

Where, v= mean velocity in m/s, R= hydraulic radius in metre, S= slope of energy gradient line in metres per metres and n= Manning's roughness coefficient. Accordingly, the discharge (Q) can be estimated using Manning’s formula as follows-

$$Q = VA = (1.486/n) * A* R^{2/3} * S^{1/2} \qquad \text{……4.50}$$

Where, Q = flow in cumecs and A = cross-sectional area in sq. m.

Chapter 5

RESULTS AND DISCUSSION

The present study on '**Hydrological Risk Assessment from and within a Torrential Watershed'** has been carried for the Tangri (Dangri) river watershed located in Ambala and Panchkula district, Haryana, India. Following data have been utilised in the present study: temporal Landsat TM data (1991, 1996, 2001, 2011, 2016 and 2018); Resourcesat LISS-III and LISS-IV data of 2012 and 2010, respectively; Cartosat-1 stereo and SoI topographical maps. The temporal LULC maps of torrents and surroundings were prepared using CART classifier in GEE environment for four broad classes and later overlaid for change detection analysis. The temporal and multi-spectral satellite data were geo-referenced and co-registered with accuracy better than a pixel using GCPs. Detailed LULC mapping of the watershed was carried out using supervised classification technique for hydrologic and hydrodynamic modeling. The drainage density map was prepared using drainage map digitised with the conjugate use of SoI topographical map and satellite data. HSG map was prepared based on re-classification of soil map. The buffer zones with five classes encompassing torrents were created with distance values from 100 m to 500 m for torrents' vulnerability analysis. The locations of various conservation measures were gathered utilising GPS and transferred to GIS database. The stream width was estimated at a few spots with the help of satellite data and also verified on the ground. The torrents' meander angles were estimated interactively using the satellite data at numerous river sections.

The torrents' vulnerability analysis was carried out based on six parameters viz., i) Catchment's Slope, ii) Soil characteristics, iii) LULC, iv) Proximity to torrents' flood plain, v) Proximity to conservation measures and vi) Channel characteristics. The soil loss from torrential regime was computed using RUSLE method with inputs drawn from satellite data. While using this method, the R-factor was estimated from precipitation data. K-factor was derived from soil map, and C, P factors were produced from LULC map of watershed. The slope length-gradient factor (LS) was obtained through DEM produced from Cartosat-1 stereo pairs. The hydrodynamic analysis of torrential regime was done using HEC-HMS and HEC-RAS software. Various alternatives have been evaluated based on MCDM techniques and suggested for further treatment of vulnerable sections of the watershed. The study outcomes are described in following sections.

5.1 TORRENTIAL AREAS CHANGE DYNAMICS

The temporal false colour composite (FCC) for the sub-watershed of Tangri (Dangri) river is shown as figure 5.1. The LULC characteristics with four broad classes of torrents' floodplains have been mapped from above remote sensing data using CART classifier in GEE environment. Similarly, the EVI products were generated within GEE platform while utilising the Landsat Level L1 ortho-rectified products of 30 m spatial resolution. The EVI values ranges between −1 to +1, and helps in measuring greenness over a terrain where higher the values, better the quality of vegetation.

5.1.1 LULC Dynamics in Tangri (Dangri) Floodplain

It is observed that the river systems of torrential regime have tendency to migrate and meander frequently. As several conservation activities have been undertaken in the watershed and also due to smaller land holdings and increasing pressure on land resources, some areas of the watershed are getting reclaimed. At the downstream reaches of watershed, expansion in agricultural tracts are evident on temporal satellite data and it has caused the shrinkage in floodplains of torrential regime (Table 5.1 and fig. 5.2). The conservation activities are ongoing mainly in vicinity to the torrents' and surroundings and also the torrents' meander during this period is contained within this distance, therefore, a buffer distance of 200 m was used to observe the LULC changes during 1991 to 2018. Table 5.1 shows torrential areas change dynamics as observed using temporal satellite data. It is observed that during this period because of ongoing conservation activities as well as due to watershed inhabitants' intervention, the area under bare torrents (dry river bed) have decreased from 701 ha to 407 ha. Similarly, the torrential areas which were under grass or scrub have increased from 550 ha to 678 ha. The land under agriculture (1478 ha to 1617 ha) and orchard/ plantation/ forest (533 ha to 560 ha) have also increased. Most of these changes are seen along the main Tangri (Dangri) river and at its downstream reach, which is the meeting point of Thathar ki Nadi with main Tangri (Dangri) river.

Table 5.1 Torrent area change dynamics observed using temporal satellite data

Year	1	2	3	4	Total	Accuracy (%)	Kappa
1991	701.14	1477.59	550.12	533.00	3261.85	92.25	0.86
1996	560.13	1551.94	600.46	549.32	3261.85	85.22	0.78
2001	474.66	1560.26	671.37	555.57	3261.85	88.89	0.80
2011	528.12	1584.43	590.54	558.77	3261.85	87.44	0.79
2016	421.76	1611.96	673.45	554.69	3261.85	90.27	0.82
2018	406.55	1617.24	678.41	559.65	3261.85	91.73	0.84

1: dry river bed, 2: cropland, 3: grass/scrub and 4: orchard/plantation/forest *(Area in ha)*

Various kinds of conservation measures are adopted in watershed for the protection of channel bed, such as retaining wall and spurs, etc. under watershed development programmes. Along the Thathar ki Nadi and near to its confluence point with main Tangri (Dangri) river, 36 spurs and retaining walls have been constructed. Along the other streams as well these kinds of structures are seen. Some vegetative measures have also been adopted for the protection of torrential areas. Figure 5.2 shows the temporal LULC of Tangri (Dangri) river sub-watershed and figure 5.3 shows the LULC changes in flood plain of the Tangri (Dangri) river.

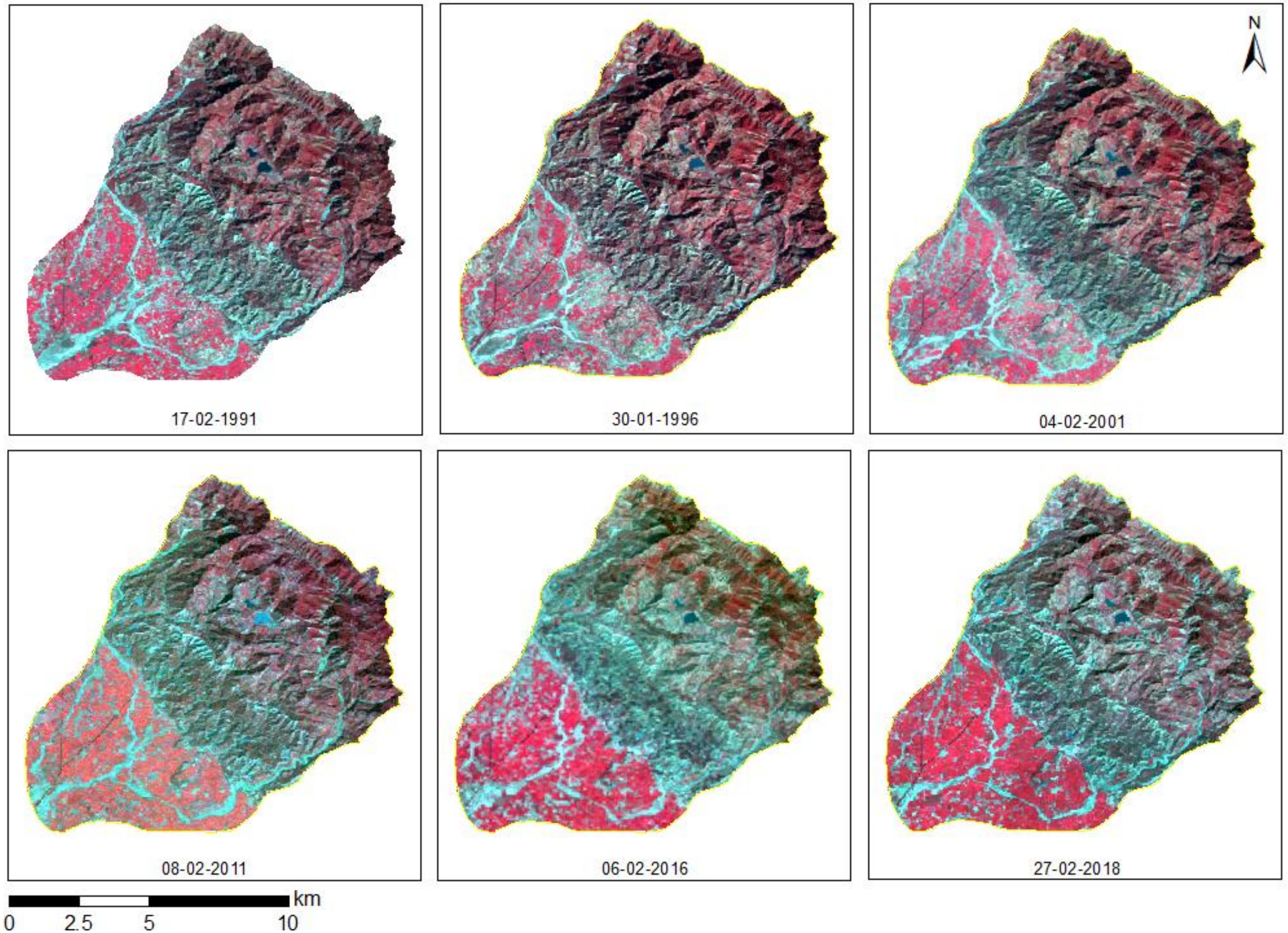


Fig. 5.1. Temporal FCCs of Tangri (Dangri) river sub-watershed

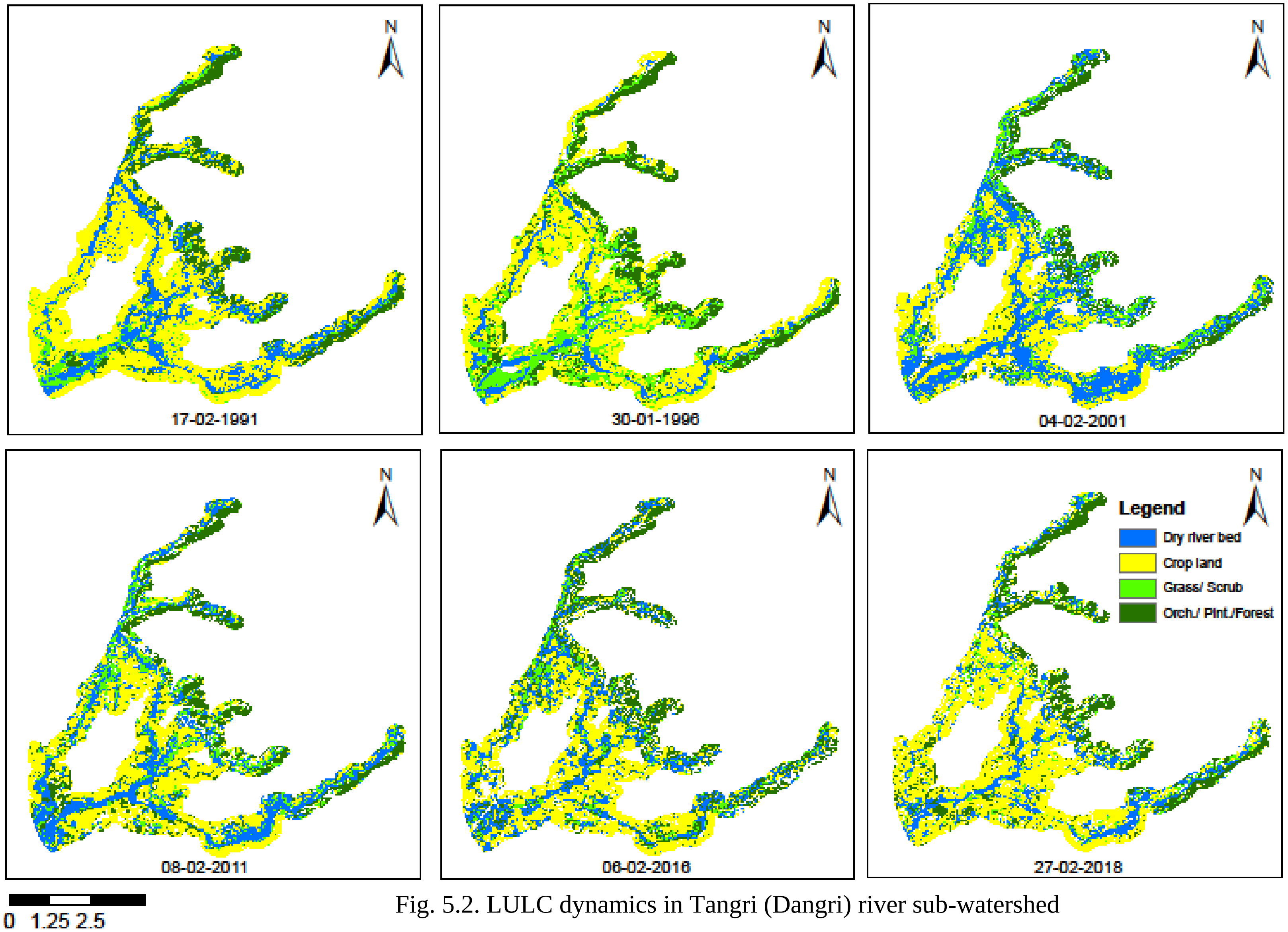


Fig. 5.2. LULC dynamics in Tangri (Dangri) river sub-watershed

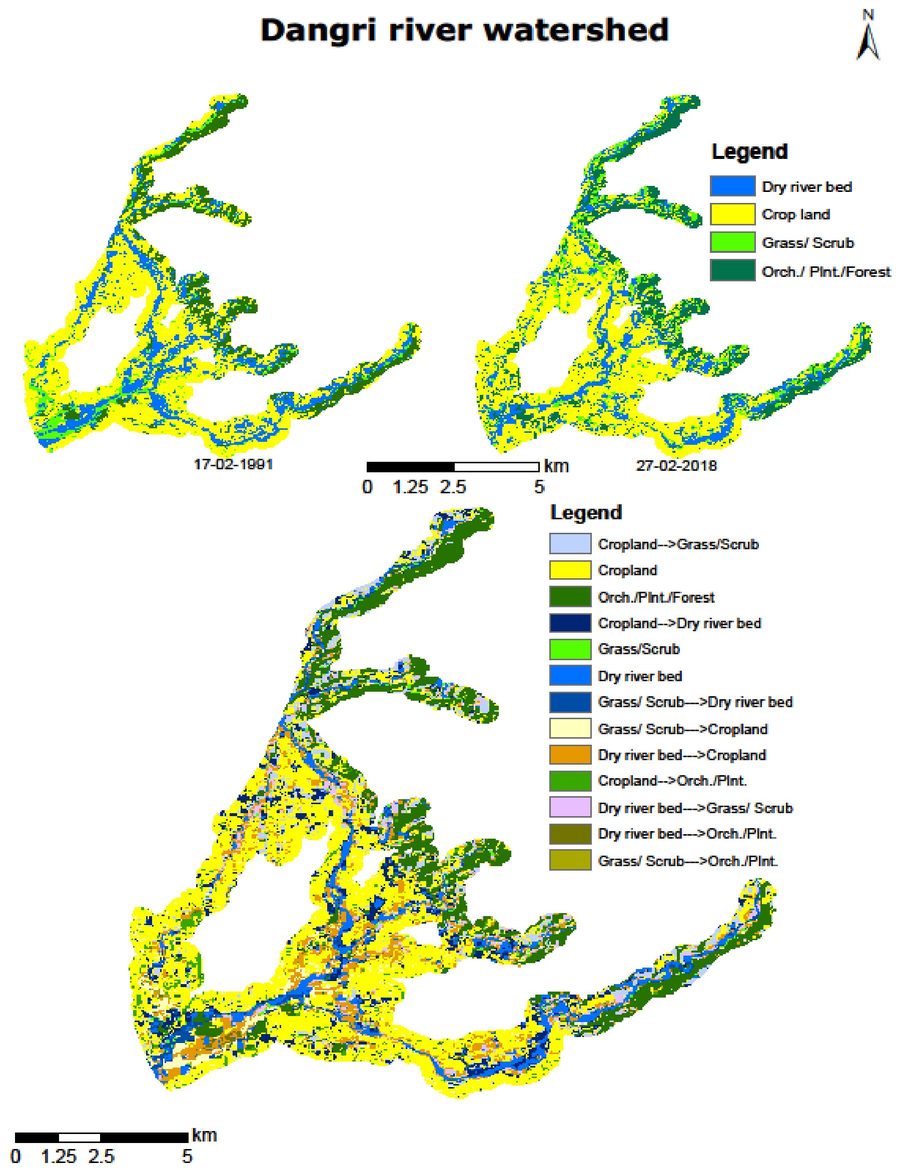


Fig. 5.3. LULC changes in flood plain, valley and surroundings of Tangri (Dangri) river

5.1.2 Temporal EVI Characteristics

Temporal EVI characteristics are shown in table 5.2. In the present study, EVI products were used for temporal understanding of vegetation dynamics because EVI is highly responsive to canopy type and architecture, leaf area index (LAI) and plant physiognomy (Hsu 2015). It is perceived that the mean EVI values are continuously improving for the watershed with their values as -0.0626 (1991) to 0.297 (2018). The maximum value of EVI has also increased from 0.118 (1991) to 0.902 (2018). Fig. 5.4 shows the Temporal EVI for Tangri (Dangri) river sub-watershed. Figures 5.5, 5.6 and 5.7 show the mean monthly EVI values for March, September and December months, respectively.

Table 5.2. Temporal EVI characteristics

Year	Minimum	Maximum	Mean	Standard Deviation
1991	-0.4703	0.1177	-0.0626	0.0634
1996	-0.4695	0.1318	-0.0492	0.0591
2001	-0.3886	0.1312	-0.0125	0.0608
2011	-0.3846	0.1301	-0.0789	0.0695
2016	-0.2035	1.0971	0.3527	0.1914
2018	-0.1666	0.9015	0.2970	0.0919

Annexure-2 shows the monthly EVI values for the Tangri (Dangri) river. Figures 5.5, 5.6, 5.7 and 5.8 show that the mean monthly EVI values are continuously increasing across seasons in Tangri (Dangri) river watershed. There are some data gaps in the GEE products but overall mean EVI trend is positive and continuously increasing which may be attributed to various conservation measures adopted in the watershed. The LULC and vegetation cover changes are considered as major indicators for watershed treatment monitoring and evaluation purpose (Kumar 2000; Thakker 2017). The present study portrays the utility of API based tools for rapid appraisal of watershed treatment activities.

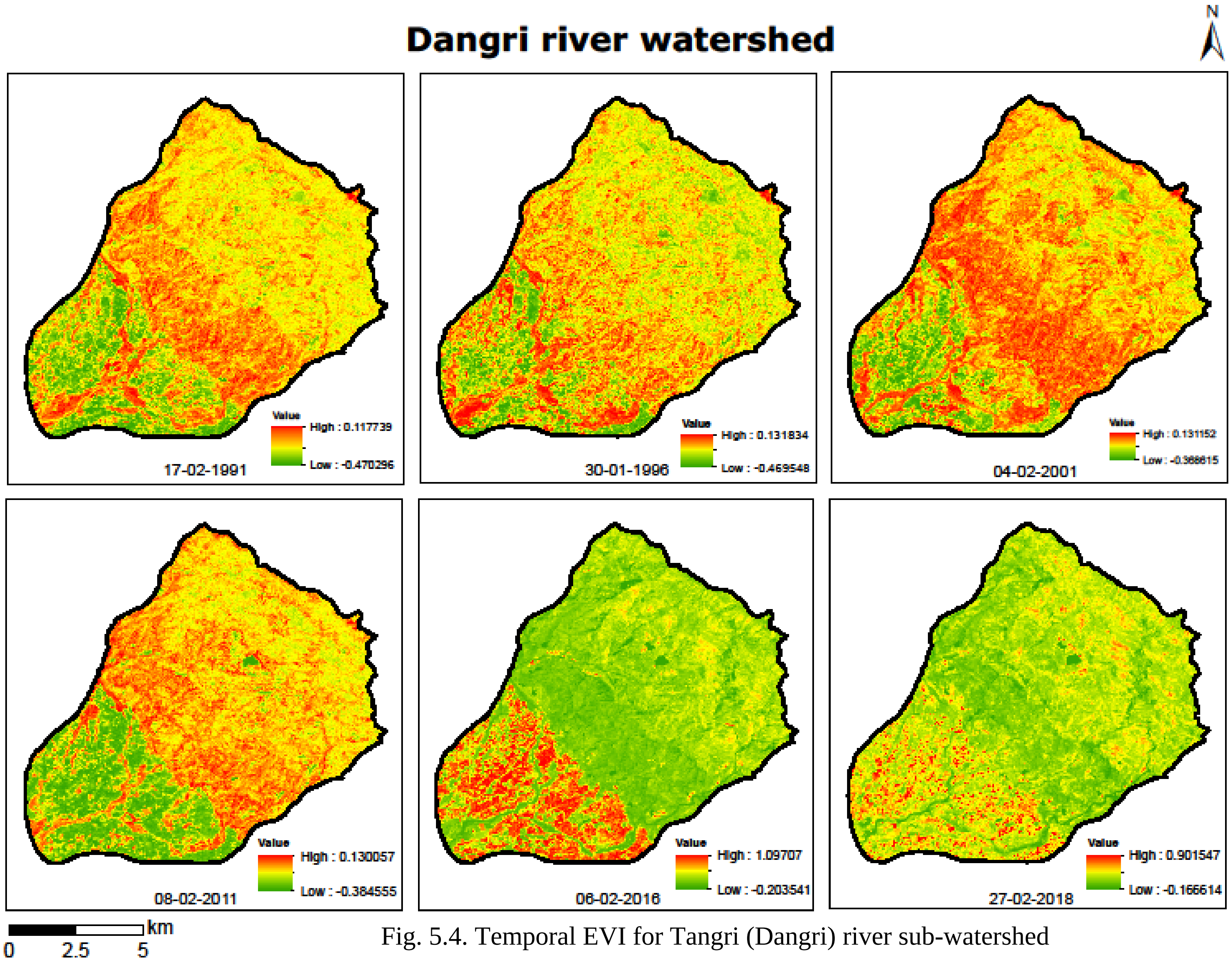


Fig. 5.4. Temporal EVI for Tangri (Dangri) river sub-watershed

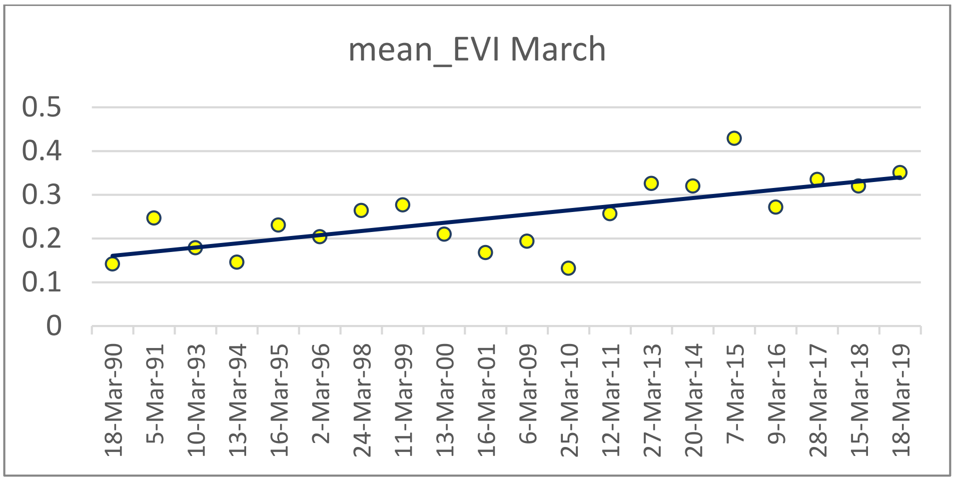


Fig. 5.5. Monthly mean EVI for March months for Tangri (Dangri) river sub-watershed

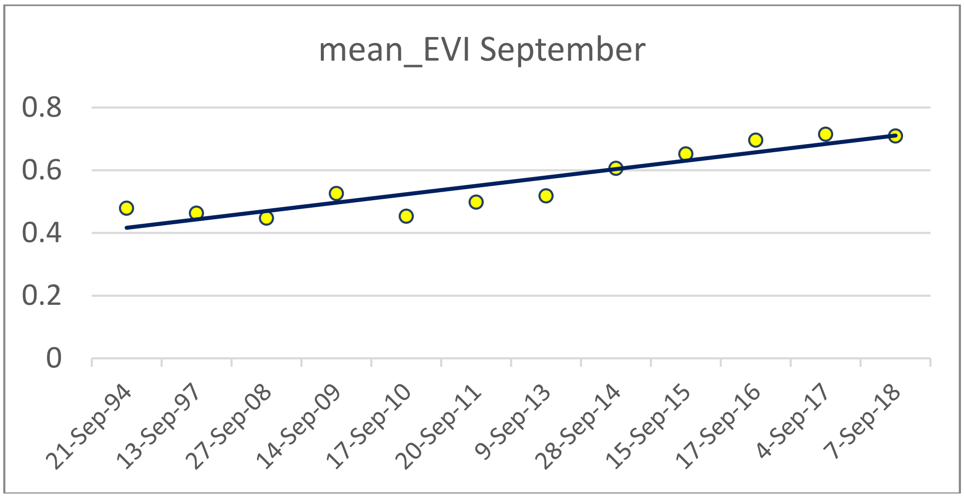


Fig. 5.6. Monthly mean EVI for September months for Tangri (Dangri) river sub-watershed

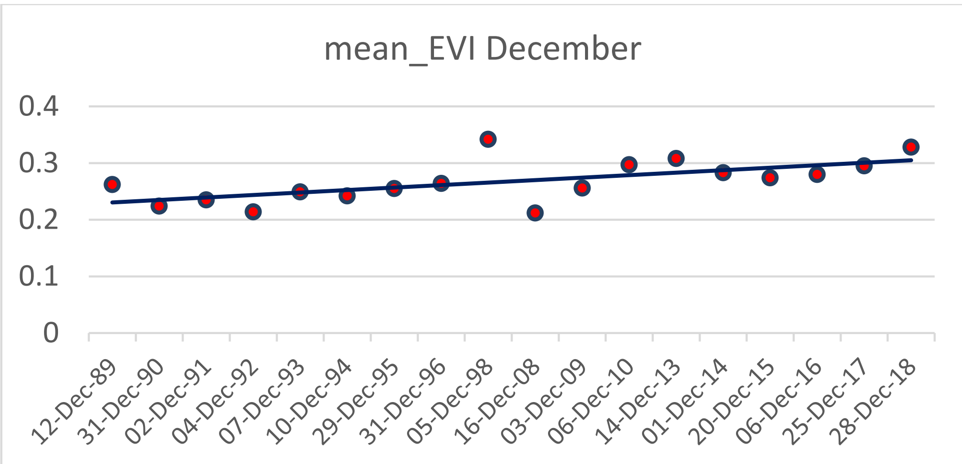


Fig. 5.7. Monthly mean EVI for December months for Tangri (Dangri) river sub-watershed

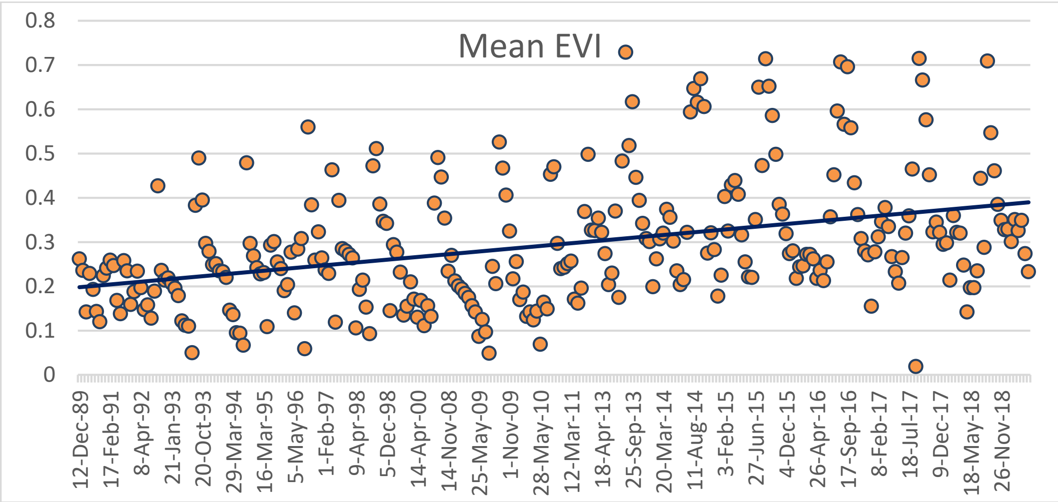


Fig. 5.8. Mean EVI for Tangri (Dangri) river sub-watershed

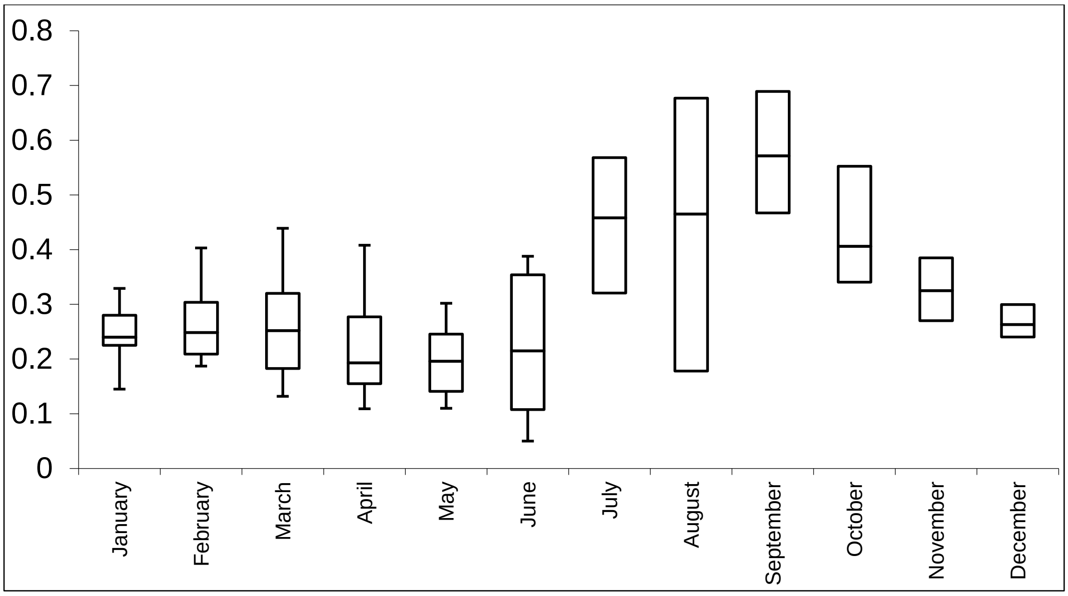


Fig. 5.9. Box plot showing the variations in monthly mean EVI for Tangri (Dangri) river sub-watershed

Figure 5.8 shows the mean EVI for various months and figure 5.9 exhibit the box plot with variations in monthly mean EVI for Tangri (Dangri) river sub-watershed. As could be seen from above figure that the maximum variation in EVI values is observed during *Kharif* season which is mainly attributed to the cropping pattern and heterogeneous sowing of various crops in the Dangri (Tangri) river sub-watershed.

5.2 TORRENTS' VULNERABILITY ANALYSIS

The torrents' vulnerability analysis has been carried out based on six parameters, viz. i) Catchment's Slope, ii) Soil characteristics, iii) LULC, iv) Proximity to torrents' flood plain, v) Proximity to conservation measures and vi) Channel characteristics. The description of these parameters are given in subsequent paragraphs. The description of soil characteristics is given under section 5.3.1.1.

5.2.1 Slope

Slope is a vital element that controls bio-physical activities and is desirable to understand the land surface characteristics such as suitability, irrigability, capability, etc. It has an important bearing on runoff, soil loss, vegetation growth and also the optimal land utilisation. The slope map (fig. 5.10) for Tangri (Dangri) river sub-watershed was prepared based on standard slope classification (NRCC, 1998) using the DEM generated from Cartosat-1 data and ERDAS software. The slope layer is categorised into ten classes as leveled (0^o - 0.3^o), nearly leveled (>0.3^o - 1.1^o), very gentle sloping (>1.1^o - 3.0^o), gentle sloping (>3.0^o - 5.0^o), moderate sloping (>5.0^o - 8.5^o), strong sloping (>8.5^o - 16.5^o), very strong sloping (>16.5^o - 24^o), extreme sloping (>24^o - 35^o), steep sloping (>35^o - 45^o), and very steep sloping (>45^o - 90^o) with least weightage given to leveled and gentle slope, and higher weightages given to acute slopes in upstream region of the catchment or the steep slopes along valleys.

Table 5.3 and figure 5.10 show the area under different slope classes of Tangri (Dangri) river sub-watershed. As could be seen from the table 5.3 that large part of the watershed especially in lower reaches are under leveled to gently sloping category (nearly 35%) whereas the middle and upper reaches of the watershed in mountainous tracts are mostly steep to very steep sloping.

Table 5.3. Area under different slope classes

Sl. No.	Slope Class	Slope Range	Area (sq. km)	% of Geog. area
1.	Leveled	0^o - 0.3^o	2.19	2.21
2.	Nearly leveled	>0.3^o - 1.1^o	8.62	8.68
3.	Very gentle sloping	>1.1^o - 3.0^o	18.20	18.33
4.	Gently sloping	>3.0^o - 5.0^o	5.09	5.13
5.	Moderate sloping	>5.0^o - 8.5^o	6.68	6.73
6.	Strong sloping	>8.5^o - 16.5^o	26.56	26.75
7.	Very strong sloping	>16.5^o - 24^o	17.81	17.94
8.	Extreme sloping	>24^o - 35^o	10.92	11.00
9.	Steep sloping	>35^o - 45^o	1.35	1.36
10.	Very steep sloping	> 45^o - 90^o	1.88	1.89
	Total		99.30	100.00

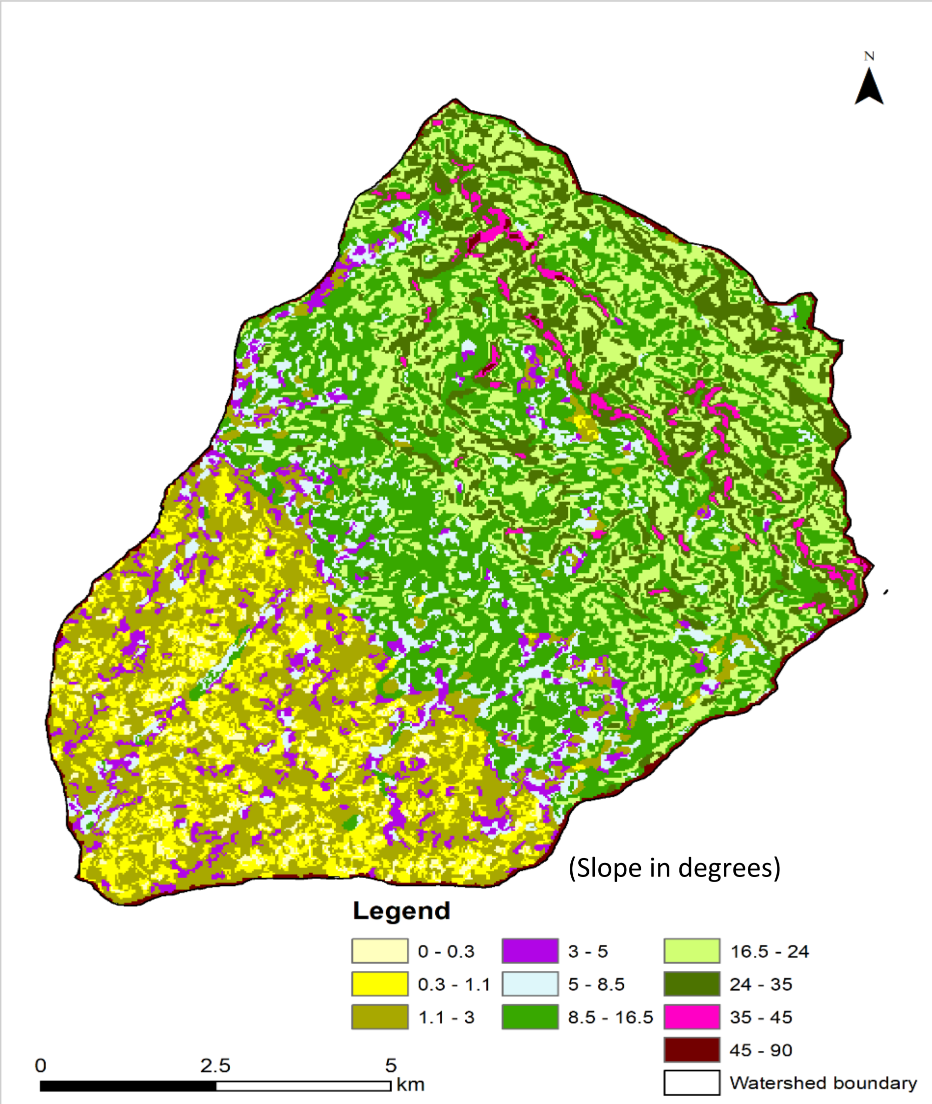


Fig. 5.10. Slope map of Tangri (Dangri) river sub-watershed

5.2.2 Land Use/Land Cover (LULC)

It provides spatial extents of different LULC classes such as forests, wastelands, cropped area (*Rabi/Kharif*), etc. LULC information derived from temporal data assists in determining cropping intensity and changes in the land utilisation pattern. The LULC information for Tangri (Dangri) river sub-watershed was derived from digital classification of IRS-P6 LISS-4 data of March 11, 2010 based on supervised classification technique.

Table 5.4. LULC characteristics of Tangri (Dangri) river sub-watershed

S. No.	LULC class			Area (sq.km.)	% of geog. area
1.	Forest	a.	Dense forest	38.30	38.57
		b.	Open forest	15.92	16.03
		c.	Scrub	9.86	9.93
2.	Agriculture	a.	Crop land	15.56	15.67
		b.	Fallow	12.47	12.56
		c.	Orchard/ Plantation	0.28	0.28
3.	River/ Water body	a.	River/Channel	3.69	3.72
		b.	Dry river bed	2.46	2.48
		c.	Water body	0.28	0.28
4.	Settlements			0.48	0.48
			Total	99.30	100.00

The maximum likelihood classifier (MLC) algorithm is a standout amongst most prevalent supervised classification methods used with remote sensing images. This method relies upon the probability that any pixel belongs to a particular class with a central speculation that probabilities are identical for all classes and information groups which follow normal distribution. The training signatures were drawn by delimiting polygons around representative sites for each of pre-defined LULC type. Spectral signatures for the individual LULC types were logged by utilising the pixels encased within the training signatures. An agreeable spectral signature is one that ensures least overlap among LULC classes to be mapped (Gao and Liu, 2010). The results of the supervised classification are shown in figure 5.11 and aerial extent of different LULC classes is as given in Table 5.4. The description of these LULC classes are as follows-

- **Forested Land:** The aerial extent of forest land (dense, open and scrub) is 64.08 sq. km (about 64.5 percent area of sub-watershed). Approximately, 9.9 percent of the forested land is under scrub vegetation and about 16.0 per cent comes under open canopied forests. Dense and moderately dense forests are confined to 38.6 per cent of total study area.

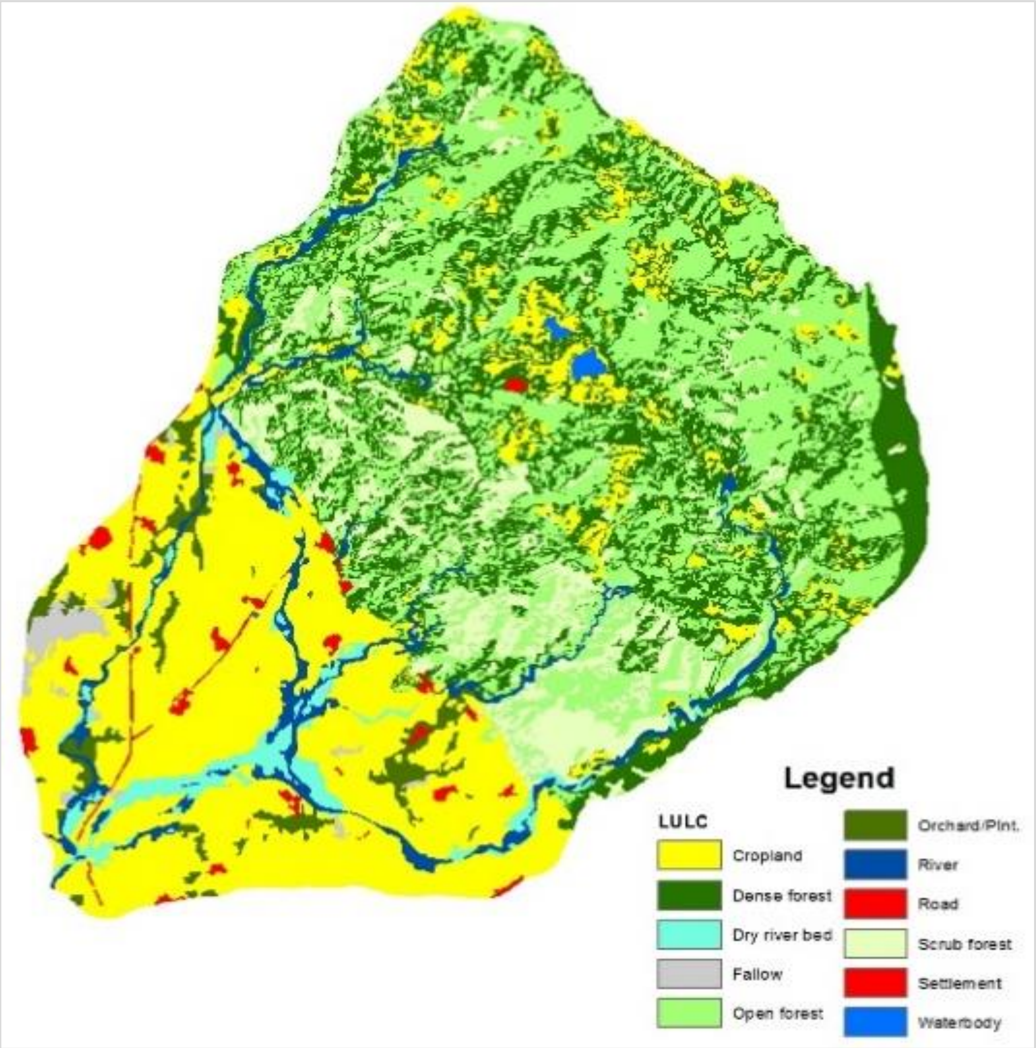


Fig. 5.11. LULC characteristics of Dangri river watershed

- **Agriculture Land:** About 28.5 (28.31 sq. km) per cent of the watershed area is under agricultural activities. Among which about 12.6 per cent is fallow land and 0.3 per cent of land is under plantation such as Eucalyptus, Poplar, *Shisham*, etc.
- **River channel and sandy area**: River channels and the dry river beds (i.e., sandy area) occupy 3.69 sq. km and 2.46 sq. km land, respectively.
- **Waterbodies**: Two waterbodies in lower Siwalik region occupied a total of 0.28 sq. km of land.

5.2.3 Drainage Characteristics

The study area is mainly drained by seasonal streams. Tangri (Dangri) is the main river flowing to southerly direction. The drainage pattern of the watershed varies from dendritic to sub-dendritic and at some places sub-parallel too. The drainage density of the Tangri (Dangri) river sub-watershed is shown in figure 5.12. It is categorised into five classes as 0.04 - 2.13, >2.13 - 4.21, >4.21 - 6.30, >6.30 - 8.38, and >8.38 - 10.47 km/ sq. km. The drainage buffer (m) of Tangri (Dangri) river sub-watershed is shown in figure 5.13. The buffers were generated surrounding the torrents and the proximity to torrents' valley and floodplain is put into five buffer regions as 200 m, 400 m, 600 m, 800 m and 1000 m.

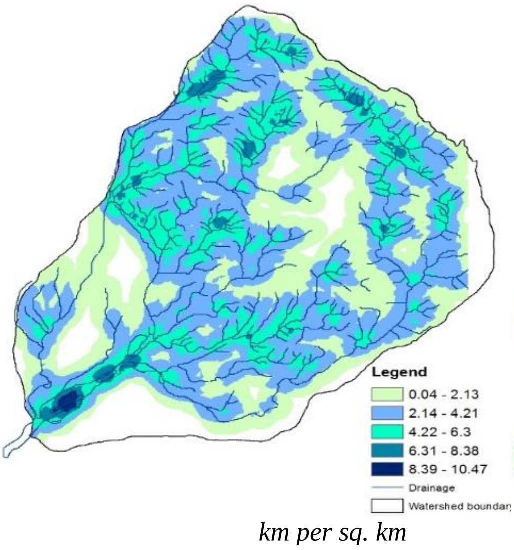


Fig. 5.12. Drainage density of Tangri (Dangri) river sub-watershed

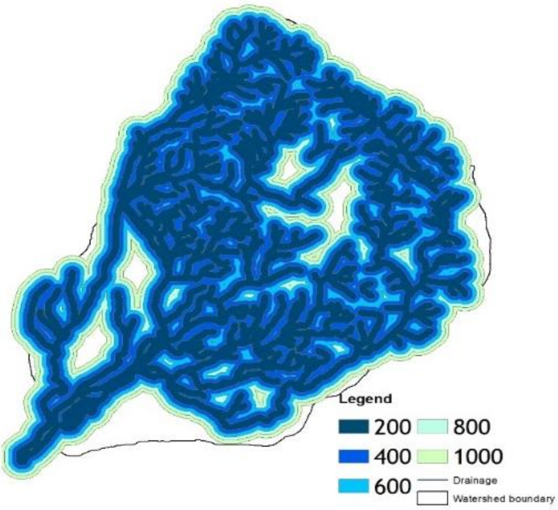


Fig. 5.13. Drainage buffer (m) of Tangri (Dangri) river sub-watershed

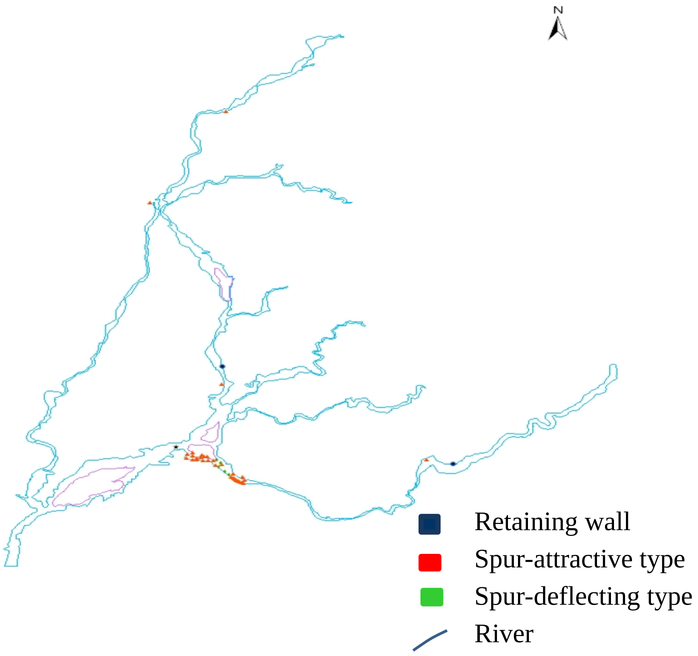
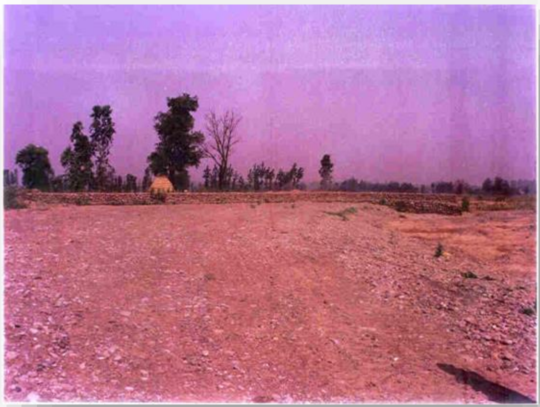


Fig. 5.14. Conservation activities adopted in sub-watershed of Tangri (Dangri) river

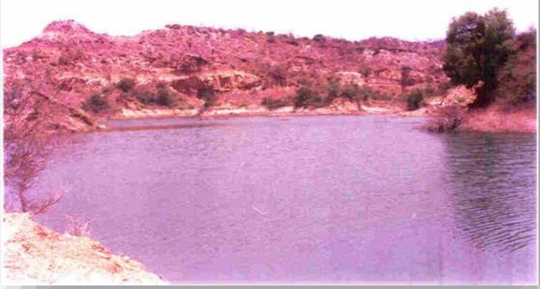
Attracting type spurs along river bed

Spurs with vegetation measures



Retaining wall

Uncontrolled mining activity on torrent bed



A water conservation structure installed in watershed

A sedimentation survey post erected by IISWC, Chandigarh

Fig. 5.15. Field photographs showing various conservation activities adopted in sub-watershed of Tangri (Dangri) river

5.2.4 Conservation Activities in Watershed

Various agencies have laid conservation structures in proximity to torrential areas such as retaining walls and spurs. These spurs are of following types: i) Repelling type: spurs making angle (60^o to 70^o) with the bank on their upstream side, ii) Attracting type: spurs making acute angle with downstream side, and iii) Deflecting type: spurs erected at right angle to the bank. Within the watershed, the spurs of attracting and deflecting types have been erected. Various species have been planted in Tangri (Dangri) river watershed. These are *Beri* (*Ziziphus mauritiana*), Ipomaea (*Ipomoea cairica*), *Kans* grass/ *Kash phool* (*Saccharum spontaneum*), *Doob* (*Cynodon dactylon*), Juliflora (*Prosopis juliflora*), *Shisham* (*Dalbergia sissoo*), *Papri* (*Podophyllum hexandrum*), Lantana (*Lantana camara*), Poplar (*Populus species*), etc. Figure 5.14 shows the locations of some of these conservation activities in watershed and figure 5.15 shows the field photographs of various conservation activities in the sub-watershed of Tangri (Dangri) river. Bhardwaj et al. (2020) carried out field survey and questionnaire based impact assessment of watershed development activities in the upstream reaches of Tangri (Dangri) river watershed. Their study concluded that almost 52% of the respondents were profoundly happy with progresses made in the agricultural and livestock practices, while nearly half of the respondents were content with socio-economic (about 46%) and environmental developments. The overall satisfaction level for above three parameters were nearly 56% in the watershed.

5.2.5 Derivation of Weights

As discussed under section 4.2.1 (Models for vulnerability assessment) and section 4.6 (Torrents vulnerability analysis), the torrents' vulnerability analysis was carried out using MCDM based AHP model. The weights of various parameters and sub-parameters were derived and their cumulative effects were assessed for torrents' vulnerability assessment. During AHP analysis, the Eigen Vector method have been applied and weightages have been derived (Table 5.5) using importance matrix for torrent vulnerability analysis for six parameters. The feature classes (table 5.5) were multiplied with the weightages which have been derived for six parameters and later the CVI is computed. This CVI coverage is reclassified into five categories as torrent vulnerability classes.

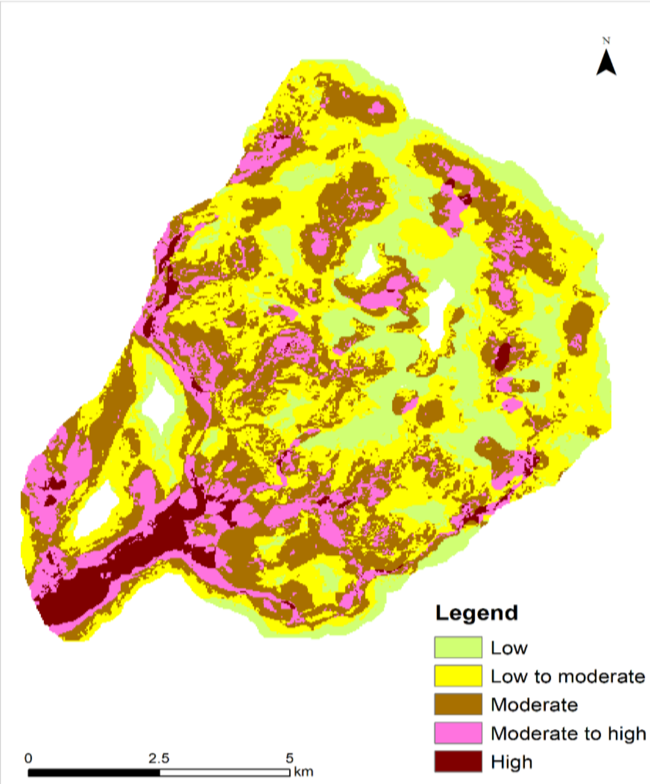


Fig. 5.16. Vulnerable areas identified in torrential system of Tangri (Dangri) river watershed

5.2.6 Torrents' Vulnerability Index

The torrents' vulnerability map has been categorised into five classes, namely high, moderate to high, moderate, moderate to low and low (Fig. 5.16). The torrent vulnerability map reveals that high and moderate to high vulnerable areas are noticed in proximity to settlements and cropland, slope transition zones, rivers confluence and also in proximity to meandering sections of the river. Other areas of the watershed fall under low vulnerable category. Table 5.6 shows the area of watershed under various vulnerability zones. It is observed that nearly 83.7% of the watershed falls under moderate to low vulnerability whereas rest (nearly 16.3%) of the watershed falls under high to moderate vulnerability towards settlements and various natural resources. The multi-criteria based vulnerability analysis also presents a methodology for the impact assessment of watershed treatment activity and to identify areas which still needs attention.

Table 5.5. Weights of parameters used in the vulnerability analysis

Para meter	Sub-category	Weight	Parameter	Sub-class	Sub-category	Weight
Slope (deg.)	0 - 0.3	0.018	**Channel characteristics**	**Bed width (m)**	0 – 15	0.51
	>0.3 - 1.1	0.024			>15 – 30	0.26
	>1.1 - 3.0	0.032			>30 – 45	0.13
	>3.0 - 5.0	0.043			>45 – 60	0.06
	>5.0 - 8.5	0.06			>60 – 75	0.03
	>8.5-16.5	0.082			0.04-2.13	0.03

Para meter	Sub-category	Weight	Parameter	Sub-class	Sub-category	Weight
	>16.5-24.0	0.113		Drainage density (km/ sq. km)	>2.13-4.21	0.06
	>24.0-35.0	0.153			>4.21-6.30	0.13
	>35.0-45.0	0.203			>6.30-8.38	0.26
	>45.0-90.0	0.272			>8.38-10.47	0.51
Soil	M1	0.0097		**Meander (deg.)**	>150°-210°	0.028
	H12	0.0114			>120°-150°/ >210° -240°	0.047
	H22	0.0135			>90°-120°/ >240°-270°	0.068
	P21	0.0165			>60°-90°/ >270°-300°	0.132
	M2	0.0204			>30°-60°/ >300°-330°	0.255
	H13	0.0251			0°-30°/ >330°-360°	0.471
	P11	0.0305				
	H11	0.0377	**Proximity to conservation measures**	Grass/ plantation		0.19
	H21	0.0461		Spur-Attractive		0.24
	P12	0.057		Spur-Deflective		0.24
	P22	0.0695		Retaining wall		0.33
	T	0.0855		Dense forest		0.02

Para meter	Sub-category	Weight	Parameter	Sub-class	Sub-category	Weight
	A1	0.1051	**LULC**	Open forest		0.024
	P13	0.1285		Scrub forest		0.032
	V	0.1554		Scrub land		0.043
	A2	0.1881		Fallow land		0.06
Proximity to torrents' flood plain (m)	200 m	0.51		Orch./Plnt.		0.082
	400 m	0.26		Terrace cultivation		0.113
	600 m	0.13		Waterbody		0.152
	800 m	0.06		Cropland		0.184
	1000 m	0.03		Settlement		0.29

Table 5.6. Area under various vulnerability zones in Tangri (Dangri) river

Sl. No.	Class	Geog. area (sq. km)	Percentage of geog. Area
1.	Low	18.63	18.76
2.	Moderate to low	37.83	38.10
3.	Moderate	26.5	26.69
4.	Moderate to high	12.39	12.48
5.	High	3.95	3.98
	Total	99.3	100.00

5.3 HYDROLOGICAL HAZARDS ASSESSMENT

5.3.1 Estimation of Soil Loss

The soil loss appraisal was done based on RUSLE method. Different theme maps were inferred using remote sensing data, brought as GIS layers and annual average soil loss was assessed using RUSLE equation. The methodology followed is given under section 4.6.2 and the results obtained is described in following paragraphs.

5.3.1.1 *Soil map*

The information on soil and their characteristics are imperative for land and water resources developmental activities undertaken on watershed basis. The variations in soil characteristics depend on the soil forming factors. The underlying lithology, topography and vegetation cover are the dominant aspects controlling the soil development. Four major physiographic units, namely Alluvial Plain, Piedmont, Siwalik Hills and Mountains (figure 5.17) are present in the study area. These physiographic units were further sub-divided based on LULC practices and vegetation cover. The unit-wise soil association, their area and land capability classification is shown in Table 5.7.

- **Alluvial Plain (A)**
    - **Plain (A1)**: Originated from alluvium and carried by the Tangri (Dangri) river and its tributaries, nearly levelled (0-1%), very deep soils, light

yellowish brown to yellowish brown, with light brownish grey mottles in the lower horizons; loamy texture, moderately well drained, cultivated, slight erosion hazards with soil association: Fine loamy, Typic Ustochrepts/ Coarse loamy, Typic Ustifluvents.

- **Bar between the rivers (A2)**: Nearly levelled (0-1%), light yellowish brown to yellowish brown, sandy to loamy sand in texture, occasionally cultivated with soil association: Coarse loamy, Typic Ustifluvents/ Typic Ustipsamments.

- **Piedmont (P)**
  - **Lower Piedmont (P1)**
    - **Lower Piedmont- Occasionally Cultivated (P11)**: Very gentle to gentle sloping, very deep soils, underlined rounded pebbles and boulders within 1 m, yellowish brown to dark yellowish brown, loamy to coarse loamy in texture, occasionally cultivated, very good land for agro-forestry with soil association: Coarse loamy, Typic Ustorthents/ Loamy skeletal Typic Ustochrepts.
    - **Lower Piedmont- Cultivated (P12)**: Gentle sloping (1-3%), very deep yellowish brown to yellowish brown, fine loamy to light coarse loamy texture, intensively cultivated with soil association: Fine loamy, Typic Ustochrepts/ Coarse loamy Typic Ustochrepts.
    - **Paleo Channels and Sand Bar (P13)** (within the lower piedmont area): Gentle sloping (1-3%), very deep soils, sandy to sandy loam in texture; occasionally cultivated, mainly wastelands with soil association: Coarse loamy Typic Ustipsamments/ Typic Ustifluvents.

Table 5.7. Soils of various physiographic units, their area and land capability classification

Unit	Physio-graphy	Soil Associations	Area (ha.)	Land capability class*
A	Alluvial Plain			
Al	Plain	Fine loamy, Typic Ustochrepts/ Coarse loamy Typic Ustifluvents	538.23	II
A2	Bar	Coarse loamy, Typic Ustifluvents/ Typic Ustipsamments	58.31	III
P	Piedmont			
P1	Lower Piedmont			
P11	Occasional cultivation	Coarse loamy, Ustorthents/ Loamy Skeletal, Typic Ustochrepts	503.74	III
P12	Cultivated	Fine loamy, Typic Ustochrepts/ Coarse loamy, Typic Ustochrepts	537.71	II
P13	Paleo channels and sand bar	Typic Ustipsamments/ Coarse loamy, Typic Ustifluvents	57.16	IV

Unit	Physio-graphy	Soil Associations	Area (ha.)	Land capability class*
P2	Upper Piedmont			
P21	Forest plantation	Loamy skeletal, Typic Ustorthents/ Coarse loamy Typic Ustorthents	68.3	IIIes
P22	Cultivation	Coarse loamy, Typic Ustorthents/ Loamy Skeletal Typic Ustorthents	718.25	IIIes
H	Siwalik Hills			
H1	Lower Siwalik			
H11	Terrace cultivation	Loamy Skeletal, Typic Ustorthents/ Loamy skeletal, Typic Ustochrepts	223.29	IIIes
H12	Fairly dense forest	Loamy skeletal, Typic Ustoehrepts/ Coarse loamy, Typic Ustorthents	3046.64	VIIes
H13	Escarpment	Fragmental Typic Ustorthents	323.44	VIIes
H2	Middle Siwalik			

Unit	Physio-graphy	Soil Associations	Area (ha.)	Land capability class*
H21	Denuded Hill highly dissected	Loamy Skeletal, Ustorthents/ Fragmental Typic Ustorthents Typic	1480.03	VIIes-2
H22	Fairly dense mixed forest	Coarse loamy, Typic Ustorthents	345.38	VIIes-1
M	Mountain (Subathus formation)			
MI	Dense mixed forest	Loamy Skeletal, Typic Ustorthents/ Loamy Skeletal Typic Ustochrepts	430.92	VIIes
M2	Escarpment	Fragmental Typic Ustorthents	215.39	VII
V	Valley	Loamy Skeletal, Typic Ustifluvents/ Coarse Loamy Typic Ustorthents	423.79	III
T	River Terraces	Coarse Loamy, Typic Ustorthents/ Typic Ustipsamments	112.49	III

* Shows the major limitations of soils i.e. soil erosion (e), soil slope (s), etc.

Source: Manchanda et al., 1994

- **Upper Piedmont (P2)**
  - **Upper Piedmont-Plantation (P21):** Developed by colluvial fan material, gentle sloping (1-3%), very deep, yellowish brown to dark yellowish brown, coarse loamy to loamy skeletal texture, underneath by pebbles and boulders, well-drained with soil association: Loamy skeletal Typic Ustorthents/ Coarse loamy Typic Ustorthents.
  - **Upper Piedmont-cultivated (P22):** Same as P21, but mainly cultivated with soil association: Coarse loamy Typic Ustorthents/ Loamy skeletal Typic Ustorthents.

- **Siwalik Hills (H)**
  - **Lower Siwalik (H1)**
    - **Terrace Cultivation (H11):** Moderately steep to very steep slope (15% - 35%), hillside slope, shallow to moderately deep, brown to dark brown, gravelly, coarse loamy texture, well drained, terrace cultivation, moderate erosion with soil association: Loamy skeletal Typic Ustorthents/ Loamy skeletal Typic Ustochrepts.
    - **Fairly Dense Forest (H12):** Same as H11, fair to moderate forest vegetation with soil association: Loamy skeletal Typic Ustochrepts/ Coarse loamy Typic Ustorthents.
    - **Escarpments (H13)**: Very steep slope (33% - 55%) with very shallow soil depth, dark brown to dark yellowish brown, gravelly, sandy loam texture, scrub with stunted trees with soil association: Fragmental Typic Ustorthents.

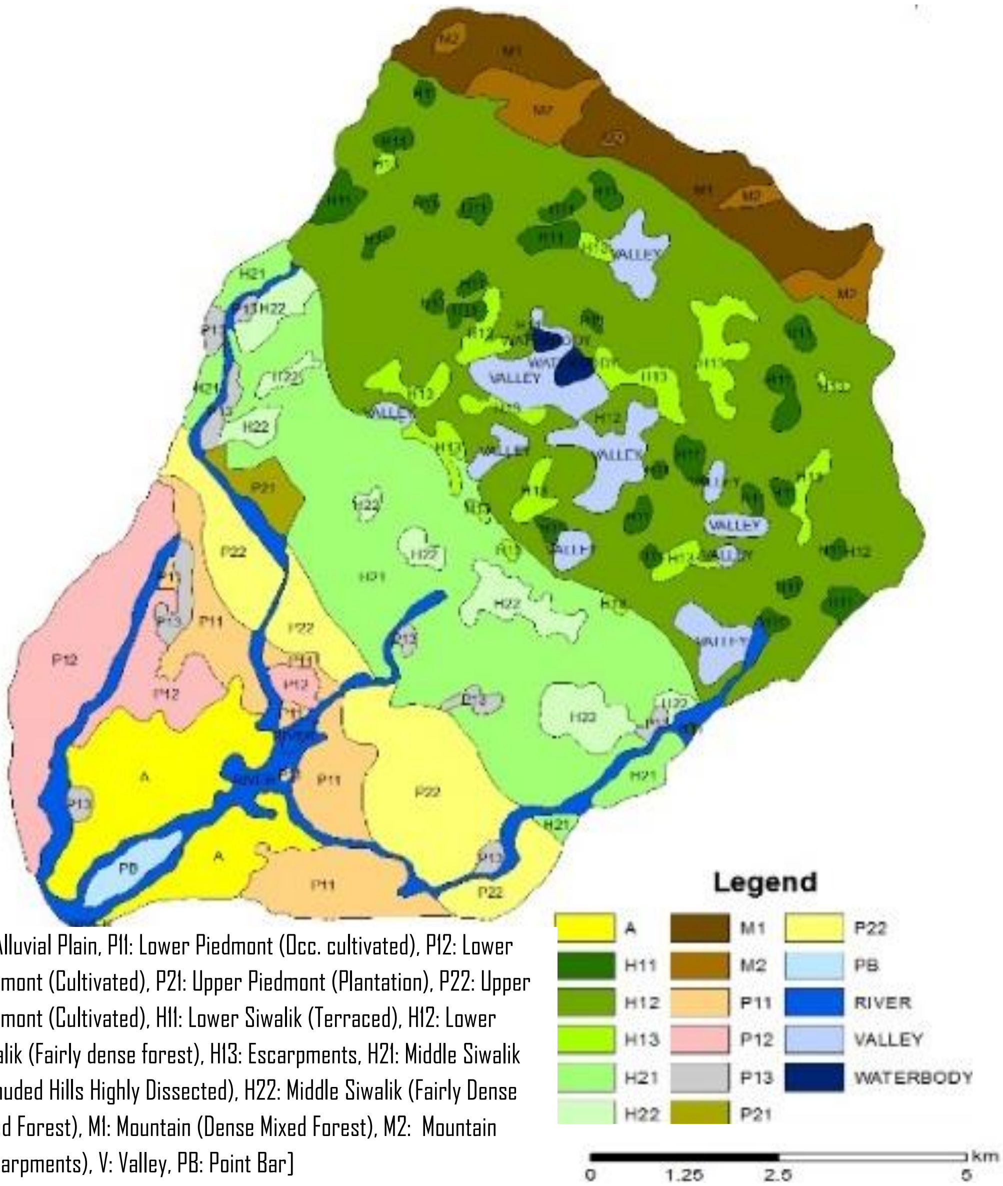
- **Middle Siwalik (H2)**
  - **Highly Dissected Denuded Hill (H21):** shrub/scrub vegetation on denuded middle Siwalik covered with steep slope (15% - 33%), shallow to moderate solum depth to coarse loamy in texture; light yellowish brown to reddish brown, loam, highly dissected, mainly wastelands, very severe erosion hazards with soil association: Loamy skeletal, Typic Ustorthents/ Fragmental Typic Ustorthents.
  - **Fairly Dense Mixed Forest** (**H22**): Lower part of steep slopes, covered with fairly dense forest because of slightly better moisture conditions, others are same as H21 with soil association: Coarse loamy, Typic Ustorthents/ Loamy Skeletal, Typic Ustochrepts.

- **Mountain (M)**
  - **Dense Mixed Forest (M1)**: Lesser Himalaya of Subathu formation, steep to very steep slope (35%-50%), shallow to moderate depth, dark reddish brown to dark brown colour, loamy skeletal texture, few rock out crops, well drained fair to moderately dense mixed forest with soil association: Loamy skeletal, Typic Ustorthents/ Loamy skeletal, Typic Ustochrepts.
  - **Escarpments (M2)**: Escarpment with the Subathu formation, very steep slope (more than 50%) fairly dense forest, very shallow soils, abundant pebbles and gravels with soil association: Fragmental Typic Ustorthents.

- **Valley (V)**
  - Narrow valley between lower Siwalik and Subathu formations, moderate to steep slope (5-10%), shallow to moderate depth, yellowish brown to dark

brown, gravelly, loam to sandy loam texture, mainly bunded and cultivated with soil association: Loamy skeletal, Typic Ustifluvents/ Coarse loamy Typic Ustorthents.

- **River Terraces** (T): River terrace within piedmont and alluvium areas, gentle slope (1-3%) very deep, light yellowish brown to dark brown, coarse loamy, well drained, cultivated mainly for vegetation and pasture land. Soil association: Coarse loamy, Typic Ustorthents/ Typic Ustipsamments.



[A: Alluvial Plain, P11: Lower Piedmont (Occ. cultivated), P12: Lower Piedmont (Cultivated), P21: Upper Piedmont (Plantation), P22: Upper Piedmont (Cultivated), H11: Lower Siwalik (Terraced), H12: Lower Siwalik (Fairly dense forest), H13: Escarpments, H21: Middle Siwalik (Denuded Hills Highly Dissected), H22: Middle Siwalik (Fairly Dense Mixed Forest), M1: Mountain (Dense Mixed Forest), M2: Mountain (Escarpments), V: Valley, PB: Point Bar]

Fig. 5.17. Soil map of Tangri (Dangri) river sub-watershed

__5.3.1.2__ Soil erodibility (K) factor

Soil erodibility (K) factor reflects the vulnerability of soil to erosion based on its essential characteristics such as texture, structure, permeability, organic matter, etc. The k-factor (figure 5.18) of RUSLE equation was computed for each soil mapping units (table 5.8) of the sub-watershed. The soils of mountainous region were assigned k-factor values from 0.28 to 0.48. The soils of moderately steep to steep sloping Siwalik hills were assigned k-factor ranging from 0.30-0.38. Soils of alluvial plain in downstream reaches of piedmont areas were described as silty loam to loamy in texture with fairly high erodibility and k-factor as 0.44-0.48. The soils of alluvial region have silt-loam-to-loam texture with k-factor as 0.44-0.48. The k-factor of soils in flood-plains near river channels with low organic-matter content and having loamy-sand to sandy-loam texture was assigned as 0.48. These values were assigned based on following soil characteristics- a) The erodibility of soil increases as the soil texture becomes finer, b) The soils with <3.5% organic matter content are treated as erodible as organic matter content helps in building soil structure as stable and erosion resistant (Evan, 1980) and c) Compacted soils exhibit higher soil erosion and runoff (Miedema, 1997).

Table 5.8. K-factor values for various physiographic-soil units

Units	Physiography	Area (ha.)	K-factor
A	Alluvial Plain		
Al	Plain	538.23	0.44
A2	Bar	58.31	0.48
P	Piedmont		

Units	Physiography	Area (ha.)	K-factor
P1	Lower Piedmont		
P11	Occasional cultivation	503.74	0.32
P12	Cultivated	537.71	0.34
P13	Paleo channels and sand bar	57.16	0.35
P2	Upper Piedmont		
P21	Forest plantation	68.3	0.32
P22	Cultivation	718.25	0.35
H	Siwalik Hills		
H1	Lower Siwalik		
H11	Terrace cultivation	223.29	0.31
H12	Fairly dense forest	3046.64	0.33
H13	Escarpment	323.44	0.37
H2	Middle Siwalik		
H21	Denuded Hill highly dissected	1480.03	0.38
H22	Fairly dense mixed forest	345.38	0.35
M	Mountain (Subathu formation)		
MI	Dense mixed forest	430.92	0.28
M2	Escarpment	215.39	0.35
V	Valley	423.79	0.48
T	River Terraces	112.49	0.44

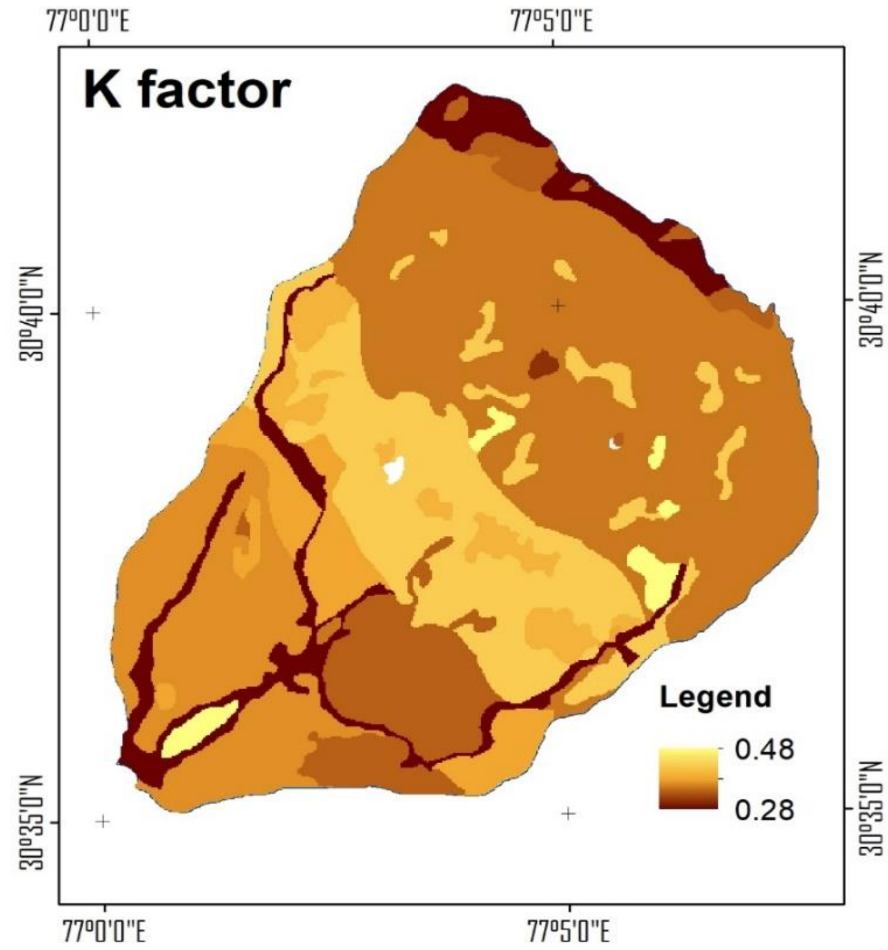


Fig. 5.18. K-factor for Tangri (Dangri) river sub-watershed

5.3.1.3 *Slope and slope length (LS) factor*

The spatial distribution of various classes in slope map (figure 5.10) reveals that 31.04% of watershed area belongs to nearly level to moderately sloping, 44.51% area belongs to moderately steep to steep-sloping and 24.45% area under steep to very-steep and escarpment classes. LS factor (figure 5.19) map shows the spatial variation within the Tangri (Dangri) river watershed. The steep sloping areas have high steepness factor (S) and low slope length (L) factor. Higher L factor is noticed where overland flow has a tendency to amass due to concave topography and lesser in the regions of convex topography such as ridge areas, where flow wanders (Hoyos, 2005). The spatial distribution of LS factor plotted against physiographic units has shown the distinct impact of physiography on LS-factor. This analysis indicates that piedmont plain have <2 LS-factor whereas the average LS-factor is found to be highest in mountains (30.47), trailed by hills (18.9) and valley (13.65). Therefore, LS-factor strongly correlates with various physiographic unit, which to a larger extent is controlling the erosion processes in the Tangri (Dangri) sub-watershed. The relationship between LS-factor and physiographic units in the sub-watershed of Tangri (Dangri) river is shown in fig. 5.20. The highest value of LS factor is noticed for M2 unit, whereas the lowest value were observed for piedmont plains and point bars.

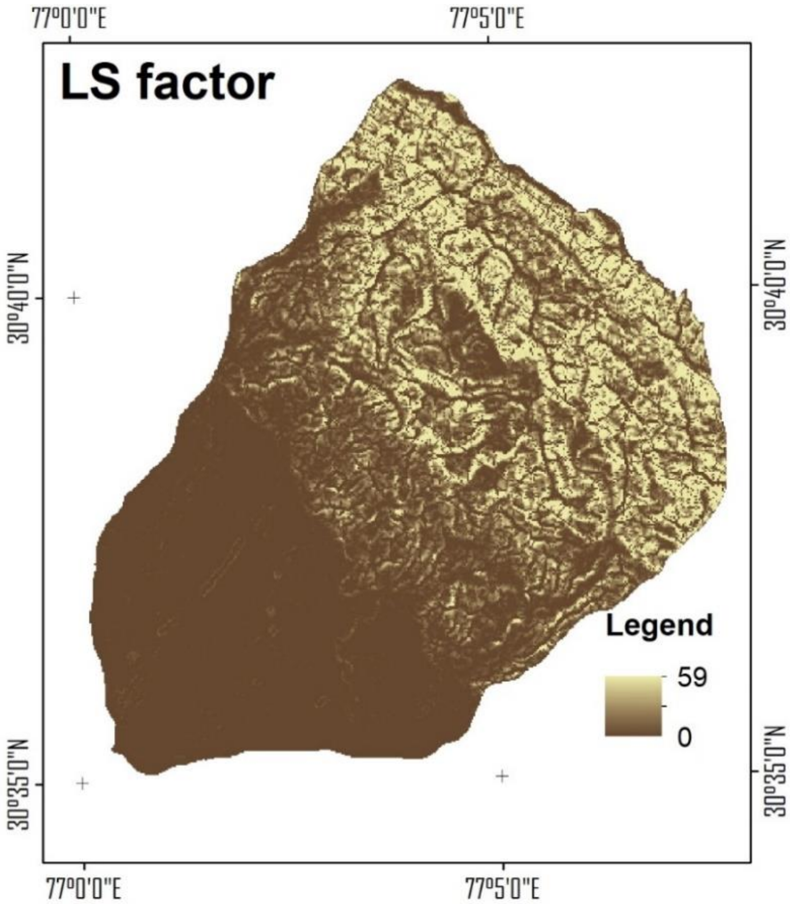


Fig. 5.19. LS-factor in the Tangri (Dangri) river sub-watershed

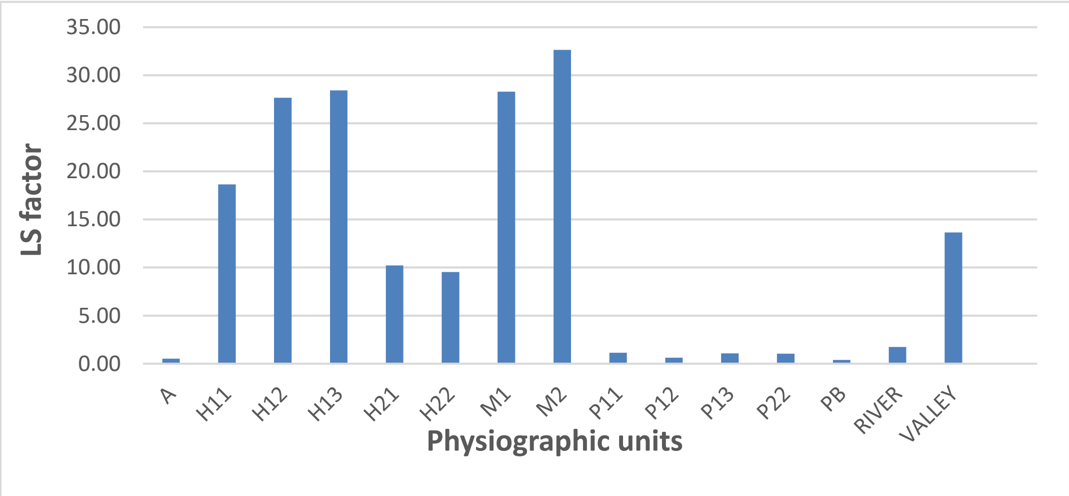


Fig. 5.20. Relationship between LS-factor and physiographic units in sub-watershed of Dangri (Tangri) river

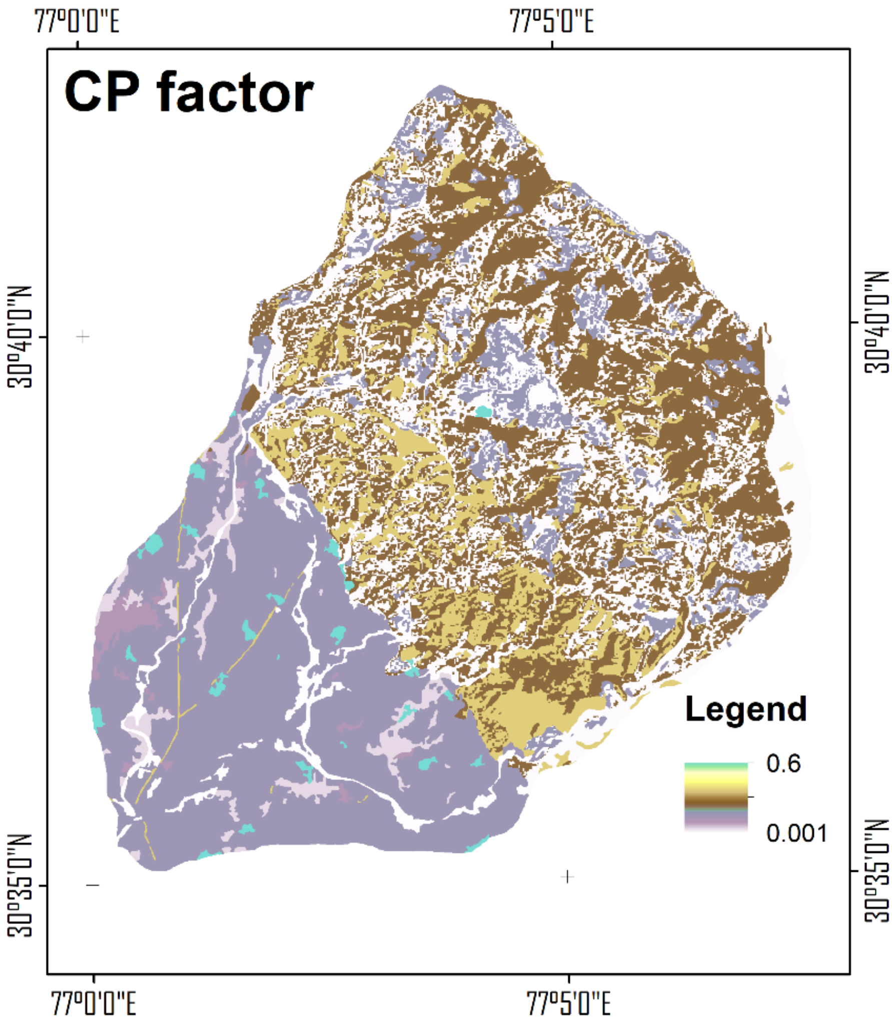


Fig. 5.21. CP-factor in the sub-watershed of Tangri (Dangri) river

__5.3.1.4__ Crop management (C) and conservation practice (P) factors

Crop management factor (C) is a function of LULC and vegetation characteristics, and roughness in RUSLE model. The C-factor related information for various LULC classes were gathered through field survey and literature. The C-factor values can range from zero (exceptionally well-protected soil) to more than one (fine tilled, ridged surface that yields high-runoff) and leaves the soil as highly vulnerable to rill erosion. Accordingly, the C-factor value varied from 0.001 to 0.6 in the study area (table 5.9, figure 5.21). Highest C-factor value was assigned to wastelands and lowest C value to dense forest in sub-watershed.

Table 5.9. LULC, C and P factor for Tangri (Dangri) river sub-watershed

S. No.	LULC class			C-factor	P-factor
	Class	Sub-class			
1.		a.	Dense	0.08	1.0
		b.	Open	0.4	1.0
		c.	Scrub	0.6	1.0
2.	Agriculture land	a.	Cropped land	0.5	0.5
		b.	Fallow/single crop	0.3	0.5
		c.	Plantation	0.1	0.5
3.	Wasteland	a.	Exposed rock	0.6	1.0
4.	River channel and Sandy area	b.	River/Channel	0.001	1.0
		c.	Sandy area along river	0.5	0.5
5.	Water body			0.001	1.0

The P-factor for most part represents how surface conditions influence flow trails and river hydraulics e.g., contouring directs runoff around slope at far lower gradient. P-factor values are governed by the conservation practices prevailing for various LULC types in Tangri (Dangri) river sub-watershed. P-factor value for forest as well as scrub areas were assigned as 1.0. P factor values for well managed areas such as agricultural land and plantation areas were assigned as 0.5.

5.3.1.5 *Soil loss*

The annual average soil loss as assessed by RUSLE equation is a function of rainfall erosivity, soil erodibility, slope gradient and length, crop cover and management factor. The model input parameters are based on remotely sensed data inputs and field investigation for the Tangri (Dangri) river sub-watershed. The spatial distribution of LULC, soil and terrain characteristics, and their influence on soil erosion have been described in the previous sections (Section 5.3.1.1 to 5.3.1.4). The annual average soil loss ($t.ha^{-1}.yr^{-1}$) as estimated for Tangri (Dangri) river sub-watershed (fig. 5.22) is described in this section.

The annual average soil loss from Tangri (Dangri) watershed is relatively higher and estimated as 40.4 $t.ha^{-1}.yr^{-1}$. The annual average soil loss as linked to various LULC classes and physiographic units were also estimated to understand the genesis and spatial distribution of various erosion contributing factors. Figure 5.23 shows the annual average soil loss against various physiographic units. The average soil loss is highest for mountain unit M2 (67.6 $t.ha^{-1}.yr^{-1}$), followed by M1 (58.1 $t.ha^{-1}.yr^{-1}$). It is followed by Siwalik hills where the highest soil loss is from

H13 unit (59.4 t.ha^{-1}.yr^{-1}), H12 unit (57.1 t.ha^{-1}.yr^{-1}) and H11 unit (46.7 t.ha^{-1}.yr^{-1}). In the piedmont region, the soil loss varied from 15.7 t.ha^{-1}.yr^{-1} to 17.8 t.ha^{-1}.yr^{-1}. The association between LULC classes with average soil loss has been plotted in fig. 5.24. The average soil loss is highest for forest scrub (61.5 t.ha^{-1}.yr^{-1}) followed by open forest (49.5 t.ha^{-1}.yr^{-1}). Table 5.10 and 5.11 show the soil losses from various LULC and physiographic-cum-soil-association classes.

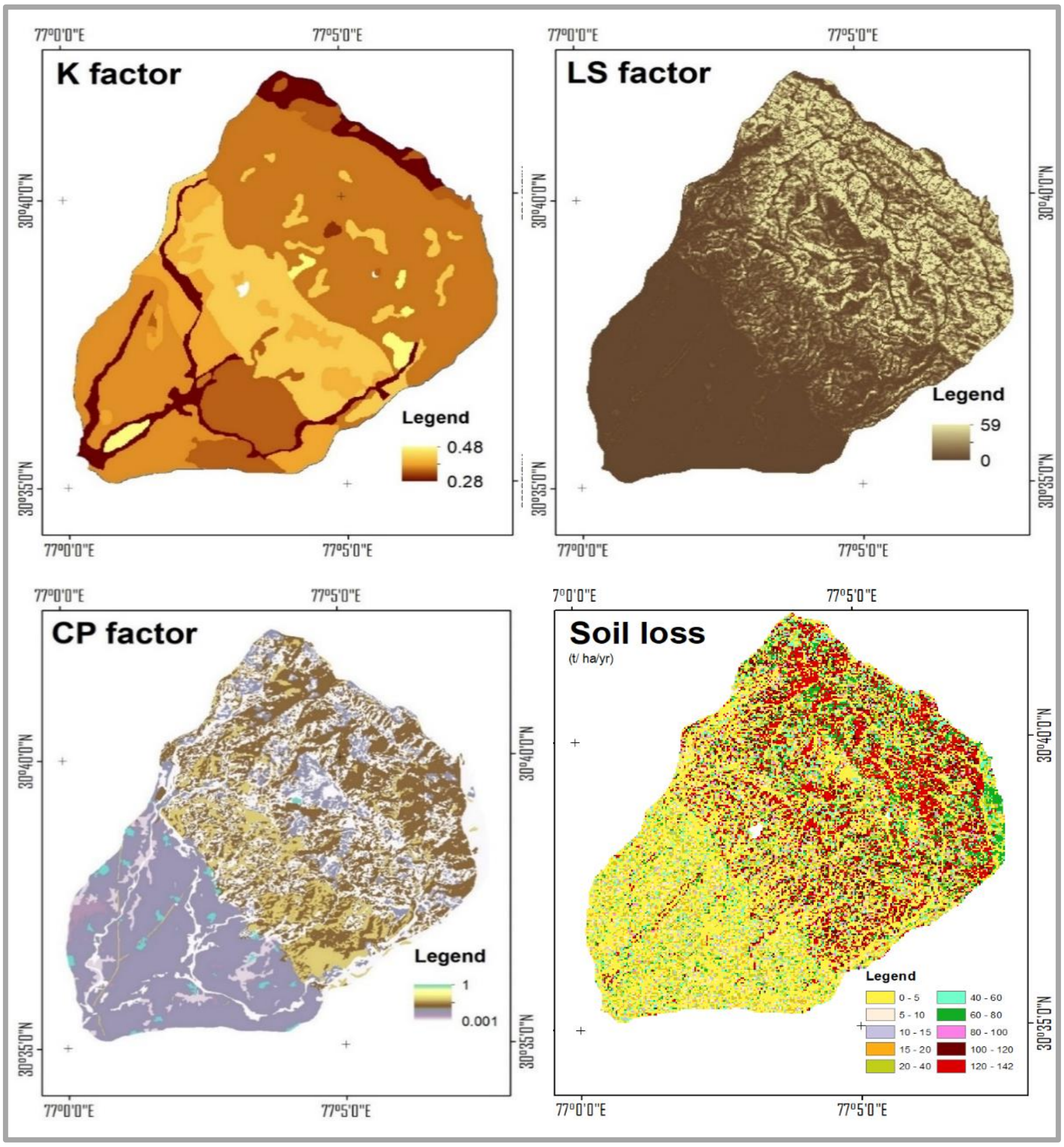


Fig. 5.22. USLE factors and annual average soil loss (t.ha^{-1}.yr^{-1}) for the sub-watershed of Tangri (Dangri) river

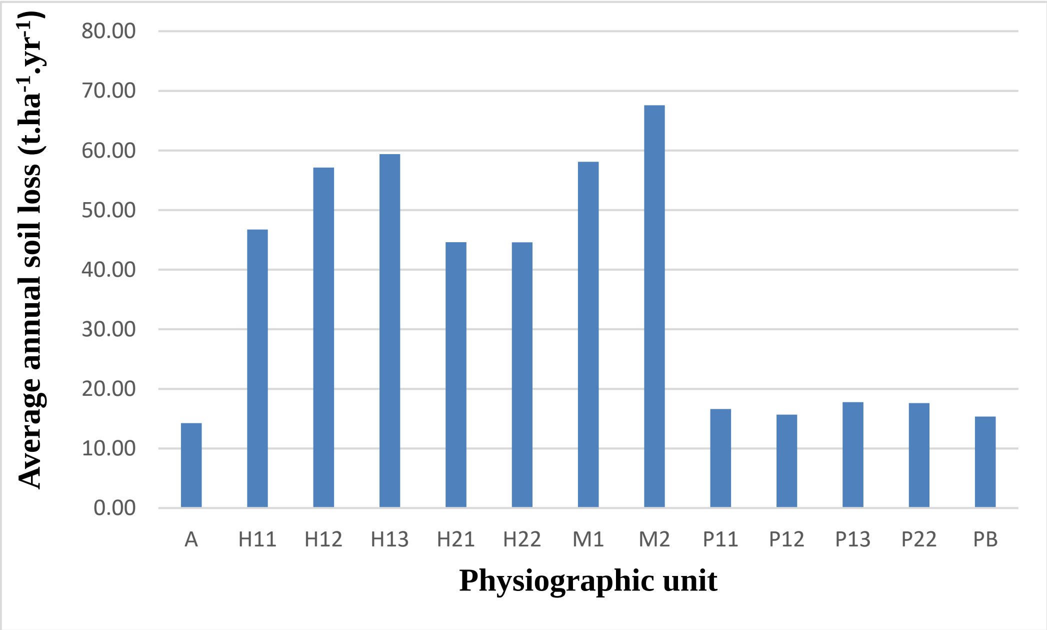


Fig. 5.23. Relationship between average soil loss and physiographic unit for the sub-watershed of Tangri (Dangri) river

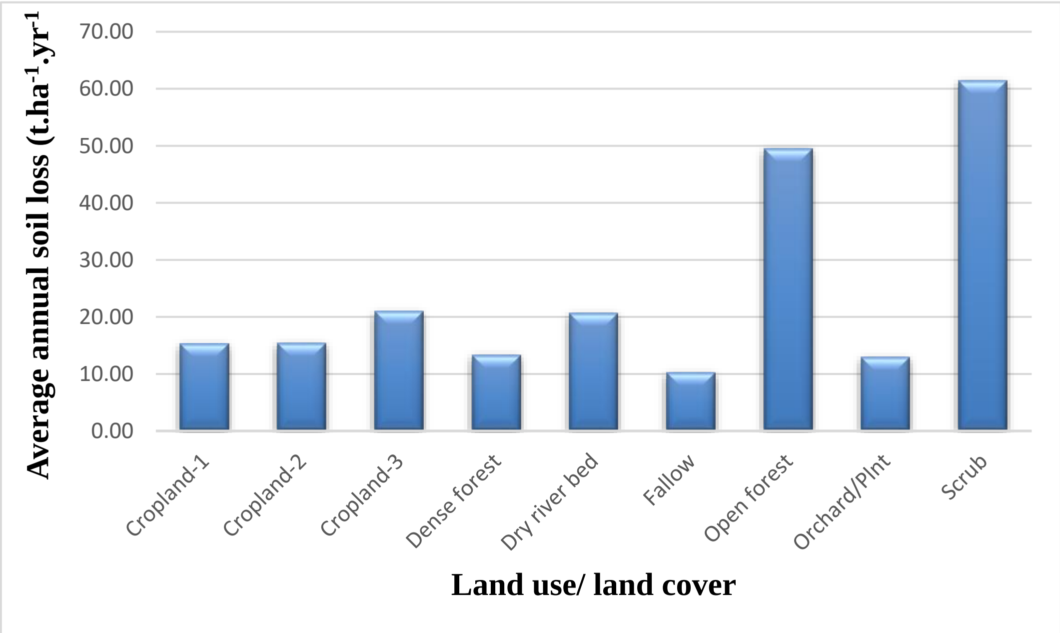


Fig. 5.24. Relationship between average soil loss and LULC characteristics for the sub-watershed of Tangri (Dangri) river

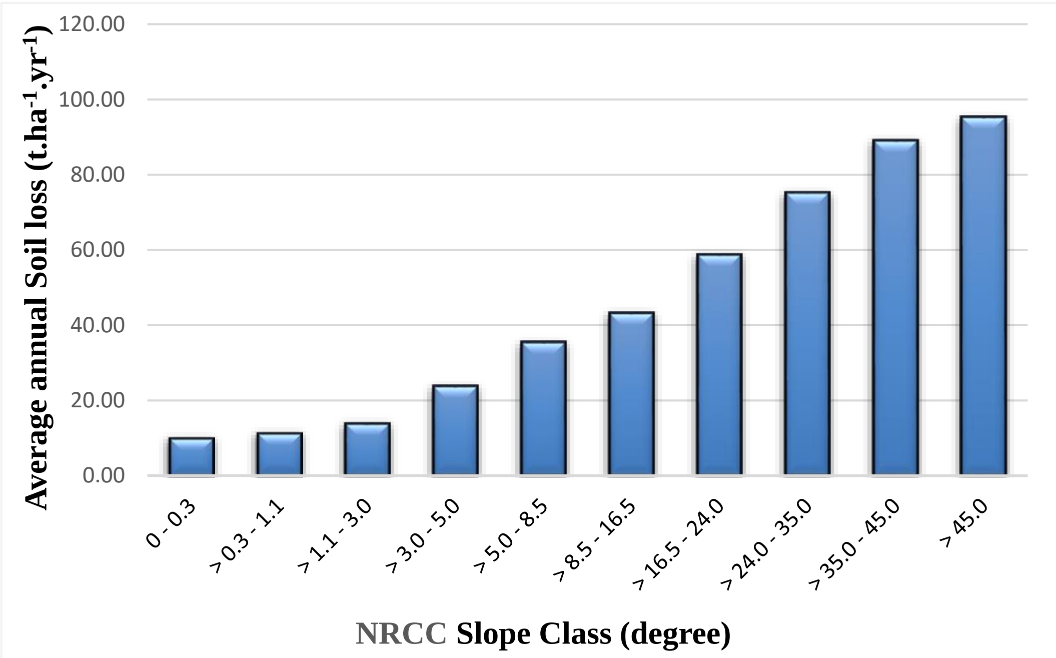


Fig. 5.25. Relationship between average soil loss and slope characteristics for the sub-watershed of Tangri (Dangri) river

Fig. 5.25 shows the relationship between average soil loss and slope characteristics for the sub-watershed of Tangri (Dangri) river. Yousuf & Singh (2016) have reported the annual average and maximum erosion rate in Siwalik foothills as 16 $t.ha^{-1}.yr^{-1}$ and more than 80 $t.ha^{-1}.yr^{-1}$, respectively. This is primarily due to pinnacle erosion in this region, though some ranges of Siwalik are vegetated too (Singh et al. 1992). Bhattacharyya et al. (2008) perceived that the soils of Siwalik are characterised as Inceptisols and Entisols with a variable soil depth ranging from 30 cm to in excess of 150 cm. Therefore, it should have variable soil loss tolerance limit ranging from 2.5 to 12.5 $t.ha^{-1}.yr^{-1}$, depending on soil depths and other conditions. The estimated soil loss in torrential watershed of Tangri river is much above the tolerance limit and therefore vulnerable sections of the watershed need immediate attention.

Table 5.10. Soil loss from varied LULC classes

Sl. No.	LULC Class	Minimum	Maximum	Average
1	Dense forest	28.51	56.93	43.31
2	Open forest	33.61	86.35	59.55
3	Scrub forest	34.68	141.97	61.47
4	Cropland	10.48	21.62	15.48
5	Fallow	4.93	24.42	10.28
6	Orchard/Plantation	8.58	16.03	12.95
7	Settlement	19.68	43.22	34.28
8	River bed	16.34	32.45	20.65

Table 5.11. Soil loss from varied physiographic-cum-soil-association classes

Sl. No.	Soil Unit	Minimum	Maximum	Average
1	A	4.42	19.91	14.26
2	H11	21.71	71.92	46.73
3	H12	15.84	81.99	57.12
4	H13	22.65	101.54	59.39
5	H21	18.97	63.00	44.61
6	H22	16.67	51.94	44.60
7	M1	18.22	91.71	58.09
8	M2	18.62	92.79	67.58
9	P11	12.13	25.40	16.62
10	P12	10.62	24.96	15.68
11	P13	10.55	30.64	17.78
12	P22	13.29	27.76	17.62
13	PB	8.93	21.26	15.36
14	River	2.98	31.66	20.35
15	Valley	12.62	41.90	41.69

5.3.2 Hydrologic and Hydrodynamic Modeling

5.3.2.1 Rainfall frequency analysis

The rainfall frequency investigation assumes an imperative place in the design practices of hydraulic structures as well in disaster management. It links extent of extreme events to the incidence of recurrence using probability distribution. Rainfall frequency analysis is based on fitting of a probability model using data for a given period of observation. In this study, the IDF curve analysis using the hourly rainfall data from 1986 to 2013 obtained from IMD for Ambala station was done for rainfall frequency analysis, after fitting a theoretical Extreme Value (EV) distribution (Gumbel Type I) for various exceedance probabilities.

Gumbel's distribution, which is a statistical strategy and frequently utilised for predicting extreme hydrological events such as floods, has been applied for flood frequency recurrence in light of the fact that (a) the river isn't essentially influenced by reservoir operations or diversions, and (b) there is no large tributary whose inflow can influence the flood peak. Figure 5.26 shows the maximum annual daily rainfall for Ambala station which was processed from daily rainfall data for Ambala station (Annexure-3). The hourly rainfall data recorded at Ambala station from 1986 to 2013 was placed in descending order for various years to compute the annual maximum rainfall intensity for various durations. Later, the exceedance probability associated with each rainfall volume was assessed. Table 5.12 shows the annual maximum rainfall intensity computed for various durations i.e., 1-hr, 2-hr, 3-hr, 6-hr, 12-hr and 24-hr. Later, the exceedance probability associated with each rainfall volume was assessed based on expression, $p = \frac{1}{T} = \frac{rank}{m+1}$ where m is number of observations, p is exceedance probability and T is corresponding return period. The volume data was converted into rainfall intensity by dividing volume by the corresponding duration. In order to compute the exceedance probabilities based on Gumbel Type I Extreme Value (EV) distribution, the frequency factors (Table 5.13) associated with various return periods (i.e., 2, 5, 10, 25, 50, 100 and 1000 years) were computed as per eq. 4.36 and 4.37 (Chapter-4) , and applied to each set of annual maxima corresponding to various durations. Later for each duration, the sample mean and standard deviations of the series of annual maxima, (x_1..., x_m) from the rainfall data was computed. Table 5.14 shows the computed rainfall intensity for various return periods. It is observed that the 1-hourly rainfall magnitude for various return periods, namely two, five, ten, twenty-five, fifty, hundred and thousand years have been estimated as 48.5 mm, 64.1 mm, 74.5 mm, 87.6 mm, 97.3 mm, 106.9 mm and 138.7 mm, respectively (Table 5.14 and fig. 5.27) based on Gumbel's distribution. Similarly, for other durations, the rainfall intensities have been computed.

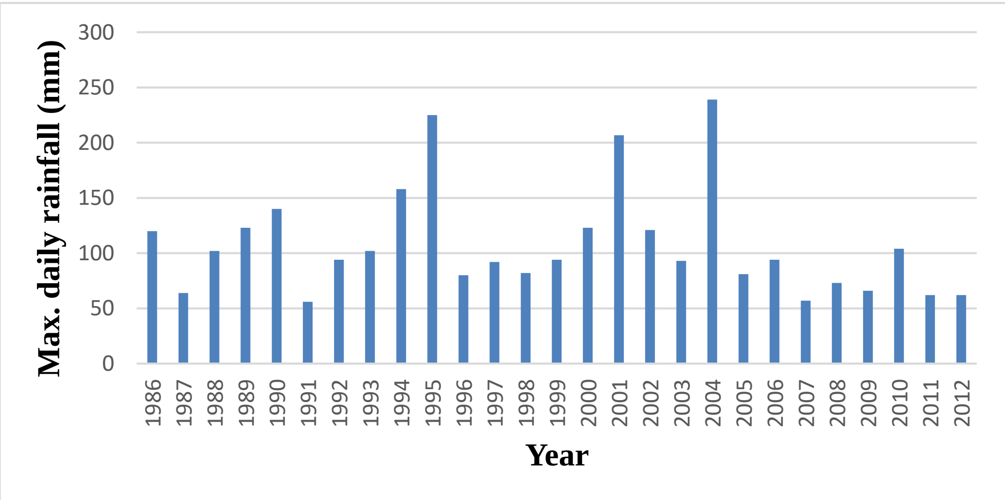


Fig. 5.26. Maximum annual daily rainfall for Ambala station

Table 5.12. Maximum annual rainfall intensity for various durations

Year	1-hr	2-hr	3-hr	6-hr	12-hr	24-hr
1986	65.0	81.5	85.4	86.8	149.6	149.6
1987	52.5	88.2	90.5	110.0	126.2	128.6
1988	110.0	190.9	190.9	191.1	191.2	368.0
1989	34.1	50.7	57.0	92.5	119.2	163.0
1990	44.0	61.0	78.0	99.2	142.3	142.3
1991	31.5	40.8	42.6	52.5	65.6	69.5
1992	37.3	43.8	49.7	56.2	60.5	61.0
1993	45.5	90.5	119.5	149.0	204.9	224.4
1994	52.6	76.4	94.4	95.7	116.4	117.6
1995	48.5	54.2	55.7	68.8	78.8	78.8
1996	31.0	39.7	42.2	43.9	43.9	43.9
1997	62.6	71.9	73.4	87.0	111.4	157.9
1998	61.6	122.1	143.6	193.7	202.0	202.0
1999	31.0	33.8	38.6	50.3	55.6	55.6
2000	54.0	55.9	56.5	90.0	102.2	151.5
2001	44.2	65.0	97.6	140.2	147.3	148.2
2002	100.0	106.7	110.0	126.5	152.3	175.1
2003	50.0	90.0	100.0	100.9	102.9	102.9
2004	42.7	73.6	86.6	118.1	159.6	161.6
2005	55.1	63.0	63.5	64.3	64.3	64.9
2006	53.5	63.7	81.7	103.5	116.6	116.6
2007	53.2	53.6	54.0	54.5	54.5	92.8
2008	50.0	97.0	105.8	110.0	110.0	110.0
2009	43.0	67.5	79.5	88.2	91.7	91.7
2010	54.2	91.0	93.8	104.3	111.7	118.9
2011	44.0	61.0	78.0	99.2	142.3	142.3
2012	31.5	40.8	42.6	52.5	65.6	69.5
2013	57.0	63.0	151.9	0.0	0.0	94.9
Mean	51.4	72.8	84.4	93.9	110.3	128.7
S.D.	17.7	31.1	35.3	41.5	48.6	64.0

Table 5.13. Frequency factors for rainfall frequency analysis

T	2	5	10	25	50	100	1000
K_T	-0.164	0.719	1.305	2.044	2.592	3.137	4.936

Table 5.14. Return period analysis for various rainfall intensities (mm/hr)

Duration (hr.)	Return period (T)						
	2	5	10	25	50	100	1000
1	48.5	64.1	74.5	87.6	97.3	106.9	138.7
2	33.8	47.6	56.6	68.1	76.6	85.1	113.0
3	26.2	36.6	43.5	52.2	58.6	65.1	86.2
6	14.5	20.6	24.7	29.8	33.6	37.4	49.8
12	8.5	12.1	14.5	17.5	19.7	21.9	29.2
24	4.9	7.3	8.8	10.8	12.3	13.7	18.5

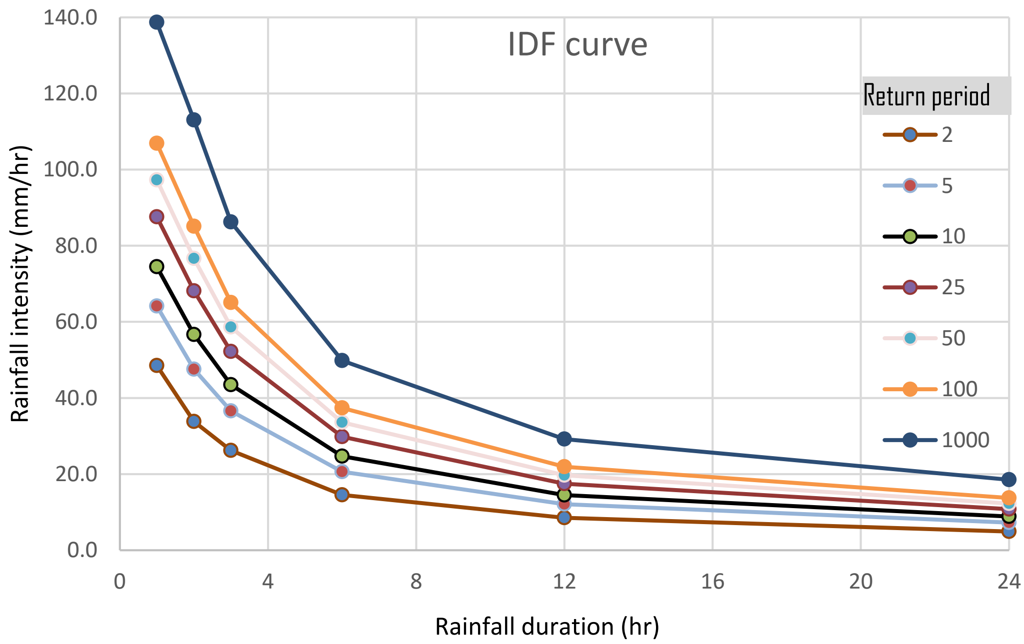


Fig. 5.27. IDF curve for Ambala station

5.3.2.2 Hydrologic analysis

a. Land use/ land cover

LULC gives degree and spatial distribution of different LULC types. It gives information about arable areas including cropland, fallow and plantation, and also about cropland in different sowing seasons (*Rabi/ Kharif*), etc. It is also useful in planning for optimal land utilisation. LULC information derived from temporal data assists in determining cropping intensity and changes in the land utilisation pattern. LULC information for Tangri (Dangri) river watershed was derived based on supervised classification technique. MLC algorithm is a standout amongst various supervised classification techniques and extensively used for information extraction from remote sensing images. This technique depends on the likelihood that a pixel has a place with a specific class. The fundamental speculation expect that these probabilities are proportionate for all classes and that information groups follows normal distribution.

Table 5.15. LULC characteristics of Tangri (Dangri) river watershed

Sl. No.	LULC class	Area (sq. km)	% of geog. area	Accuracy (%)	Kappa
1	Cropland	192.88	40.00	87.33	0.84
2	Fallow	29.73	6.17	80.22	0.76
3	Orchard/Plnt.	56.05	11.63	88.12	0.87
4	Dense forest	41.30	8.57	89.34	0.89
5	Open forest	51.61	10.70	86.27	0.83
6	Scrub forest	4.90	1.02	82.73	0.82

Sl. No.	LULC class	Area (sq. km)	% of geog. area	Accuracy (%)	Kappa
7	Land with/ without scrub	50.25	10.42	81.34	0.77
8	Waterbody	0.18	0.04	92.35	0.91
9	Settlement/Road	18.37	3.81	80.23	0.76
10	River	36.87	7.65	81.66	0.79
	Grand Total	482.15	100.00		

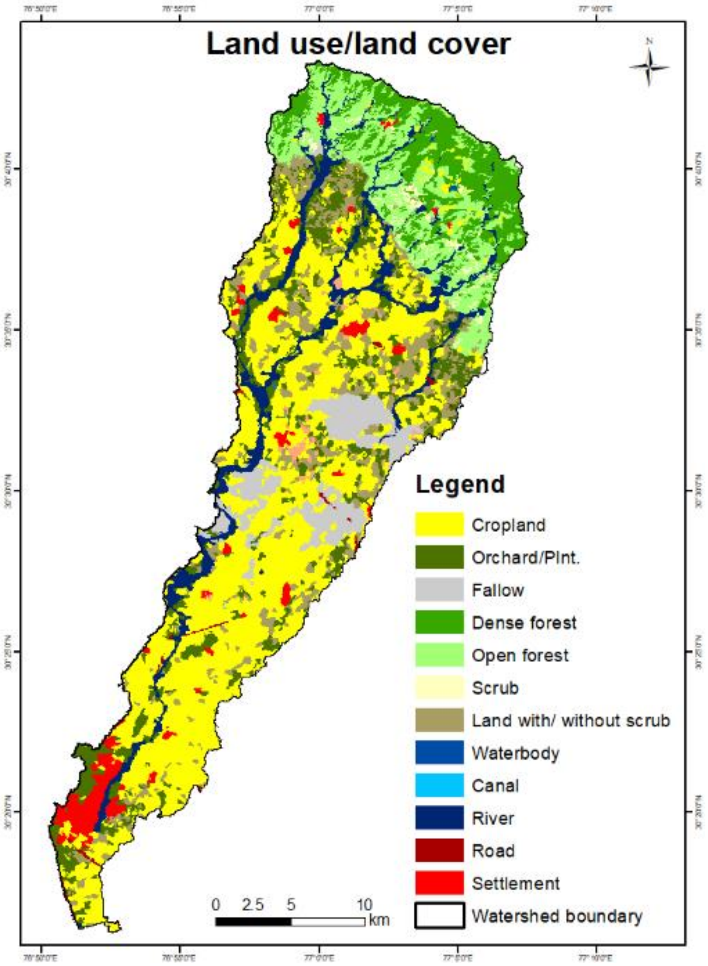


Fig. 5.28. LULC characteristics of whole Tangri (Dangri) river catchment

The training signatures for supervised classification were assigned by delimiting polygons around representative sites for each of predetermined LULC type. The spectral signatures for these LULC types were produced from statistical characteristics of the pixels enclosed by these polygons. The aerial extent of various LULC classes are shown in fig. 5.28 and table 5.15. The LULC is classified into following categories- Cropland, Fallow, Orchard/ Plantation, Dense forest, Open forest, Scrub, Land with or without scrub, Waterbody, Settlement, River, Road and Canal. The agricultural activities are ongoing at large scale in alluvial plains and floodplains of Tangri (Dangri) river and also as terrace cultivation. The area under agricultural activities occupy 278.7 sq. km of the watershed. The hills and mountains have extensive forest cover i.e., 97.8 sq. km. (as dense, open and scrub forest). The piedmont region has land with/ without scrub to the extent of 50.3 sq. km.

b. Soil map

The information on soil and their characteristics is imperative for any developmental activity related to land and water on watershed basis. The variation in soil properties depends on the soil forming factors. The underlying lithology, topography and vegetation cover are dominant elements that govern soil development. Within study area, there are four major physiographic units, namely Alluvial plain, Piedmont, Siwalik hills and Mountains. These physiographic units were further sub-divided based on LULC characteristics and vegetation cover. The unit-wise soil association is presented in figure 5.29 and table 5.16.

Table 5.16. Soil classes in Tangri (Dangri) river watershed

Sl. No.	Soil class	Area (sq. km)	% of geog. area
1.	Active Flood Plain- Coarse Loamy, Cal-Typic Ustofluvents	29.90	6.20
2.	Active Flood Plain- Coarse Loamy, Typic Ustofluvents	8.61	1.79
3.	Old Alluvial Plain- Fine Loamy, F. Ustochrepts	182.93	37.94
4.	Recent Flood Plain- Coarse Loamy, Typic Ustochrepts	4.90	1.02
5.	Recent Flood Plain- Coarse Loamy, Typic Ustofluvents	77.33	16.04
6.	Recent Flood Plain- Fine Loamy, Fluventic Ustochrepts	16.77	3.48
7.	Recent Flood Plain- Fine Loamy, Typic Ustochrepts	50.04	10.38
8.	Recent Flood Plain- Fine Loamy, Udic Ustochrepts	1.48	0.31
9.	Siwalik- Loamy skeletal, Coarse Loamy, Typic Ustorthents	83.68	17.36
10	Siwalik- Loamy skeletal, Typic Ustorthents	26.50	5.50
	Total	482.14	100.00

Source: National Bureau of Soil Survey and Land Utilisation Planning

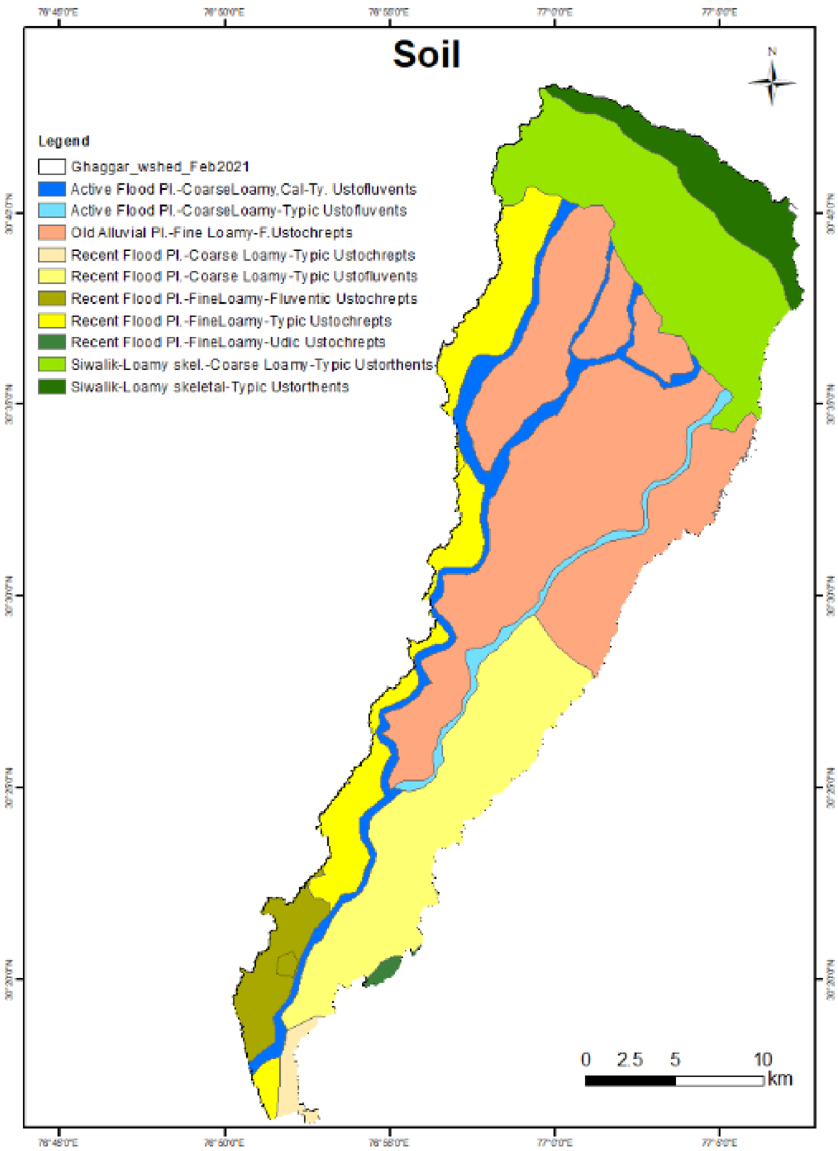


Fig. 5.29. Soil map of Tangri (Dangri) river watershed

c. *Runoff Curve Number*

The SCS runoff CN method of USDA SCS which represents empirical relationship among retention (rainfall stored in depressions), runoff properties and the rainfall was utilised in present study to evaluate the discharge corresponding to varying return periods.

d. *Watershed and drainage characteristics*

The DEM data derived from Cartosat-1 stereo pairs was pre-processed to derive the catchment boundaries. During this process, following datasets were derived for ensuing examination: depression-filled DEM, flow direction and flow accumulation in which every pixel gets a value proportionate to add up to number of cells that deplete to it, and a delta value in which each pixel's characteristic is determined for its tendency to flow and add to flow accumulation based on flow direction. The watersheds were delineated using flow accumulation data interactively with seed points at the identified pour points. Figure 5.30 shows the flow direction, flow accumulation and watershed boundary delineated for the Tangri (Dangri) river.

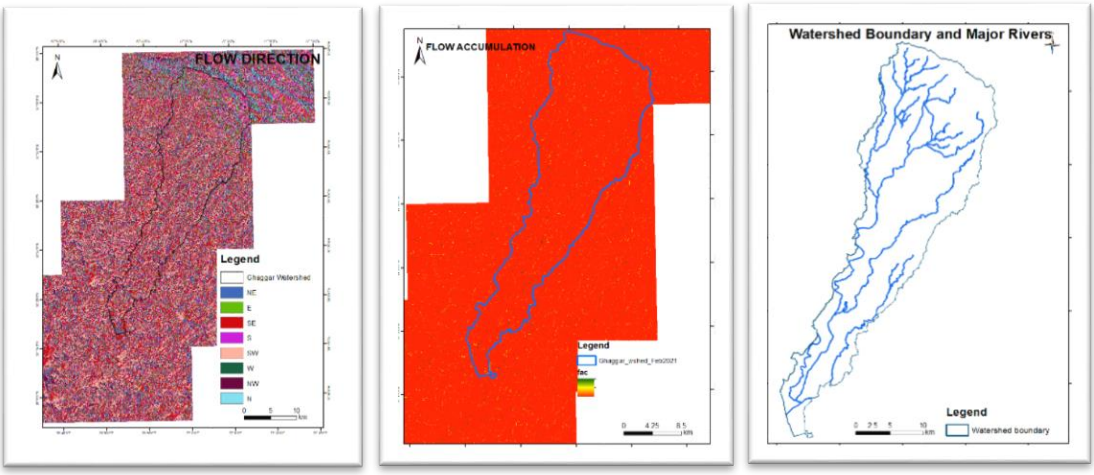


Fig. 5.30. Watershed boundary delineation from Cartosat-1 DEM for Tangri (Dangri) river watershed

e. *Peak runoff*

The precipitation information is most imperative contribution for event-based HEC-HMS based analysis. The 24-hour storms for 2, 5, 10, 25, 50, 100 and

1000 years as analysed based on Gumbel's distribution were utilised as input to compute the peak flows as summarised in Table 5.17. The Muskingum-Cunge routing method is used for flood routing. It could be seen from the table that peak discharge (cumecs) for various return periods varied from 591 cumecs to 2824 cumecs.

Table 5.17. Peak discharge computed for varying return periods in Tangri (Dangri) river watershed

Return period	24-hr Rainfall (mm/hr.)	Peak discharge (cumecs)
2 year	4.9	591.07
5 year	7.3	907.51
10 year	8.8	1081.08
25 year	10.8	1411.95
50 year	12.3	1809.04
100 year	13.7	2023.84
1000 year	18.5	2824.00

5.3.2.3 *Observed discharge*

The discharge of Tangri (Dangri) river is measured at Gauge and Discharge (G&D) site no.5 near Ambala-Shahbad road crossing and Shahpur town. It is being measured with the help of float and sounding system at R.L. 267.60 m. The discharge data for the period 2001 to 2017 is shown in Annexure-4. As seen from the Annexure-4, the discharge data is available for monsoon months whereas for other months the data is not available. Based on Gumbel's extreme value theory, the discharge data was processed to derive values for varying return periods. After deriving the maximum discharge for various years, the data was processed for return period analysis. Table 5.18 and 5.19, and figure 5.31 demonstrate the return period analysis of discharge measured on Tangri (Dangri) river. As seen from the table 5.19 that discharge values for return periods 2, 5, 10, 15, 20, 25, 30, 50, 60, 75, 100 and 1000 years are 620.2, 1020.3, 1282.5, 1430.5, 1530.7, 1613.4, 1678.3, 1859.3, 1923.4, 2001.8, 2102.8 and 2908.41 cumecs, respectively. As the observed discharge data was available for limited number of years than the desirable 35 years of record, it has posed limitations in the return period analysis. Fig.5.32 shows the log-log plot of the return period analysis of discharge data measured on Tangri (Dangri) river.

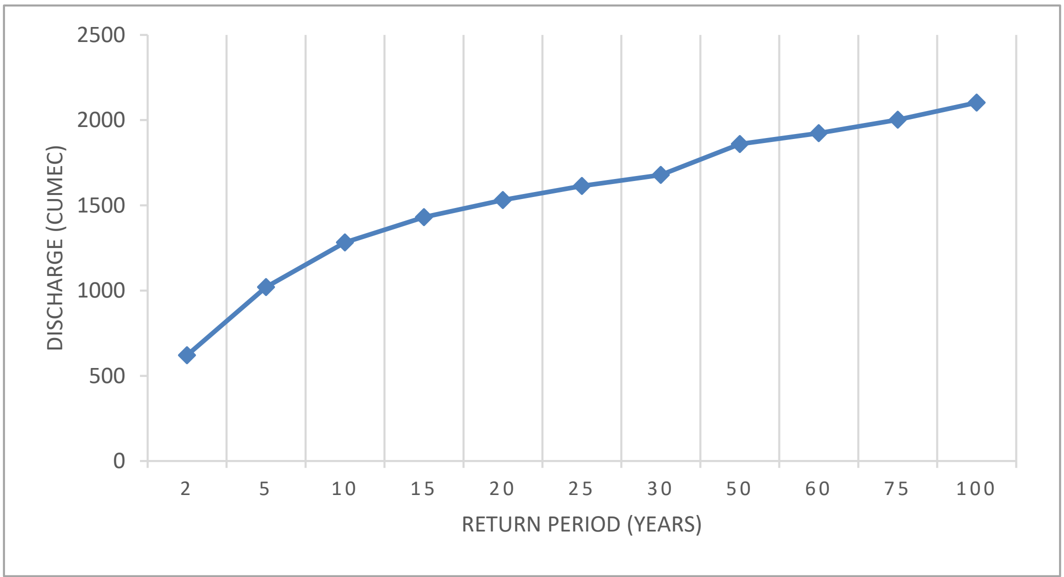


Fig. 5.31. Return period analysis of discharge data measured on Tangri (Dangri) river

Table 5.18. Parameters for return period analysis of discharge data (cumecs) measured on Tangri (Dangri) river

Year	Discharge (Q) cumecs	m	n+1/ m	m/n+1*10 0	Q^2	m*100/ n+1
2012	1127.00	1	18.00	5.56	1270129.00	5.56
2010	1127.00	2	9.00	11.11	1270129.00	11.11
2017	1081.36	3	6.00	16.67	1169339.45	16.67
2016	1081.36	4	4.50	22.22	1169339.45	22.22
2004	1081.36	5	3.60	27.78	1169339.45	27.78
2008	995.39	6	3.00	33.33	990801.25	33.33
2002	995.39	7	2.57	38.89	990801.25	38.89
2009	866.66	8	2.25	44.44	751099.56	44.44
2005	663.48	9	2.00	50.00	440205.71	50.00
2013	560.36	10	1.80	55.56	314003.33	55.56
2011	531.90	11	1.64	61.11	282917.61	61.11
2015	420.27	12	1.50	66.67	176626.87	66.67
2001	394.04	13	1.38	72.22	155267.52	72.22
2014	357.10	14	1.29	77.78	127520.41	77.78
2003	294.31	15	1.20	83.33	86618.38	83.33
2006	26.62	16	1.13	88.89	708.62	88.89
2007	22.83	17	1.06	94.44	521.21	94.44
Sum	11626.43					
SD	388.4234					
Mean	683.91					

Table 5.19. Return period analysis of discharge data (cumecs) measured on Tangri (Dangri) river

Return Period T (Years)	Mean (x)	SD	K	K*SD	x+KSD
2	683.90	388.40	-0.16	-63.70	620.20
5	683.90	388.40	0.87	336.40	1020.30
10	683.90	388.40	1.54	598.60	1282.50
15	683.90	388.40	1.92	746.50	1430.50
20	683.90	388.40	2.18	846.80	1530.70
25	683.90	388.40	2.39	929.50	1613.40
30	683.90	388.40	2.56	994.40	1678.30
50	683.90	388.40	3.03	1175.40	1859.30
60	683.90	388.40	3.19	1239.50	1923.40
75	683.90	388.40	3.39	1317.90	2001.80
100	683.90	388.40	3.65	1418.90	2102.80
1000	683.91	388.42	5.73	2224.50	2908.41

Fig.5.32. Return period analysis of discharge data measured on Tangri (Dangri) river (log-log plot)

5.3.2.4 Comparison of discharge

The observed and estimated discharge were compared based on Nash–Sutcliffe model efficiency as given in Eq. 5.1.

$$\text{DC} = 1 - \frac{\sum_{i=1}^{n}(Q_e - Q_o)^2}{\sum_{i=1}^{n}(Q_o - \overline{Q_o})^2} \quad \text{……5.1}$$

Where, Q_e is estimated peak discharge (cumecs) for each time step *i*, Q_o *is* observed peak discharge for each time step *i*, $\overline{Q_o}$ is observed mean peak discharge and *n* is the total no. of observations. Table 5.20 shows the Nash–Sutcliffe model efficiency coefficient computed for the modelled output. Nash–Sutcliffe model efficiency coefficient was obtained as 0.88 from the analysis.

Table 5.20. Nash–Sutcliffe model efficiency coefficient

Return period	Observed (Q_o)	Estimated (Q_e)	$Q_e - Q_o$	$(Q_e - Q_0)^2$	$(Q_o - \overline{Q_o})$	$(Q_e - \overline{Q_o})^2$
2	620.21	591.07	29.14	849.14	-1009.34	1018773.00
5	1020.28	790.51	229.77	52794.25	-609.27	371213.41
10	1282.47	1001.08	281.39	79180.33	-347.08	120466.51
25	1613.40	1311.95	301.45	90872.10	-16.15	260.91
50	1859.28	1559.04	300.24	90144.06	229.73	52774.56
100	2102.82	1823.84	278.98	77829.84	473.27	223981.79
1000	2908.41	2824.00	84.41	7125.05	1278.86	1635475.59
	$\overline{Q_o}$ =1629.55			Σ=398794.77		Σ=3422945.78
Nash–Sutcliffe model efficiency coefficient						0.88

5.3.2.5

5.3.2.5 *Hydrodynamic modeling*

a. Manning's Coefficient

Manning's equation is one of the most commonly used equation governing open channel flow. It applies to uniform flow in open channels and is a function of channel velocity, flow area and channel slope. There are numerous factors that affect n-values, including: surface roughness, vegetation, silting/ scouring, obstruction, size/ shape of channel, seasonal change, suspended material, bed load, stage (depth of flow) and discharge. Table 5.21 shows the Manning's coefficient used in the present study. The roughness coefficients, n, varies with the type of vegetative cover, longitudinal slope, and average flow depth. The value of Manning's coefficient varied from 0.025 to 0.10 for Dangri (Tangri) river catchment.

Table 5.21. Manning's Coefficient

Sl. No.	Class Code	Manning's n
1	Dense Forest	0.10
2	Open Forest	0.06
3	Scrub Forest	0.04
4	Crop Land	0.04
5	Fallow Land	0.03
6	Orchard/Plantation	0.06
7	Scrub Land	0.035
8	Settlement	0.025
9	River bed and surroundings with vegetation cover	0.035
10	River bed and surroundings without vegetation cover	0.025

b. *River system schematics*

In HEC-RAS analysis, the river system schematics were defined in terms of reach, cross-sections, flow paths, ineffective areas, etc. The stream centre-line was drawn along the main channel to represent the centre of mass of flow. Later, the flow paths were defined for the left and right overbanks. These lines have helped in drawing cross-sections perpendicular to flow path, and also signify centroid flow path for assessing the reach lengths between cross-sections. The cross-sections were drawn at desirable interval all along the Tangri (Dangri) river and at locations wherever changes were likely to occur in discharge, slope, shape, or roughness, etc. Wherever such abrupt changes were expected, several cross-sections were utilised to describe changes regardless the distance between cross-sections. These cross-sections characterise the flow carrying capability of streams and the adjoining floodplain. It was ensured that cross-sections should spread transversely in whole floodplain and ought to be at right angle to expected flow lines. At few places to accommodate the curvilinear nature of the river section, the cross-section cut-lines were tuned accordingly such that cross-section remain as perpendicular to the anticipated flow lines. Figure 5.33 shows the river system schematics for Tangri (Dangri) river.

The cross-sectional details in HEC-RAS model contain information about river, reach, and river station. These details depict height and position information entered from left to right, while looking towards downstream segment of channel. The numbering system have been consistent such that higher river stations were at upstream region and lower river stations were marked towards downstream reaches.

These geometry parameters were later intersected with DEM to have 3D properties for all reaches and cross-sections marked on various rivers/ reaches. Later, the geometry layer was intersected with LULC information. These processes have helped in identifying the river sections, their geometry and corresponding LULC and elevation characteristics useful for inundation modeling. Table 5.22 shows the river geometry parameters for various reaches of Tangri (Dangri) river.

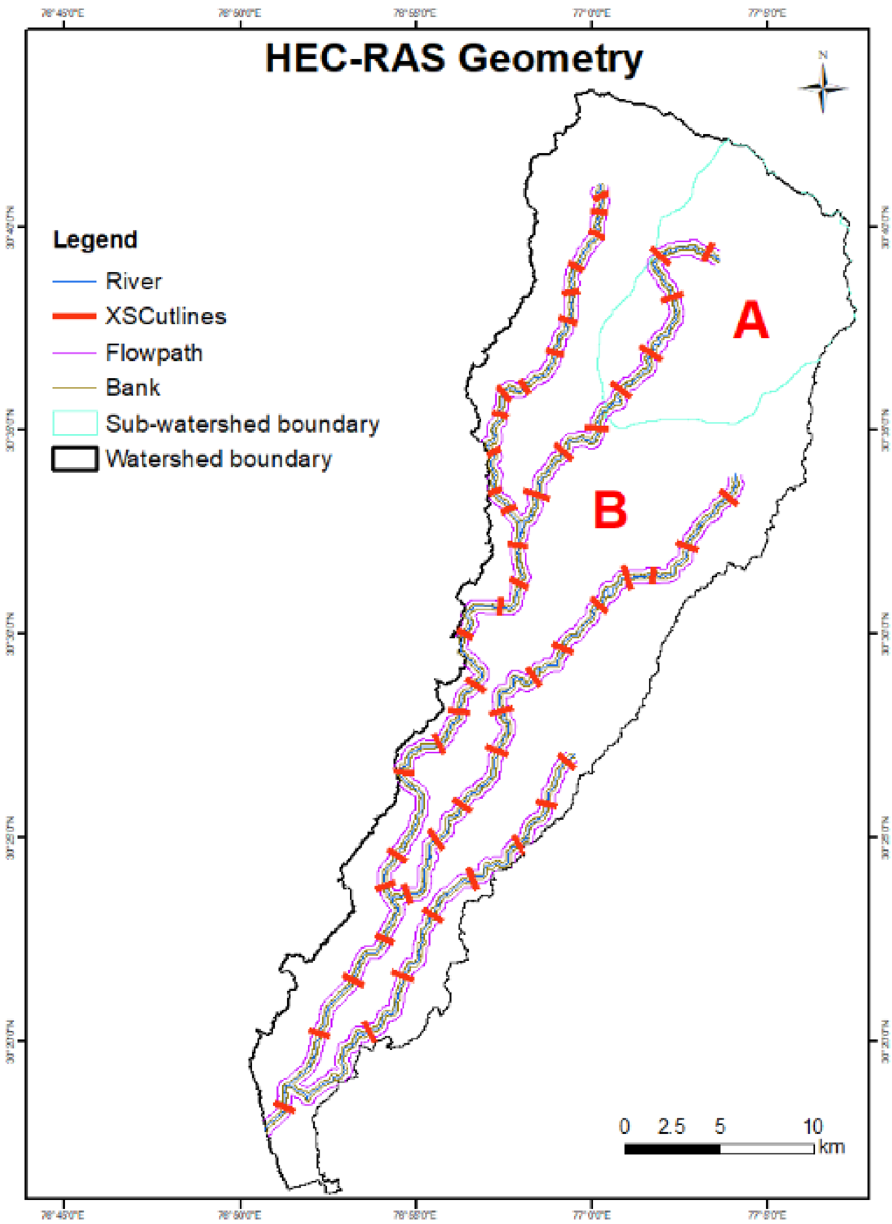


Fig. 5.33. River system schematics for Tangri (Dangri) river

c. *HEC-RAS water surface computation*

During the process of hydraulic modeling in HEC-RAS, the river network, river and floodplain geometry, river reaches, junctions, Manning's roughness coefficient values, etc. are required. The river network in HEC-RAS is characterised by various interconnected reaches. In the present study, stream centre-lines and the floodplains geometry were delineated from Resourcesat-1 multispectral and DEM produced from Cartosat-1 stereo data. The cross-sectional details were built to segregate river network into five major reaches with well-defined junctions. Initially, two-dimensional parameters were defined based on river system schematics and for hydraulic computations. Later, the three-dimensional properties of channels and floodplains were delineated from DEM. The LULC layer along with Manning's roughness variability was ingested into HEC-RAS model. The stream network, geometry and cross-sectional details were transferred from HEC-GeoRAS to HEC-RAS model. HEC-RAS model was executed with river schematics details and discharge values corresponding to varying return periods. The HEC-RAS model has computed the inundation depths corresponding to discharge values at the catchment outlet. The flood hazard map was produced based on peak flows for various return periods as simulated through HEC-HMS and entered into the HEC-RAS model. The flood inundated areas are shown in figure 5.34 for the 10-year design storm in flood hazard map. Table 5.23 shows the rainfall, runoff and flood depths and table 5.24 shows the hydrodynamic properties for Tangri (Dangri) sub-watershed and whole catchment.

Table 5.22. Reach-wise river system schematics

Reach	Length (m)	River width (m)	
		Minimum	Maximum
R1	21269.1	14	17
R2	22913.3	19	24
R3	32743.0	24	42
R4	25661.9	28	56
R5	23871.4	34	78
R6	12658.1	42	92
R7	1324.4	51	98

Table 5.23. Rainfall, runoff and flood depths

Return period	24-hr Rainfall (mm/hr.)	Runoff (cumecs)	Minimum flood depth (m)	Maximum flood depth (m)
2 year	4.9	591.07	0.03	0.26
5 year	7.3	907.51	0.08	0.43
10 year	8.8	1081.08	0.17	0.59
25 year	10.8	1411.95	0.26	0.77
50 year	12.3	1809.04	0.33	0.84
100 year	13.7	2023.84	0.40	1.19
1000 year	18.5	2824.00	0.53	2.12

The hydrodynamics properties for whole catchment of Tangri (Dangri) river and also for sub-watershed marked as ‘A’ and ‘B’ in figure 2.1 is given in table

5.24. The table describes the river behaviour corresponding to rainfall of 10-year return period. Above analysis is based on Technical Release 55 (TR-55) flow path segments and parameters in-built within HEC-RAS model. This strategy was utilised to separate overland shallow and stream discharge along the longest flow path. The stream section parameter estimates length between four points and inclined in all sub-catchment based on length and slope characteristics.

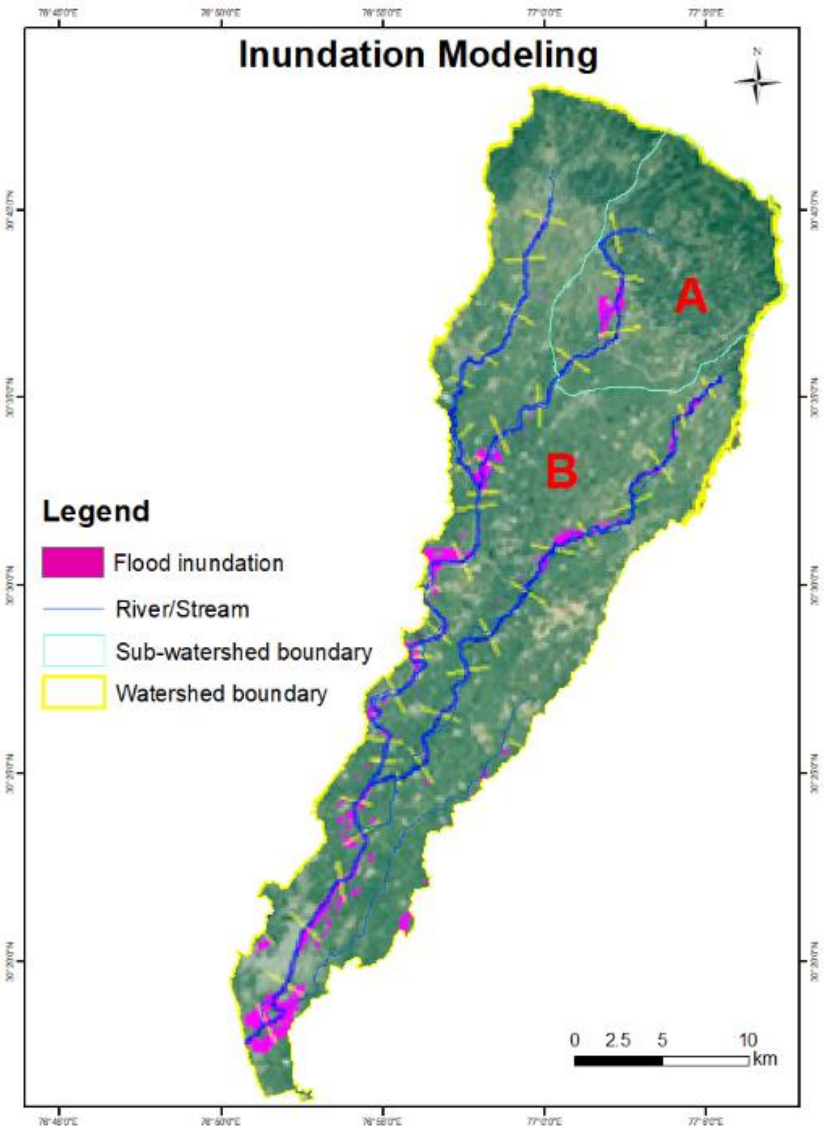


Fig. 5.34. Inundation area near Tangri (Dangri) river for 10-year return period

Table 5.24. Hydrodynamic properties for Tangri (Dangri) sub-watershed and whole watershed

Watershed Name	A	B
Watershed ID	Sub-watershed (A)	Whole-catchment (B)
Manning's Roughness coefficient	0.10	0.04
Flow length (m)	14765	59618
24-hour 10 year rainfall (mm/hr.)	172.0	172.0
Land slope *(m/m)*	0.29	0.05
Sheet flow T_t (hr.)	0.69	1.27
Shallow concentrated flow characteristics		
Surface description (1-unpaved, 2-paved)	1	1
Flow length (m)	8669	35686
Watercourse slope (m/m)	0.0098	0.0009
Average velocity - computed (m/s)	0.49	0.19
Shallow Concentrated Flow T_t (hr.)	0.95	1.46
MXO Path	geo_hms.mxd hms.mxd	
$AVHOME directory		
Name of table to store results of calculation	Subbasin279	
Workspace path	J:\Modelling\outlet\outlet.gdb	

The TR55 data has been exported as worksheet format for further analysis. Table 5.24 describes the distinct pattern of flow length, flow velocity and corresponding time of travel for the sub-watershed (marked as 'A') and also the whole catchment of Tangri (Dangri) river (marked as 'B'). The sub-watershed ('A') is largely forested comprising of hill and mountain slopes of Siwalik and Outer Himalaya. The torrents are formed within this sub-watershed which further aggravates the flow velocity and sediment bed load in fluvial system. This fluvial system carries bed load which are deposited in the lower reaches. The flow length is 14765 m in upper sub-watershed ('A') whereas it is 59618 m in whole catchment

('B') (Table 5.24). Accordingly, the sheet flow travel time, T_t is 0.69 hours for sub-watershed ('A') whereas it is 1.27 hours for the whole catchment ('B').

d. Flood hazards on surrounding LULC

Table 5.25 shows estimates of inundated areas for diverse return periods and corresponding effects on surrounding LULC. The Tangri (Dangri) river catchment has a gross geographical area of 482 km^2 and based on flood inundation modeling, it is observed that 1.42%, 2.76%, 4.84%, 8.43%, 12.58%, 16.14% and 24.32% areas of catchment are likely to get inundated corresponding to rainfall intensity of two, five, ten, twenty-five, fifty, hundred and thousand years return periods, respectively. The inundated areas for various return periods are shown in figure 5.35.

Table 5.25. Effect of flood hazards on various LULC classes based on flood inundation modeling

Return period	Inundated area (sq. km)					
	Cropland	Fallow	Orch./Plnt./ Forest	Scrub/ Others	Total	% of geog. area
2	5.27	0.48	0.18	0.92	6.84	1.42
5	10.03	1.25	0.77	1.26	13.30	2.76
10	18.46	1.98	1.39	1.50	23.33	4.84
25	32.85	3.20	1.86	2.72	40.63	8.43
50	50.50	3.80	2.92	3.42	60.64	12.58
100	58.95	4.65	5.43	8.76	77.79	16.14
1000	92.80	5.49	8.30	10.64	117.22	24.32

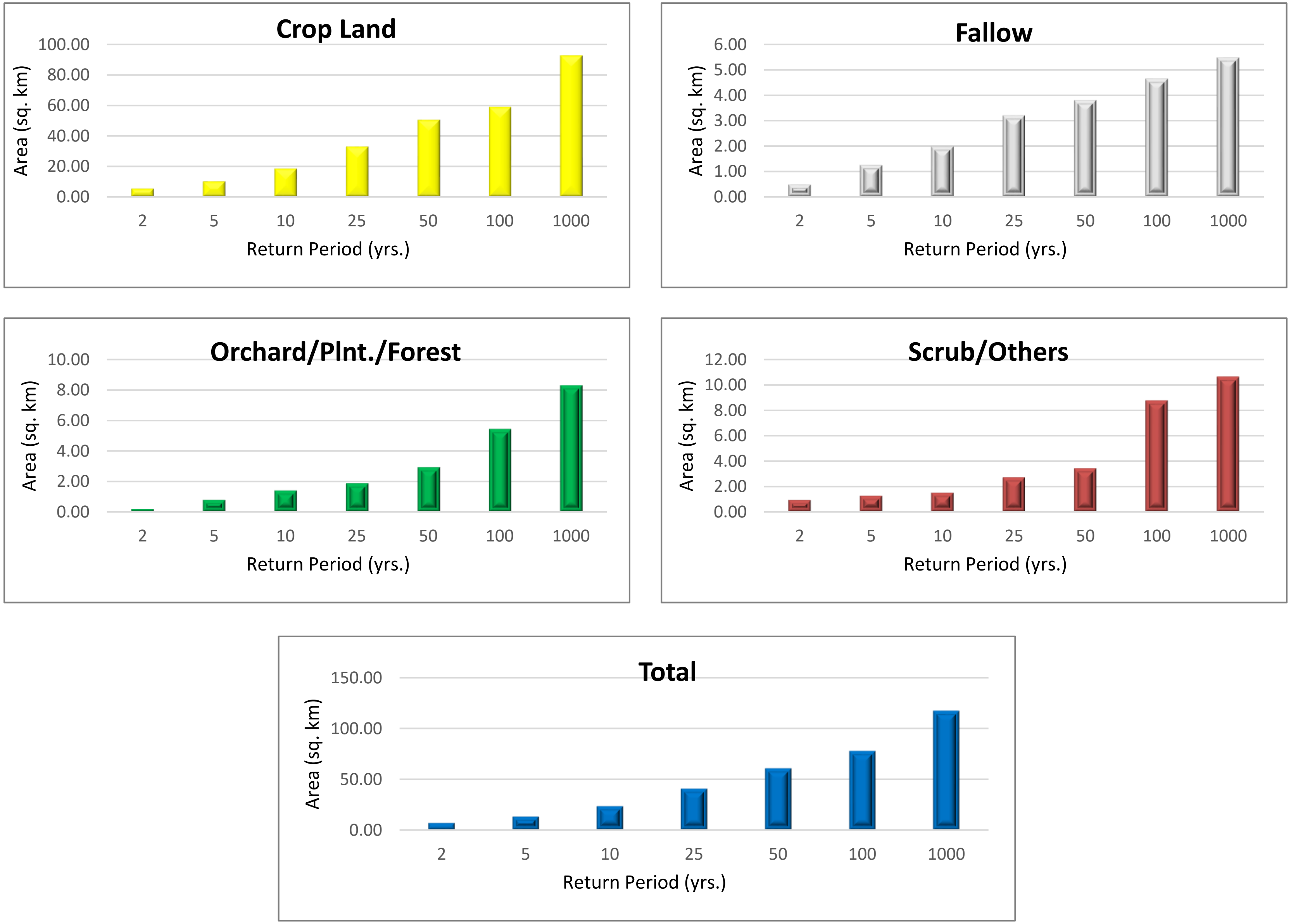


Fig. 5.35. Effect of flood hazards on various LULC classes based on inundation modeling

5.4 APPROACHES FOR TREATING TORRENTS

The solution lies in regulating the quantum of runoff coming down the hill slopes and the accompanying silt load. The treatments must therefore, cover measures in the watershed to moderate the runoff peak and volume, and to reduce the soil erosion and consequent silt load. As far as the main Tangri (Dangri) torrential river is concerned, several remedies can further be adopted for effective conservation of land and water resources in the watershed such as *i*) Conservation practices on agricultural fields, *ii*) Vegetative measures on torrential channels, *iii*) Upstream catchment treatment measures, *iv*) Protection of banks from erosion by providing marginal *bunds* at a reasonable distance from the edge, *v*) Control of grazing and deforestation and/ or vi) channel desiltation. The rivers sections which are subjected to severe erosion, the retaining walls can also be used. It is also desirable to construct temporary or permanent structures at or near sections where the gradient is steep, to facilitate siltation and thereby stabilising the grades and also by planting of live hedges of *Vitex negundo, Arundo donax*, *Ipomoea carnea*, etc. along the banks. Table 5.26 shows some plant species for protection of the river bank.

The freshly deposited silt near the spurs and behind the live hedges should immediately be stabilised by planting cuttings of *Pennisetum purpureum* (Napier) in rows laid normal to the general direction of flow and spaced 1 m to 2 m from row to row. The sites having excessive proportion of coarse fragments and boulders should preferable be planted with *Aristida cyanantha, Saccharum bengalensis* and *S. Spontaneum*. The areas behind the bank should be afforested with suitable tree species like *Dalbergia sissoo*, *Acacia catechu*, *Albizia stipulata*, Eucalyptus *spp.*, *etc*. The torrents training and reclamation works should start from both the banks while taking care that the channel width is not much restricted and sufficient section is left for safe discharge of the expected peak runoff. Any obstruction in the main channel bed (e.g. uprooted trees) should immediately be removed to avoid further aggregation.

Table 5.26. Some plant species for protection of river bank in torrential areas

Sl. No.	Plant	Scientific Name
1.	Beri	*Ziziphus species*
2.	Ipomoea	*Ipomoea species*
3.	Munj	*Saccharum munja*
4.	Dub	*Cynodon dactylon*
5.	Juliflora	*Prosopis juliflora*
6.	Shisham	*Dalbergia sissoo*
7.	Papri	*Podophyllum hexandrum*
8.	Lantana	*Lantana camara*
9.	Kans	*Saccharum spontaneum*
10.	Poplar	*Populus species*
11.	Nara	*Phragmites karka*

5.4.1 Methods of Bank Protection

a. Retaining walls for protection of lower bank

The retaining wall works as revetment on steep slope near the toe i.e. lower bank in protecting stream bank from erosion. It acts as a toe wall and basically its design is as per the conventional retaining wall. As a rule of thumb for gabion structures, the bottom width is kept equal to 2/3 of height with 1 m top width (Brooks and Nielsen, 2010). The wall is taken to safe foundation and apron of ½ to 2 times the possible depth of scour is used.

b. Spurs

Unlike retards which are aligned parallel to the bank, the spurs are constructed at an angle extending from the bank towards the stream thereby deflecting the current away from the eroding bank and directing the flow centrally. The spurs can be effectively used to reduce stream bank erosion and salvage the area from streambed where stream takes to meandering. Depending upon the alignment or angle, they make with the bank, the spurs are classified as: i) Repelling type: spurs making angle (60^o to 70^o) with the bank on their upstream side, ii) Attracting type: spurs making acute angle with downstream side. They divert the current to the opposite bank, while the repelling type do not do so but simply help in keeping the current away from the main bank along which they are erected, and iii) Deflecting type: spurs erected at right angle to the bank and these are suitable for checking erosion along straight reaches (Adhikary et al., 2012). Depending upon the material of construction, the spurs are broadly of two types, viz. i) Permeable spurs:

permeable spurs are those through which water can move. They are useful where scouring is not that deep and streams are small, and ii) Impermeable spurs: these are relatively more permanent structures made of dry boulders/ stones or masonry (Sharma, 2017). It is desirable to regulate runoff coming down the hill slopes and accompanying silt load. The treatments must therefore, cover measures in watershed to moderate the runoff peak and volume, and to reduce the soil erosion and consequent silt load. Sheng (1999) discussed on types of watershed treatment measures for torrent control in European Countries. He said that in general, engineers favour structural measures while foresters or agronomists prefer the vegetative measures. However, viable treatment practices include all site-specific measures based on availability of resources, channel and bio-physical characteristics, etc. Also, one should consider their long-term effectiveness and sustainability. Fay (2012) said that combined use of structural and vegetative slope protection systems is more cost-effective. Accordingly, various strategies can be adopted in combination or individually at sites depending on the proximity to torrential beds, vulnerability to natural resources and arable land.

5.4.2 Alternatives for Torrents' Treatment

The section 5.4 describes various methods for further treatment of vulnerable sections in a torrential regime. Broadly, these methods are categorised as follows: i) Conservation structures (spurs, retaining walls, etc.) on torrents' bed and banks as described under section 5.4.1, ii) Biological works (afforestation/plantation, grass cover, etc.) in valleys and flood plains as described in section 5.4 and table 5.26, iii) Biotechnical structures (wood dams, masonry sills dried vegetative mat, etc.) in moderate slopes and lower order drainages, iv) Agronomic measures (crop rotation, inter/mixed cropping, etc.), v) Channel desiltation and vi) Grazing reduction. In consultation with experts, the prioritisation of these soil and water conservation measures were performed using two different MCDM models, namely TOPSIS and ELECTRE where ELECTRE is an outranking type method which inspects whether an alternative outpaces another whereas TOPSIS is based on distance to ideal point for finding alternatives among choices. In the present study, the online tool (*https://www.decision-radar.com/*) was used for MCDM and finding alternatives. The list of criteria and alternatives are defined under Table 5.27 and 5.28, respectively. Table 5.29 shows the importance matrix for various alternatives based on relative importance of various criteria and their importance in having various alternatives.

5.4.2.1 Criteria and alternatives

Since, MCDA involves information and priorities abstraction, the judgments depend on exactness and objectivity of resource constraints and goals. Through these judgements, the preparations for sustainable development of a watershed with its inhabitants depicting an agrarian society and primarily dependent on farming and forests produce can be prioritised. The six alternatives as mentioned in Table 5.28 have been selected taking into account the prevalent methods in the neighbourhood regions for further conservation of land and water resources in Tangri (Dangri) river watershed.

- **Criteria description:**

C_1 (Slope): The slope of watershed mirrors the rate of change of elevation with distance along principal flow path. The slope influences the energy of overflow and along these lines reflects the inclination of watershed towards soil erosion and land degradation. The soil and water conservation practices are dependent on slope characteristics of the watershed.

C_2 (LULC): Land cover is bio-physical spread on the earth's surface while land use is portrayed by the courses of action, practices and inputs that individuals attempt in a specific land cover type to deliver, change or to preserve it. The land use, its degree and administration are the key elements which influence the watershed characteristics, though relying on kind of vegetation and its quality. The land cover controls the hydrological characteristics of the watershed e.g., infiltration, water retention, runoff production, erosion, sedimentation, etc.

C_3 (**Soil):** Soil assumes a fundamental job in supporting bio-resources present in any watershed e.g., in forested environments, soils decide species composition, timber productivity, wildlife habitat, wealth, biodiversity, etc. In cultivated fields, soil quality assumes a major role in crop productivity. In urbanised regions, soil assumes an indispensable job in decreasing runoff through infiltration and nutrients attenuation.

C_4 (**Proximity to conservation structures)**: The conservation structures are likely to protect the environment, nearby properties and bio-resources. They retard the river flow, protect the banks and surrounding bio-resources. They also conserve the precious soil that otherwise gets eroded due to fluvial action.

C_{-5} (Proximity to torrents): It is important because the proximity to torrents determine the vulnerability to human settlements and arable land. Torrential regimes often face flash floods and washing away of precious soil from adjoining cultivated fields and other vulnerable areas. They cause extensive damage in general to all lands which fall into their regime.

C_{-6} (Channel characteristics): The channel characteristics are defined as a composite of various parameters that reflect the channel bed width, meander angle and drainage density characteristics, etc.

Table 5.27. List of criteria

ID	Decision Criterion
C_{-1}	Slope
C_{-2}	LULC
C_{-3}	Soil
C_{-4}	Proximity to conservation structures
C_{-5}	Proximity to torrents
C_{-6}	Channel characteristics

- **Alternatives description:**

A-1 **(Conservation structures)**: Soil and water conservation (SWC) structures include all mechanical or structural measures that control the velocity of surface runoff and thus minimise the soil erosion and retain water wherever it is needed. They usually consist of engineering works involving physical structures, made of earth/ stones/ masonry or other material. The construction of these structures such as terraces, check dams, and water diversions, reduce the effects of slope length and angle. SWC structures can be designed to either conserve water or to safely discharge it away. They supplement agronomic or vegetative measures but do not substitute for them.

A-2 **(Biological works)**: These are practiced to roughen the whole surface and retard the movement of soil and other fluvial material. The grass, scrub or tree cover which spread on the ground surface and have broad root framework retard the soil erosion processes. The plant canopy shield soil from unfavourable impact of precipitation. The grasses and legumes produce thick turf which helps in decreasing soil erosion processes. The vegetation also provides organic matter to the soil. Subsequently, the fertility of soil increments and the physical state of soil is improved. The use of these measures depends upon the severity of erosion.

A-3 **(Biotechnical structures):** The interventions adopted biotechnical structures helps in retarding the flow velocity and thereby in-situ conservation of moisture and control of soil erosion. They are particularly practiced in upstream region of the catchment which involves preparing a framework for integrating different land-use and livelihood systems using water as the 'entry point' in the design of interventions. Some examples of these interventions are wood dams, masonry sills, dried vegetative mat, etc.

A-4 **(Agronomic measures)**: It is a cultivating framework that can minimise various losses in arable land while recovering degraded lands. It promotes the upkeep of an everlasting soil cover, least soil disorder, and enhancement of plant species. Some of the measures adopted under this category are: crop rotation, inter/mixed cropping, etc.

A-5 **(Channel desiltation):** Desilting is the evacuation of fine residue and silt that has gathered in a stream so as to reestablish its regular limit, without enlarging or developing of the waterway. Desiltation works can possibly improve the hydraulic performance of a stream. On the other hand, aimless desilting can cause unfriendly effects on a waterway's ecology and fluvial characteristics.

A-6 (Grazing reduction): Overgrazing lessens the effectiveness, productivity, and biodiversity of land and is among the reasons for desertification and soil degradation. It is likewise observed as a reason for the spread of obtrusive types of non-local plants and of weeds.

Table 5.28. List of alternatives

ID	Decision Alternative
A-1	Conservation structures
A-2	Biological works
A-3	Biotechnical structures
A-4	Agronomic measures
A-5	Channel desiltation
A-6	Grazing reduction

Table 5.29. Importance matrix for various alternatives

Sl. No.	Alternatives/ Criteria		Slope	LULC	Soil	Proximity to conservation structures	Proximity to torrents	Channel characteristics
			C-1	C-2	C-3	C-4	C-5	C-6
	Weightages		0.028	0.049	0.085	0.146	0.253	0.439
1.	**Conservation structures**	**A-1**	7	8	6	8	9	10
2.	**Biological works**	**A-2**	6	8	7	9	9	8
3.	**Biotechnical structures**	**A-3**	9	6	9	3	8	9
4.	**Agronomic measures**	**A-4**	5	6	7	8	9	7
5.	**Channel desiltation**	**A-5**	6	5	4	9	8	7
6.	**Grazing reduction**	**A-6**	6	3	4	7	9	6

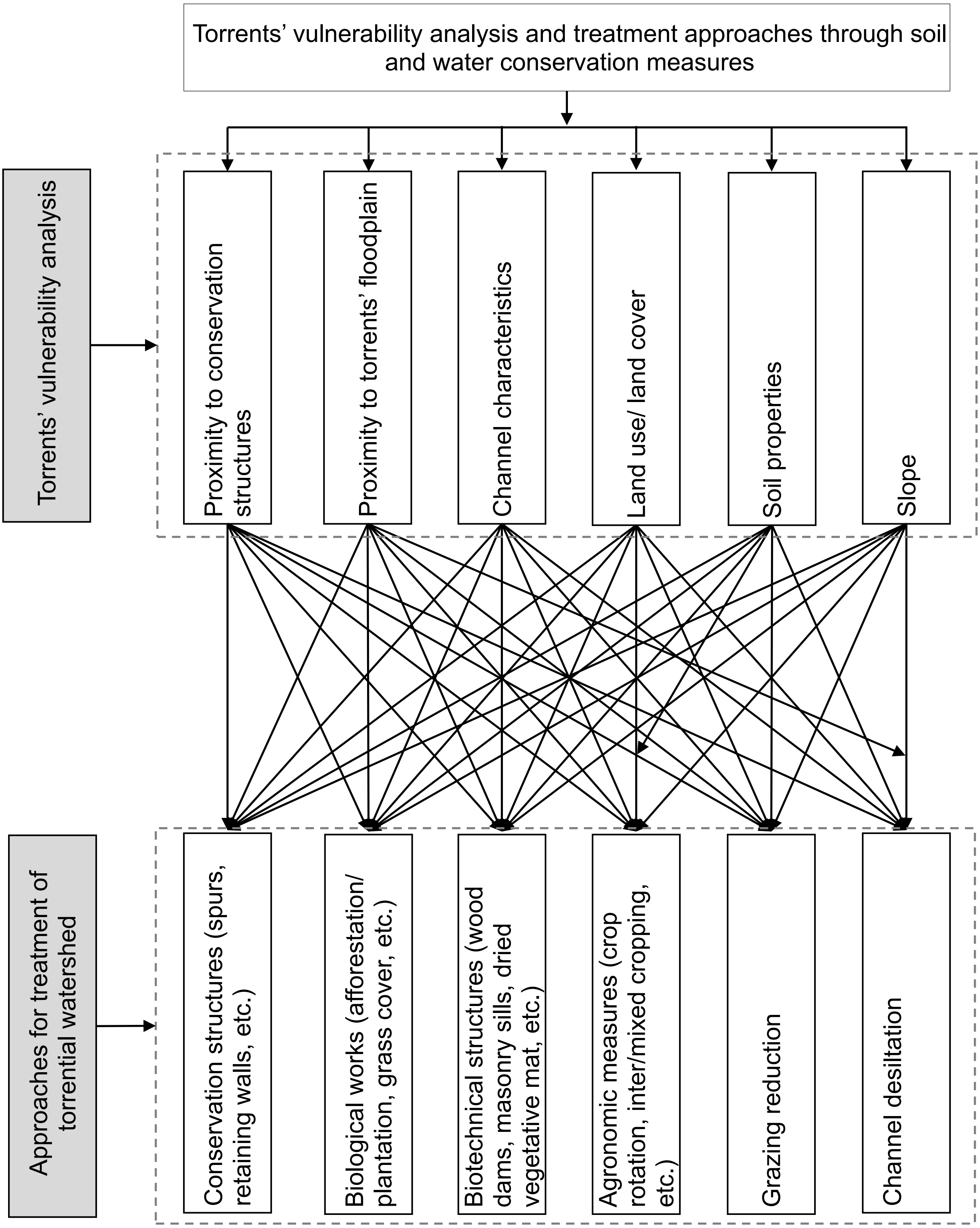


Fig. 5.36. Torrents' vulnerability analysis and approach for soil and water conservation measures

5.4.2.2 TOPSIS method

The TOPSIS technique has various stages to distinguish the priorities among alternatives. The whole strategy of this technique is finished through a progression of several interlinking advances. Figures 4.8 and 5.36 define overall methodology for torrents' vulnerability analysis and soil and water conservation measures that can be adopted for effective treatment of a torrential regime and prevent the further degradation of vulnerable sections. Following sections depict these steps as adopted in this study for assessing various alternatives.

a. Step 1: Development of Decision Matrix

Under TOPSIS method, the first step is the creation of Decision Matrix. Table 5.30 shows the decision matrix which contains various criteria and alternatives used for building decision matrix. In this matrix, the elements C_1, C_2…, C_n refer to criteria; whereas A_1, A_2…, A_n refer to alternatives considered in the study. The matrix elements are associated with criteria (i) concerning alternative (j). Thus, the decision matrix is figured for understanding the significance of different activities for treatment/ reclamation of torrential regime. The criteria weightages were adopted as given in table 5.29.

b. Step 2: Normalised Decision Matrix

Normalised Decision Matrix (r_{ij}) is attained through Eq. (4.12) given under section 4.2.1.2 which changes over dimensionless estimations of decision matrix. Table 5.30 shows the Normalised Decision Matrix (r_{ij}) as obtained in the present study. It is realised from table 5.30 that minimum and maximum value varies from 0.0086 and 0.2255, respectively.

Table 5.30. Normalised Decision Matrix

	C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**
A-1	0.0121	0.0256	0.0325	0.0626	0.1071	0.2255
A-2	0.0104	0.0256	0.0379	0.0704	0.1071	0.1804
A-3	0.0155	0.0192	0.0487	0.0235	0.0952	0.2029
A-4	0.0086	0.0192	0.0379	0.0626	0.1071	0.1578
A-5	0.0104	0.0160	0.0216	0.0704	0.0952	0.1578
A-6	0.0104	0.0096	0.0216	0.0548	0.1071	0.1353

c. Step 3: Separation between Positive and Negative Ideal Solutions

The deviation of each alternative (D^-) from negative ideal solution (A^-) and from (D^+) with positive ideal solution (A^+) is calculated using equation given under section 4.2.1.2 based on Euclidean method, and the results obtained are given in Table 5.31.

Table 5.31. Ideal solutions and their deviations

	A-1	**A-2**	**A-3**	**A-4**	**A-5**	**A-6**
Best answer vector is **(A^+)**	0.0155	0.0256	0.0487	0.0704	0.1071	0.2255
Worst answer vector is **(A^+)**	0.0086	0.0096	0.0216	0.0235	0.0952	0.1353
Choices distance from best vector is **(D^+)**	0.0183	0.0467	0.0538	0.0696	0.0746	0.0969
Choices distance from worst vector is **(D^-)**	0.1010	0.0700	0.0738	0.0504	0.0525	0.0335
Closeness vector of each choices	0.8463	0.6001	0.5783	0.4199	0.4130	0.2570

5.4.2.3 ELECTRE method

The *ELimination Et Choix Traduisant la REalit´e* (ELimination and Choice Translating Reality) methods, abbreviated as ELECTRE, belongs to the outranking methods. As per the steps and procedure defined under 4.2.1.3, the MCDM analysis was carried out as given hereunder-

c. **Step 1- Initial/ Decision Matrix:**

The factor weights were determined during this step. The alternatives that should be positioned dependent on prevalence are given in decision matrix row, and columns depict the criteria used for ranking the alternatives. Thus, the matrix weights were determined depending on the criteria weights and the alternatives' preferences. Table 5.29 shows the initial matrix for the watershed.

d. **Step 2 – Normalised Decision Matrix Construction**:

The normalised matrix X_{ij} was established as described under section 4.2.1.3, after the creation of decision matrix. Table 5.32 shows the Normalised Decision matrix.

Table 5.32. Normalised decision matrix

	C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**
A-1	0.0121	0.0256	0.0325	0.0626	0.1071	0.2255
A-2	0.0104	0.0256	0.0379	0.0704	0.1071	0.1804
A-3	0.0155	0.0192	0.0487	0.0235	0.0952	0.2029
A-4	0.0086	0.0192	0.0379	0.0626	0.1071	0.1578
A-5	0.0104	0.0160	0.0216	0.0704	0.0952	0.1578
A-6	0.0104	0.0096	0.0216	0.0548	0.1071	0.1353

e. **Step 3 – Concordance and Discordance Sets:**

The attributes sets were divided into two different subsets for each pair of alternatives. Later, the concordance set which consists of all attributes is used wherein the first alternative is preferred over second. Table 5.33 and 5.34 shows the concordance and discordance matrix based on various criteria and alternatives identified for the watershed. As per the results obtained from the analysis, the Concordance Mean Decision Matrix is 0.3374 whereas the Discordance Mean Matrix is 0.5734.

Table 5.33. Concordance matrix

	C-$_1$	**C-$_2$**	**C-$_3$**	**C-$_4$**	**C-$_5$**	**C-$_6$**
A-$_1$	0	0.467	0.887	0.516	0.854	0.747
A-$_2$	0.231	0	0.448	0.662	0.826	0.719
A-$_3$	0.113	0.552	0	0.552	0.601	0.601
A-$_4$	0.085	0	0.399	0	0.387	0.719
A-$_5$	0.146	0	0.146	0.174	0	0.634
A-$_6$	0	0	0.399	0.028	0.253	0

Table 5.34. Discordance decision matrix

	C-$_1$	**C-$_2$**	**C-$_3$**	**C-$_4$**	**C-$_5$**	**C-$_6$**
A-$_1$	1.0000	0.1735	0.4146	0.0799	0.1157	0.0000
A-$_2$	1.0000	0.0000	0.4802	0.0000	0.0000	0.0000
A-$_3$	1.0000	1.0000	0.0000	0.8677	1.0000	0.4628
A-$_4$	1.0000	1.0000	1.0000	0.0000	0.4824	0.0766
A-$_5$	1.0000	1.0000	0.9604	1.0000	0.0000	0.5277
A-$_6$	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000

f. Step 4 - Dominant Concordance and Discordance Matrix

The two indices, namely concordance and discordance were used to measure relationship between objects in ELECTRE method. Firstly, the concordance index C (a, b) measures whether 'a' is at any rate equivalent to b. Then again, the discordance index D (a, b) prudently decides the inclination for 'b' when compared with 'a'. Concordance sets were utilised while preparing the elements of concordance matrix (C). Concordance dominant matrix is worked out with the assistance of value threshold, which is by looking at each element of estimation of matrix in concordance with the threshold value. Similarly, the dominant discordance matrix is also prepared based on threshold value. These matrices are given in Table 5.35 and 5.36.

Table 5.35. Dominant concordance matrix

	C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**
A-1	0	1	1	1	1	1
A-2	0	0	1	1	1	1
A-3	0	1	0	1	1	1
A-4	0	0	0	0	0	1
A-5	0	0	0	0	0	1
A-6	0	0	0	0	0	0

Table 5.36. Dominant discordance matrix

	C_{-1}	C_{-2}	C_{-3}	C_{-4}	C_{-5}	C_{-6}
A_{-1}	1	1	1	1	1	1
A_{-2}	0	1	1	1	1	1
A_{-3}	0	0	1	0	0	1
A_{-4}	0	0	0	1	1	1
A_{-5}	0	0	0	0	1	1
A_{-6}	0	0	0	0	0	1

5.4.2.4 Comparison of methods

The results from both the methods are collectively given in Table 5.37 and compared. The two MCDM based techniques i.e., TOPSIS and ELECTRE have yielded identical priorities for the treatment of vulnerable sections of the watershed in spite of the fact that ELECTRE is an outranking method which inspects whether an alternative outpaces another whereas TOPSIS is based on distance to ideal point for finding alternatives among choices. It also confirms that the chosen criteria, their weights and the resultant distribution have distinct impact on MCDM analysis. As seen from the table that alternative A_{-1} (Conservation structures) has scored highest among both the methods. The alternative with second highest score is yielded by A_{-2} (Biological works). The third and fourth ranks are scored by A_{-3} (Biotechnical structures) and A_{-4} (Agronomic measures) alternatives by TOPSIS as well as ELECTRE methods. Similarly, the results from TOPSIS and ELECTRE methods are same for fifth and sixth alternatives i.e., A_{-5} (Channel desiltation) and A_{-6} (Grazing reduction).

Table 5.37. Comparison of alternatives

Alternatives		TOPSIS		ELECTRE
		Weights	**Ranking**	**Ranking**
A-1	Conservation structures with score	0.846	1	1
A-2	Biological works with score	0.600	2	2
A-3	Biotechnical structures measures with score	0.578	3	3
A-4	Agronomic measures with score	0.420	4	4
A-5	Channel desiltation with score	0.413	5	5
A-6	Grazing reduction with score	0.257	6	6

It is observed that both the methods have resulted into different prioritisation of alternatives for further treatment of vulnerable sections of the torrential regime though, some similarity exist in the obtained results. This happens in light of the fact that the identified MCDM techniques have differently scored the matrix because the ELECTRE is an outranking type method which inspects whether an alternative outpaces another whereas TOPSIS is based on distance to ideal point for finding alternatives among choices and hence the picked alternatives have yielded different weightages. It also confirms that the chosen criteria, their weights and the resultant distribution have different impact on methods chosen for MCDM analysis. However, the MCDM analysis has helped to prioritise these alternatives and also towards identifying the vulnerable sections of the torrential regime. However, it is emphasized that though the alternatives are prioritised at watershed scale but the locale-specific selection of remedial measures based on above methodology can be practiced based on terrain bio-physical characteristics and resources availability.

Chapter-6

CONCLUSIONS

The present investigation on temporal change dynamics of torrential regime, and torrents' hazard and vulnerability assessment in a hilly watershed of Himalayan region is carried out to analyse- i) Temporal behaviour of torrential systems demonstrated through time-series remote sensing data, ii) Understanding the efficacy of hydrological model(s) that work(s) well with fluvial regime of torrential streams and that carry flashfloods and have moderate slopes in upstream region, and wide and relatively shallow river beds in the downstream regions, and iii) Hydrological risk assessment from and within torrential river systems.

The change dynamics of torrential areas is carried out using Landsat satellite data available from GEE platform for temporal investigation and visualisation of Earth's natural resources. Within GEE environment and using the EEP, the JavaScript API was developed for the classification of temporal satellite data and analysing the vegetation characteristics. LULC change was analysed with CART classifier and the vegetation characteristics was assessed based on EVI product. Typically, in any torrential system, the LULC classes during the process of lateral migration and due to watershed inhabitants' intervention falls under four major categories, namely cropland/ fallow, orchard/ plantation/ forest, grass/ scrub and dry-river-bed. Hence, these broad categories of LULC were used to classify multispectral data. Based on temporal visualisation of satellite data of three decades within watershed, it was assessed that the torrents' migration is contained within

200 m from river's centre line therefore, a buffer zone surrounding the torrents was generated with 200 m as distance value for torrents' change dynamics.

It is observed that the river systems of torrential regime have tendency to migrate and meander frequently. Various kinds of conservation measures have been adopted in the watershed for the protection of channel beds, such as retaining wall and spurs under watershed development programmes. Along the Thathar ki Nadi and near to its confluence point with main Tangri (Dangri) river, 36 spurs and retaining walls have been constructed. Along the other streams as well these kinds of structures are seen. Some vegetative measures have also been adopted for the protection of torrential areas. As various conservation measures have been adopted in the Tangri (Dangri) watershed and also due to smaller land holdings and increasing pressure on land resources, some areas of watershed are getting reclaimed. The expansion in agricultural tracts are evident on temporal satellite data in lower reaches of the watershed and it has caused the shrinkage in floodplains of torrential regime. It is observed that during this period because of ongoing conservation activities as well as due to watershed inhabitants' intervention, the area under bare torrents (dry river bed) have decreased from 701 ha to 407 ha. Similarly, the torrential areas which were under grass or scrub have increased from 550 ha to 678 ha. The land under agriculture (1478 ha to 1617 ha) and orchard/ plantation/ forest (533 ha to 560 ha) have also increased. Most of these changes were seen along the main Tangri (Dangri) river and at its downstream reach, which is the meeting point of Thathar ki Nadi with main Tangri (Dangri) river. It is estimated that the mean EVI values are continuously improving for the watershed with their values as -0.0626 (1991) to 0.297 (2018). The maximum value of EVI has also increased from 0.118 (1991) to 0.902 (2018). The monthly mean EVI for March, September and December months for Tangri (Dangri) river sub-watershed were also analysed. It is observed that though there are some data gaps in the GEE products but overall mean EVI trend is positive and continuously increasing which is credited to various soil and water conservation measures adopted in the watershed.

The vulnerability assessment of torrential regime of Tangri (Dangri) river has been done based on six parameters, viz. i) Catchment's Slope, ii) Soil characteristics, iii) LULC, iv) Proximity to torrents' flood plain, v) Proximity to conservation measures and vi) Channel characteristics. The slope map was produced based on standard slope classification (NRCC, 1998) and categorised into ten classes as leveled (0^o - 0.3^o), nearly leveled (>0.3^o - 1.1^o), very gentle sloping (>1.1^o - 3.0^o), gentle sloping (>3.0^o - 5.0^o), moderate sloping (>5.0^o - 8.5^o), strong sloping (>8.5^o - 16.5^o), very strong sloping (>16.5^o - 24^o), extreme sloping (>24^o - 35^o), steep sloping (>35^o - 45^o), and very steep sloping (>45^o - 90^o) with least weightage given to leveled and gentle slope, and higher weightage given to acute slopes in upstream region of the catchment or the steep slopes along valleys. The physiographic-cum-soil association map is classified into following 16 classes, namely A1, A2, P11, P12, P13, P21, P22, T, H11, H12, H13, H21, H22, M1, M2 and V. The weights of various classes were given in light of their criticalness towards torrents' vulnerability. The LULC information for Tangri (Dangri) river sub-watershed was derived from digital classification of IRS-P6

LISS-4 data based on supervised classification technique. Following LULC classes were derived based on digital classification: Forest (Dense, Open and Scrub), Agriculture (Crop land, Fallow, Orchard/ Plantation), River/ Water body (River/Channel, Dry river bed, Water body) and Settlements. About 64.5 percent area of sub-watershed falls under forested land, 28.3 per cent under agriculture and rest under river channel, waterbody and settlements. The study area is mainly drained by seasonal streams. Based on drainage density characteristics, the watershed area was categorised into five classes as 0.04 - 2.13, >2.13 - 4.21, >4.21 - 6.30, >6.30 - 8.38 and >8.38 - 10.47 km/ sq. km. The drainages buffers were generated surrounding the torrents and the proximity to torrents' valley and floodplain was put into five buffer regions as 200 m, 400 m, 600 m, 800 m and 1000 m. Various agencies have laid conservation structures in proximity to torrential areas such as retaining walls and spurs.

The torrents' vulnerability analysis was carried out using MCDM based AHP model. The weights of various parameters and sub-parameters were derived and their cumulative effects were assessed for torrents' vulnerability assessment. During AHP analysis, the Eigen Vector method have been applied to the matrix and weightages have been derived using importance matrix for torrent vulnerability analysis. These weightages were multiplied with feature class attributes to compute CVI. The CVI coverage was reclassified into five categories to prepare the torrent vulnerability classes, namely high, moderate to high, moderate, moderate to low and low. The torrent vulnerability map reveals that high and moderate to high vulnerable areas were noticed in proximity to settlements and cropland, slope transition zones, rivers confluence and also in proximity to meandering sections of the river. Other areas of the watershed fall under low vulnerable category. It is observed that nearly 43% areas of watershed fall under moderate to high vulnerability whereas rest (nearly 57%) of the watershed fall under moderate to low vulnerability towards settlements and various natural resources. The moderate to high vulnerable areas are mostly spread out along the main Tangri (Dangri) river and its tributaries and are caused due to heavy bed load emanating from the hilly areas, and finally contribute to the main Tangri (Dangri) river. Moderate vulnerable areas have spread out all along the whole watershed. Areas under moderate to low vulnerability are mostly located in middle part of catchment due to moderate slope and low drainage density. Other areas in the watershed fall under low vulnerable category. The multi-criteria based vulnerability analysis also presents a methodology for the impact assessment of watershed treatment activity and to identify critical areas which still need attention.

The annual average soil loss as assessed by RUSLE equation loss is a function of erosivity of rainfall, soil erodibility, slope length and gradient, crop cover and management factor. The model input parameters for RUSLE method were derived from remote sensing images and field investigation for the Tangri (Dangri) river sub-watershed. The annual average soil loss in watershed is relatively higher and estimated as 40.4 $t.ha^{-1}.yr^{-1}$. The annual average soil loss is highest ($t.ha^{-1}.yr^{-1}$) for mountain units. It is followed by Siwalik hills where the highest (59.4 $t.ha^{-1}.yr^{-1}$) soil loss is from H13 (Escarpments and very steep slopes) followed by H12 (Fairly Dense Forest) (57.1 $t.ha^{-1}.yr^{-1}$) and H11 (Terraced Cultivation) unit

(46.7 $t.ha^{-1}.yr^{-1}$). In the piedmont region, the soil loss varies from 15.7 $t.ha^{-1}.yr^{-1}$ to 17.8 $t.ha^{-1}.yr^{-1}$. The relationship between LULC classes with average soil loss is plotted. The average soil loss is highest for forest scrub (61.5 $t.ha^{-1}.yr^{-1}$) followed by open forest (49.5 $t.ha^{-1}.yr^{-1}$).

The hydrologic and hydrodynamic modeling was done using HEC-HMS and HEC-RAS hydrological tools. The DEM derived from Cartosat-1 stereo data was pre-processed in HEC-HMS environment for catchment's hydrologic properties extraction. The daily and hourly rainfall data for Ambala station (1986-2013) was analysed to assess the rainfall return period following the Gumbel's distribution. The peak river flows for two, five, ten, twenty-five, fifty, hundred and thousand year's recurrence interval were obtained by using the rainfall data of varying return periods. The NRCS CN values is estimated for various hydrologic-soil-cover-complex of the watershed which varied from 26 to 98. The Nash–Sutcliffe model efficiency was obtained as 0.88 based on comparison between observed and simulated discharge. In the hydrodynamic modeling, the requisite information consisting of three primary parts viz., plan, geometry and stream information were fed into the model. With Cartosat-1 DEM and Resourcesat LISS-3 data as background layers, the stream centre-line, banks, flow path and cross-sections were drawn. Using the geometry and peak flow information, the floodplain delineation was attempted and inundation modeling was done to evaluate the impact of peak flows on encompassing LULC based on rainfall of varying return periods. The Manning's roughness coefficient values which signifies resistance to inflow in streams and floodplains were defined for various LULC classes of the watershed.

The value of Manning's coefficient ranges from 0.025 to 0.10 for Tangri (Dangri) river catchment.

In HEC-RAS analysis, the river system schematics were defined in terms of reach, cross-sections, flow paths, ineffective areas, etc. The stream centre-line was drawn along the main channel to represent the centre of mass of flow. Later, the flow paths were defined for the left and right overbanks. These lines have helped in detailing the cross-sections perpendicular to flow lines, and they also signify the centroid flow path for determining the reach lengths between cross-sections. The cross-sections were drawn at demonstrative locations all the way through Tangri (Dangri) river and at places wherever changes are likely to happen in discharge, slope, shape, or roughness, etc. Wherever such abrupt changes were expected, numerous cross-sections were used to designate changes irrespective of distance between cross-sections. These cross-sections characterised the flow carrying ability of the stream and the contiguous floodplain. The Tangri (Dangri) river system based on confluence of various tributaries was divided into five major reaches with well-defined junctions. The LULC layer along with Manning's roughness variability was ingested into the HEC-RAS model. The drainage network and cross-section, reaches and junctions with Manning's coefficient based on LULC characteristics were transferred from HEC-GeoRAS to HEC-RAS framework.

HEC-RAS model was executed with river schematics details and discharge values corresponding to varying return periods. The HEC-RAS model has computed the inundation depths corresponding to discharge values at the catchment outlet. The flood hazard map is produced based on peak flows for varying return periods as simulated by HEC-HMS and later exported into HEC-RAS model for flood hazard simulations. The results indicate that 1.42%, 2.76%, 4.84%, 8.43%, 12.58%, 16.14% and 24.32% of catchment area is likely to get inundated due to rainfall intensity of two, five, ten, twenty-five, fifty, hundred and thousand years return periods, respectively.

Following management action plans have been proposed to further conserve the torrential regime: i) adoption of soil and water conservation measures to save agricultural and forest lands from erosion, ii) to harvest excess water flow for the recharge of aquifers and enlarge the potential of its off-season utility, on ground (farm dams) and below the ground (aquifer storage), iv) to save structures and civil establishments from damage, v) torrent training and reclamation works should be carried out at both the banks, and vi) construction of structures to confine the flow and protect the bank from scouring.

Using the MCDM based techniques, various alternatives for the treatment of vulnerable sections of the torrential regime were prioritised. These alternatives were as follows: i) Conservation structures (spurs, retaining walls, etc.) on torrents' bed and banks (A_{-1}), ii) Biological works (afforestation/plantation, grass cover, etc.) in valleys and flood plains (A_{-2}), iii) Biotechnical structures (wood dams, masonry sills dried vegetative mat, etc.) in moderate slopes and lower order drainages (A_{-3}), iv) Agronomic measures (crop rotation, inter/mixed cropping, etc.) (A_{-4}), v) Grazing reduction (A_{-5}) and vi) Channel desiltation (A_{-6}). In consultation with experts, the prioritisation of these soil and water conservation measures were performed using two different MCDM models, namely TOPSIS and ELECTRE, where ELECTRE is an outranking type method which inspects whether an alternative outpaces another whereas TOPSIS is based on distance to ideal point for finding alternatives among choices. These alternatives were weighed with various criteria options such as- i) Slope, ii) LULC, iii) Soil, iv) Proximity to conservation structures, v) Proximity to torrents and vi) Channel characteristics. Based on AHP based MCDM technique, weights of these criteria were obtained as follows- 0.028, 0.049, 0.085, 0.146, 0.253 and 0.439, respectively. The results from both the methods, i.e. TOPSIS and ELECTRE were compared and found to be identical. The alternative A_{-1} (Conservation structures) has scored highest among both the methods. The alternative with second highest score is yielded by A_{-2} (Biological works) followed by A_{-3} (Biotechnical structures), A_{-4} (Agronomic measures), A_{-5} (Channel desiltation) and A_{-6} (Grazing reduction) alternatives. The two MCDM based techniques i.e., TOPSIS and ELECTRE have yielded identical priorities for the treatment of vulnerable sections of the watershed in spite of the fact that ELECTRE is an outranking method which inspects whether an alternative outpaces another whereas TOPSIS is based on distance to ideal point for finding alternatives among choices. It also confirms that the chosen criteria, their weights and the resultant distribution have distinct impact on MCDM analysis. Thus, the MCDM analysis is useful for identifying the vulnerable sections of the torrential regime and also towards prioritizing alternatives. However, it is emphasized that though the alternatives are prioritized at watershed scale but the locale-specific selection of remedial measures based on above methodology can be practiced based on various biophysical characteristics and resources availability in the watershed.

6.1 SCOPE FOR FURTHER WORK

The methodology used and the results produced through this study can be utilised for planning and management of torrential regimes. The study has helped to simulate the runoff corresponding to different design storms and corresponding effects on surrounding LULC characteristics. A tributary of the Tangri (Dangri) river flows through the Ambala city and surroundings. It is therefore, desirable to carry out simulations on flood water effects on urban settlements of Ambala city. Following specific conclusions are drawn from this study-

- Torrents' lateral migration caused significant LULC changes in the vicinity. Due to conservation activities ongoing, large tract of land got converted to more productive use, which were hitherto categorised as dry river bed or under grass/scrub cover.
- Multi-criteria analysis helped in assessing potential vulnerable areas in vicinity to torrential system.
- Various alternatives for further treatment of vulnerable section of the torrential regime was assessed and prioritised using MCDM based techniques.
- Annual average soil loss (Tons/ha/yr.) varies from 14.26 to 67.6, with highest values from Siwalik hills and lowest from Alluvial plain.
- HEC-HMS and HEC-RAS have proven to be very efficient modeling tools for flood extent forecasting.
- Study revealed that large areas falling close to Tangri (Dangri) river flood-plain are under severe threat to floods for various return periods.

- Study thus revealed multitude of problems faced by torrential system and effective solutions can be derived using geospatial data and techniques.

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ANNEXURES

Annexure-1

API codes for analysing LULC and vegetation change characteristics of torrents and surrounding based on time-series Landsat images within GEE environment

```
//2018 Data/////////
```

a. LULC change characteristics

```
var filtered2018 = L8.filterDate('2018-01-01', '2018-04-28')
.filterBounds(roi)
.filter(ee.Filter.lt('CLOUD_COVER', 10))
.mosaic();
//.sort('CLOUD_COVER', false)
//.first();

var rgb_vis = {min: 0, max: 0.3, bands: ['B5', 'B4', 'B3']};
Map.addLayer(filtered2018.clip(roi), rgb_vis,'2018');
//Map.addLayer(filtered1);


var newfc2018 =
dry_river2018.merge(agri_2018).merge(grass_2018).merge(orch_2018);
// print(newfc);

var bands2018 = ['B2', 'B3', 'B4', 'B5', 'B6', 'B7'];

var training2018 = filtered2018.select(bands2018).sampleRegions({
  collection: newfc2018,
  properties: ['landcover2018'],
  scale: 30
});

var classifier2018 = ee.Classifier.cart().train({
  features: training2018,
  classProperty: 'landcover2018',
  inputProperties: bands2018
});
print(classifier2018.explain());

var classified2018 = filtered2018.select(bands2018).classify(classifier2018);
```

```
Map.addLayer(classified2018.clip(roi), {min: 1, max: 4, palette: ['red', 'green',
'blue','yellow']},'Classified2018');

Export.image.toDrive({
  image: classified2018 ,
  description: 'classified2018',
  scale: 30,
  region: roi
});
```

b. EVI characteristics

```
var evi2018 = filtered2018.expression(
    '2.5 * ((NIR - RED) / (NIR + 6 * RED - 7.5 * BLUE + 1))', {
      'NIR': filtered2018.select('B5'),
      'RED': filtered2018.select('B4'),
      'BLUE': filtered2018.select('B2')
});

Map.addLayer(evi2018.clip(roi), {min: -1, max: 1, palette: ['FF0000',
'00FF00']},'EVI 2018');

Export.image.toDrive({
  image: evi2018 ,
  description: 'EVI2018',
  scale: 30,
  region: roi
});
```

//2016 Data//////////

a. LULC change characteristics

```
var filtered2016 = L8.filterDate('2016-02-20', '2016-02-23')
.filterBounds(roi)
.filter(ee.Filter.lt('CLOUD_COVER', 10))
.mosaic();
//.sort('CLOUD_COVER', false)
//.first();

var rgb_vis = {min: 0, max: 0.3, bands: ['B5', 'B4', 'B3']};
Map.addLayer(filtered2016.clip(roi), rgb_vis,'2016');
//Map.addLayer(filtered1);
```

```
var newfc2016 =
dry_river2016.merge(agri_2016).merge(grass_2016).merge(orch_2016);
// print(newfc);

var bands2016 = ['B2', 'B3', 'B4', 'B5', 'B6', 'B7'];

var training2016 = filtered2016.select(bands2016).sampleRegions({
  collection: newfc2016,
  properties: ['landcover2016'],
  scale: 30
});

var classifier2016 = ee.Classifier.cart().train({
  features: training2016,
  classProperty: 'landcover2016',
  inputProperties: bands2016
});
print(classifier2016.explain());

var classified2016 = filtered2016.select(bands2016).classify(classifier2016);
Map.addLayer(classified2016.clip(roi), {min: 1, max: 4, palette: ['red', 'green',
'blue','yellow']},'Classified2016');


Export.image.toDrive({
  image: classified2016 ,
  description: 'classified2016',
  scale: 30,
  region: roi
});
```

b. EVI characteristics

```
var evi2016 = filtered2016.expression(
    '2.5 * ((NIR - RED) / (NIR + 6 * RED - 7.5 * BLUE + 1))', {
      'NIR': filtered2016.select('B5'),
      'RED': filtered2016.select('B4'),
      'BLUE': filtered2016.select('B2')
});

Map.addLayer(evi2016.clip(roi), {min: -1, max: 1, palette: ['FF0000',
'00FF00']},'EVI 2016');

Export.image.toDrive({
  image: evi2016 ,
  description: 'EVI2016',
  scale: 30,
```

```
  region: roi
});
```

///2011 data ///////////////

a. LULC change characteristics

```
var filtered2011 = L5TM.filterDate('2011-02-01', '2011-02-23')
.filterBounds(roi)
.filter(ee.Filter.lt('CLOUD_COVER', 10))
.mosaic();
//.sort('CLOUD_COVER', false)
//.first();

var rgb_vis = {min: 0, max: 0.3, bands: ['B4', 'B3', 'B2']};
Map.addLayer(filtered2011.clip(roi), rgb_vis,'2011');
//Map.addLayer(filtered1);


var newfc2011 =
dry_river2011.merge(agri_2011).merge(grass_2011).merge(orch_2011);
// print(newfc);

var bands2011 = ['B2', 'B3', 'B4', 'B5', 'B6', 'B7'];

var training2011 = filtered2011.select(bands2011).sampleRegions({
  collection: newfc2011,
  properties: ['landcover2011'],
  scale: 30
});

var classifier2011 = ee.Classifier.cart().train({
  features: training2011,
  classProperty: 'landcover2011',
  inputProperties: bands2011
});
print(classifier2011.explain());

var classified2011 = filtered2011.select(bands2011).classify(classifier2011);
Map.addLayer(classified2011.clip(roi), {min: 1, max: 4, palette: ['red', 'green',
'blue','yellow']},'Classified2011');


Export.image.toDrive({
  image: classified2011 ,
  description: 'classified2011',
  scale: 30,
```

```
  region: roi
});
```

b. EVI characteristics

```
var evi2011 = filtered2011.expression(
    '2.5 * ((NIR - RED) / (NIR + 6 * RED - 7.5 * BLUE + 1))', {
      'NIR': filtered2011.select('B5'),
      'RED': filtered2011.select('B4'),
      'BLUE': filtered2011.select('B2')
});

Map.addLayer(evi2011.clip(roi), {min: -1, max: 1, palette: ['FF0000',
'00FF00']},'EVI 2011');

Export.image.toDrive({
  image: evi2011 ,
  description: 'EVI2011',
  scale: 30,
  region: roi
});
```

///2001 data //////////////

a. LULC change characteristics

```
var filtered2001 = L5TM.filterDate('2001-03-01', '2001-03-30')
.filterBounds(roi)
.filter(ee.Filter.lt('CLOUD_COVER', 10))
.mosaic();
//.sort('CLOUD_COVER', false)
//.first();

var rgb_vis = {min: 0, max: 0.3, bands: ['B4', 'B3', 'B2']};
Map.addLayer(filtered2001.clip(roi), rgb_vis,'2001')


var newfc2001 =
dry_river2001.merge(agri_2001).merge(grass_2001).merge(orch_2001);
// print(newfc);

var bands2001 = ['B2', 'B3', 'B4', 'B5', 'B6', 'B7'];

var training2001 = filtered2001.select(bands2001).sampleRegions({
  collection: newfc2001,
  properties: ['landcover2001'],
```

```
  scale: 30
});

var classifier2001 = ee.Classifier.cart().train({
  features: training2001,
  classProperty: 'landcover2001',
  inputProperties: bands2001
});
print(classifier2001.explain());

var classified2001 = filtered2001.select(bands2001).classify(classifier2001);
Map.addLayer(classified2001.clip(roi), {min: 1, max: 4, palette: ['red', 'green',
'blue','yellow']},'Classified2001');


Export.image.toDrive({
  image: classified2001 ,
  description: 'classified2001',
  scale: 30,
  region: roi
});
```

b. EVI characteristics

```
var evi2001 = filtered2001.expression(
    '2.5 * ((NIR - RED) / (NIR + 6 * RED - 7.5 * BLUE + 1))', {
      'NIR': filtered2001.select('B5'),
      'RED': filtered2001.select('B4'),
      'BLUE': filtered2001.select('B2')
});

Map.addLayer(evi2001.clip(roi), {min: -1, max: 1, palette: ['FF0000',
'00FF00']},'EVI 2001');

Export.image.toDrive({
  image: evi2001 ,
  description: 'EVI2001',
  scale: 30,
  region: roi
});
```

///**1996 data** //////////////

a. LULC change characteristics

```
var filtered1996 = L5TM.filterDate('1996-01-01', '1996-02-28')
.filterBounds(roi)
```

```
.filter(ee.Filter.lt('CLOUD_COVER', 10))
.mosaic();
//.sort('CLOUD_COVER', false)
//.first();

var rgb_vis = {min: 0, max: 0.3, bands: ['B4', 'B3', 'B2']};
Map.addLayer(filtered1996.clip(roi), rgb_vis,'1996')

var newfc1996 =
dry_river1996.merge(agri_1996).merge(grass_1996).merge(orch_1996);
// print(newfc);

var bands1996 = ['B2', 'B3', 'B4', 'B5', 'B6', 'B7'];

var training1996 = filtered1996.select(bands1996).sampleRegions({
  collection: newfc1996,
  properties: ['landcover1996'],
  scale: 30
});

var classifier1996 = ee.Classifier.cart().train({
  features: training1996,
  classProperty: 'landcover1996',
  inputProperties: bands1996
});
print(classifier1996.explain());

var classified1996 = filtered1996.select(bands1996).classify(classifier1996);
Map.addLayer(classified1996.clip(roi), {min: 1, max: 4, palette: ['red', 'green',
'blue','yellow']},'Classified1996');
Export.image.toDrive({
  image: classified1996 ,
  description: 'classified1996',
  scale: 30,
  region: roi
});
```

b. EVI characteristics

```
var evi1996 = filtered1996.expression(
    '2.5 * ((NIR - RED) / (NIR + 6 * RED - 7.5 * BLUE + 1))', {
      'NIR': filtered1996.select('B5'),
      'RED': filtered1996.select('B4'),
      'BLUE': filtered1996.select('B2')
});
```

```
Map.addLayer(evi1996.clip(roi), {min: -1, max: 1, palette: ['FF0000',
'00FF00']},'EVI 1996');

Export.image.toDrive({
  image: evi1996 ,
  description: 'EVI1996',
  scale: 30,
  region: roi
});
```

///1991 data //////////////

a. LULC change characteristics

```
var filtered1991 = L5TM.filterDate('1991-02-01', '1991-02-28')
.filterBounds(roi)
.filter(ee.Filter.lt('CLOUD_COVER', 10))
.mosaic();
//.sort('CLOUD_COVER', false)
//.first();

var rgb_vis = {min: 0, max: 0.3, bands: ['B4', 'B3', 'B2']};
Map.addLayer(filtered1991.clip(roi), rgb_vis,'1991')

var newfc1991 =
dry_river1991.merge(agri_1991).merge(grass_1991).merge(orch_1991);
// print(newfc);

var bands1991= ['B2', 'B3', 'B4', 'B5', 'B6', 'B7'];

var training1991 = filtered1991.select(bands1991).sampleRegions({
  collection: newfc1991,
  properties: ['landcover1991'],
  scale: 30
});

var classifier1991 = ee.Classifier.cart().train({
  features: training1991,
  classProperty: 'landcover1991',
  inputProperties: bands1991
});
print(classifier1991.explain());

var classified1991 = filtered1991.select(bands1991).classify(classifier1991);
Map.addLayer(classified1991.clip(roi), {min: 1, max: 4, palette: ['red', 'green',
'blue','yellow']},'Classified1991');
```

```
Export.image.toDrive({
  image: classified1991 ,
  description: 'classified1991',
  scale: 30,
  region: roi
});
```

b. EVI characteristics

```
var evi1991 = filtered1996.expression(
    '2.5 * ((NIR - RED) / (NIR + 6 * RED - 7.5 * BLUE + 1))', {
      'NIR': filtered1991.select('B5'),
      'RED': filtered1991.select('B4'),
      'BLUE': filtered1991.select('B2')
});

Map.addLayer(evi1991.clip(roi), {min: -1, max: 1, palette: ['FF0000',
'00FF00']},'EVI 1991');

Export.image.toDrive({
  image: evi1991 ,
  description: 'EVI1991',
  scale: 30,
  region: roi
});
```

Codes for Seasonal EVI

```
// Load a Landsat 8 image.

var image =
ee.Image('LANDSAT/LC08/C01/T1_TOA/LC08_044034_20140318');

// Compute the EVI using an expression.

var evi = image.expression(

    '2.5 * ((NIR - RED) / (NIR + 6 * RED - 7.5 * BLUE + 1))', {

      'NIR': image.select('B5'),

      'RED': image.select('B4'),

      'BLUE': image.select('B2')

});

Map.centerObject(image, 9);

Map.addLayer(evi.clip(roi), {min: -1, max: 1, palette: ['FF0000', '00FF00']},'EVI
2018');

Export.image.toDrive({

  image: filtered1996,

  description: 'imageToDriveExample',

  scale: 30,

  region: roi

});
```

Table 4.3. Monthly mean EVI values

Sl. No.	Date	Mean EVI	Sl. No.	Date	Mean EVI
1	12/12/1989	0.262	26	12/4/1992	0.214
2	1/13/1990	0.236	27	12/20/1992	0.219
3	3/18/1990	0.142	28	1/21/1993	0.207
4	4/3/1990	0.229	29	2/22/1993	0.196
5	4/19/1990	0.193	30	3/10/1993	0.179
6	5/21/1990	0.143	31	4/11/1993	0.122
7	6/6/1990	0.12	32	4/27/1993	0.112
8	12/31/1990	0.224	33	5/13/1993	0.11
9	2/1/1991	0.241	34	6/14/1993	-0.05
10	2/17/1991	0.259	35	8/1/1993	0.383
11	3/5/1991	0.247	36	8/17/1993	0.49
12	4/6/1991	0.168	37	10/20/1993	0.395
13	5/8/1991	0.138	38	11/5/1993	0.297
14	11/16/1991	0.258	39	11/21/1993	0.279
15	12/2/1991	0.235	40	12/7/1993	0.249
16	12/18/1991	0.159	41	12/23/1993	0.251
17	1/19/1992	0.188	42	1/24/1994	0.235
18	2/4/1992	0.234	43	2/9/1994	0.233
19	4/8/1992	0.197	44	2/25/1994	0.22
20	4/24/1992	0.147	45	3/13/1994	0.146
21	5/10/1992	0.158	46	3/29/1994	0.136
22	5/26/1992	0.128	47	6/1/1994	0.095
23	7/13/1992	0.189	48	6/17/1994	0.094
24	8/14/1992	0.427	49	8/20/1994	0.067
25	11/18/1992	0.236	50	9/21/1994	0.479

Sl. No.	Date	Mean EVI	Sl. No.	Date	Mean EVI
51	10/23/1994	0.297	80	2/20/1998	0.272
52	11/8/1994	0.269	81	3/24/1998	0.264
53	12/10/1994	0.242	82	4/9/1998	0.106
54	1/11/1995	0.228	83	4/25/1998	0.193
55	3/16/1995	0.231	84	5/11/1998	0.214
56	4/17/1995	0.109	85	5/27/1998	0.153
57	11/11/1995	0.293	86	6/12/1998	0.093
58	11/27/1995	0.301	87	7/30/1998	0.472
59	12/29/1995	0.255	88	8/31/1998	0.511
60	1/30/1996	0.24	89	11/3/1998	0.386
61	2/15/1996	0.19	90	11/19/1998	0.347
62	3/2/1996	0.204	91	12/5/1998	0.342
63	4/3/1996	0.277	92	1/22/1999	0.145
64	5/5/1996	0.14	93	2/7/1999	0.294
65	7/8/1996	0.284	94	3/11/1999	0.277
66	7/24/1996	0.308	95	3/27/1999	0.232
67	8/9/1996	0.059	96	4/12/1999	0.135
68	8/25/1996	0.56	97	4/28/1999	0.155
69	10/12/1996	0.384	98	3/13/2000	0.21
70	11/13/1996	0.259	99	3/29/2000	0.171
71	11/29/1996	0.323	100	4/14/2000	0.13
72	12/31/1996	0.264	101	3/16/2001	0.168
73	2/1/1997	0.237	102	8/23/2001	0.111
74	2/17/1997	0.229	103	4/20/2008	0.156
75	9/13/1997	0.463	104	5/6/2008	0.132
76	9/29/1997	0.119	105	6/23/2008	0.388
77	10/15/1997	0.394	106	7/25/2008	0.491
78	1/19/1998	0.285	107	9/27/2008	0.447
79	2/4/1998	0.28	108	10/13/2008	0.354

Sl. No.	Date	Mean EVI	Sl. No.	Date	Mean EVI
109	11/14/2008	0.234	138	6/29/2010	0.149
110	11/30/2008	0.27	139	9/17/2010	0.453
111	12/16/2008	0.212	140	10/3/2010	0.47
112	2/2/2009	0.201	141	12/6/2010	0.297
113	3/6/2009	0.194	142	12/22/2010	0.24
114	3/22/2009	0.184	143	1/23/2011	0.243
115	4/7/2009	0.175	144	2/8/2011	0.251
116	4/23/2009	0.156	145	3/12/2011	0.257
117	5/9/2009	0.142	146	4/29/2011	0.171
118	5/25/2009	0.087	147	5/15/2011	0.162
119	6/10/2009	0.125	148	5/31/2011	0.196
120	6/26/2009	0.097	149	7/2/2011	0.369
121	7/12/2009	0.049	150	9/20/2011	0.498
122	8/13/2009	0.245	151	10/22/2011	0.327
123	8/29/2009	0.206	152	3/27/2013	0.326
124	9/14/2009	0.526	153	4/11/2013	0.354
125	9/30/2009	0.467	154	4/18/2013	0.322
126	10/16/2009	0.406	155	5/4/2013	0.274
127	11/1/2009	0.325	156	5/20/2013	0.204
128	11/17/2009	0.217	157	6/5/2013	0.23
129	12/3/2009	0.256	158	6/21/2013	0.37
130	2/5/2010	0.17	159	7/7/2013	0.175
131	2/21/2010	0.187	160	7/23/2013	0.483
132	3/25/2010	0.132	161	8/24/2013	0.729
133	4/10/2010	0.142	162	9/9/2013	0.518
134	4/26/2010	0.124	163	9/25/2013	0.617
135	5/12/2010	0.144	164	10/27/2013	0.446
136	5/28/2010	0.069	165	11/12/2013	0.394
137	6/13/2010	0.164	166	11/28/2013	0.342

Sl. No.	Date	Mean EVI	Sl. No.	Date	Mean EVI
167	12/14/2013	0.308	196	5/10/2015	0.255
168	12/30/2013	0.301	197	5/26/2015	0.221
169	1/15/2014	0.199	198	6/11/2015	0.22
170	1/31/2014	0.262	199	6/27/2015	0.351
171	2/16/2014	0.307	200	7/29/2015	0.65
172	3/20/2014	0.32	201	8/14/2015	0.473
173	4/5/2014	0.374	202	8/30/2015	0.714
174	4/21/2014	0.356	203	9/15/2015	0.652
175	5/7/2014	0.302	204	10/1/2015	0.586
176	5/23/2014	0.235	205	10/17/2015	0.498
177	6/8/2014	0.204	206	11/2/2015	0.385
178	6/24/2014	0.215	207	11/18/2015	0.363
179	7/10/2014	0.322	208	12/4/2015	0.319
180	7/26/2014	0.594	209	12/20/2015	0.274
181	8/11/2014	0.647	210	1/5/2016	0.28
182	8/27/2014	0.616	211	1/21/2016	0.218
183	9/12/2014	0.669	212	2/6/2016	0.244
184	9/28/2014	0.606	213	2/22/2016	0.246
185	10/14/2014	0.275	214	3/9/2016	0.272
186	11/15/2014	0.321	215	3/25/2016	0.272
187	12/1/2014	0.283	216	4/10/2016	0.262
188	12/17/2014	0.178	217	4/26/2016	0.218
189	1/18/2015	0.225	218	5/12/2016	0.236
190	2/3/2015	0.403	219	5/28/2016	0.213
191	2/19/2015	0.325	220	6/13/2016	0.255
192	3/7/2015	0.429	221	6/29/2016	0.357
193	3/23/2015	0.439	222	7/15/2016	0.452
194	4/8/2015	0.408	223	7/31/2016	0.596
195	4/24/2015	0.316	224	8/16/2016	0.707

Sl. No.	Date	Mean EVI	Sl. No.	Date	Mean EVI
225	9/1/2016	0.566	254	12/25/2017	0.295
226	9/17/2016	0.696	255	1/10/2018	0.298
227	10/3/2016	0.558	256	1/26/2018	0.214
228	10/19/2016	0.434	257	2/11/2018	0.36
229	11/4/2016	0.362	258	2/27/2018	0.322
230	11/20/2016	0.308	259	3/15/2018	0.32
231	12/6/2016	0.28	260	3/31/2018	0.248
232	12/22/2016	0.271	261	5/2/2018	0.142
233	1/7/2017	0.155	262	5/18/2018	0.197
234	1/23/2017	0.278	263	6/3/2018	0.197
235	2/8/2017	0.312	264	6/19/2018	0.235
236	2/24/2017	0.346	265	7/5/2018	0.444
237	3/12/2017	0.378	266	8/22/2018	0.288
238	3/28/2017	0.335	267	9/7/2018	0.709
239	4/13/2017	0.267	268	10/9/2018	0.547
240	4/29/2017	0.233	269	10/25/2018	0.461
241	5/15/2017	0.207	270	11/10/2018	0.385
242	6/16/2017	0.265	271	11/26/2018	0.349
243	7/2/2017	0.32	272	12/28/2018	0.328
244	7/18/2017	0.359	273	1/13/2019	0.329
245	8/3/2017	0.465	274	1/29/2019	0.301
246	8/19/2017	0.019	275	3/18/2019	0.351
247	9/4/2017	0.715	276	4/3/2019	0.326
248	9/20/2017	0.666	277	4/19/2019	0.349
249	10/6/2017	0.576	278	5/5/2019	0.274
250	10/22/2017	0.452	279	5/21/2019	0.233
251	11/7/2017	0.323			
252	11/23/2017	0.345			
253	12/9/2017	0.322			

Annexure-3

Rainfall data (Indian Meteorological Department)

YEAR	MN	DRF01	DRF02	DRF03	DRF04	DRF05	DRF06	DRF07	DRF08	DRF09	DRF10	DRF11	DRF12	DRF13	DRF14	DRF15	DRF16	DRF17	DRF18	DRF19	DRF20	DRF21	DRF22	DRF23	DRF24	DRF25	DRF26	DRF27	DRF28	DRF29	DRF30	DRF31
1986	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	2	0	0	0	0	0	0	0	0	0	19	16	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0			
1986	3	0	0	0	0	0	0	0	0	0	0	0	10	0	1	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0
1986	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	7	0	0	0	
1986	5	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	27	0	8	0	0	0	0	0	3	0	0	4	6
1986	6	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	25	19	3	0	0	10	
1986	7	1	0	0	0	0	0	0	2	16	0	3	13	0	0	0	3	0	1	0	0	0	84	18	0	0	62	75	0	0	0	0
1986	8	86	4	0	6	0	0	1	0	0	0	4	0	23	0	0	0	0	70	40	0	36	0	0	0	0	0	0	0	0	0	0
1986	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	1	1	55	120	0	
1986	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	4	
1986	12	0	0	0	0	0	0	0	0	0	0	0	0	47	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	9	10	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	21	0	0	0	0	0	0	0	14	0	0	0			
1987	3	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	7	4	0	0	0	0	0	0	0	0
1987	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1987	5	7	11	7	0	0	0	6	16	64	0	1	0	3	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
1987	6	5	0	0	0	0	0	0	0	44	25	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1987	7	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
1987	8	0	0	0	0	11	0	0	0	0	0	0	0	0	20	2	0	0	0	21	0	0	1	0	0	0	0	0	50	51	0	0
1987	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
1987	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1987	12	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	9	6		
1988	3	0	0	0	0	0	0	0	0	6	0	11	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0
1988	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1988	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0
1988	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	34	0	0	0	17	0	0	5	0	0	3	23	
1988	7	0	0	55	38	2	35	87	2	0	0	0	0	46	28	2	1	7	0	2	0	8	4	2	83	35	0	20	29	3	0	38
1988	8	97	41	0	0	2	0	0	46	56	2	0	3	0	4	8	0	0	0	2	4	10	0	1	0	0	0	0	0	0	0	0
1988	9	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	10	0	0	0	0	4	45	102	61	5	61	0	0	0	
1988	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1988	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	8	2	0	0	0	0	0
1989	1	0	1	4	0	0	20	0	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0			
1989	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	43	0	0	0
1989	4	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1989	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	6
1989	6	3	0	0	0	24	0	0	0	0	0	0	0	0	5	40	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	
1989	7	2	19	0	0	0	0	0	0	0	0	0	0	7	52	10	0	0	0	0	0	0	16	0	0	0	0	0	6	51	30	2
1989	8	12	114	3	0	0	0	0	0	0	0	0	17	0	23	0	0	0	22	0	60	12	32	37	2	0	0	6	123	1	0	0
1989	9	0	16	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	
1989	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	0	0	0	0	
1989	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	5	0	15	8	0	0	0	0	0	0	0
1990	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

YEAR	MN	DRF 01	DRF 02	DRF 03	DRF 04	DRF 05	DRF 06	DRF 07	DRF 08	DRF 09	DRF 10	DRF 11	DRF 12	DRF 13	DRF 14	DRF 15	DRF 16	DRF 17	DRF 18	DRF 19	DRF 20	DRF 21	DRF 22	DRF 23	DRF 24	DRF 25	DRF 26	DRF 27	DRF 28	DRF 29	DRF 30	DRF 31
1990	2	0	0	0	0	0	0	0	0	0	0	0	0	25	22	0	0	0	0	6	0	19	0	0	0	5	0	7	20			
1990	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0
1990	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1990	5	0	0	0	0	2	0	0	0	0	0	3	0	16	0	0	0	0	10	1	2	0	0	0	0	0	0	0	0	0	0	0
1990	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	5	0	0	
1990	7	90	0	15	0	5	2	0	80	15	10	2	0	0	1	0	0	0	50	0	0	0	0	0	0	0	0	5	140	55	2	0
1990	8	0	8	0	11	1	0	0	40	0	7	23	5	4	22	0	0	0	0	0	14	0	0	0	0	0	0	2	6	13	1	0
1990	9	0	0	0	15	16	0	19	100	99	1	0	0	24	22	0	0	0	0	4	0	0	0	0	0	1	16	0	0	27	0	
1990	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	
1990	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	16
1991	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	2	0	0	0	0	0	0	0	0	0	0	7	13	0	0	0	0	0	0	0	0	0	0	0	5	0	10	55	0			
1991	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	4	0	0	0	0	0	0	0	0	4	6	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1991	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0
1991	6	0	0	0	0	0	0	0	1	0	23	0	10	0	0	2	0	0	16	10	0	0	0	0	0	0	0	0	0	0	0	
1991	7	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	4	0	0	56	10	0	0	0	0	0	0	25	12	0
1991	8	0	0	0	50	35	0	0	0	21	7	0	0	0	0	0	0	0	33	0	0	0	10	0	1	0	2	0	0	0	0	18
1991	9	0	1	0	0	26	0	0	0	32	0	1	0	0	0	0	4	11	0	0	0	0	0	0	0	0	0	0	0	0	0	
1991	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1991	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	10	33	0	3	0	0	0	0	0
1992	1	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0
1992	2	0	0	0	0	0	15	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
1992	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1992	5	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0	
1992	7	0	0	0	0	0	15	0	0	27	0	0	16	0	0	0	0	0	1	0	0	0	0	0	42	2	43	2	0	24	0	0
1992	8	0	94	3	0	0	32	0	0	0	20	35	0	11	0	0	48	17	0	89	45	0	0	0	0	3	0	9	2	0	0	0
1992	9	0	3	0	25	8	0	0	0	24	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1992	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	5	0	0	0	0	0	0	0	0	
1992	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	1	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	6	8	0			
1993	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	26	0	0	0	0	0	0
1993	4	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1993	5	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	6
1993	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	10	0	0	0	0	0	
1993	7	0	0	0	0	16	0	0	16	24	32	102	96	8	0	0	3.2	2	8	7	0	6	51	2.5	0	0	0	0	0	0	0	0
1993	8	0	0	0	0	0	0	2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	9	0	3	19	54.5	61	72	1	0	1	0	12	20	1	0	0	0	0	0	0	0	0	0	0	0	45	0	0	0	0	0	
1993	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1993	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	1	0	0	0	0	0	0	0	0	0	0	0	16	20.2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	2	0	0	0	0	0	0	0	7.5	4	0	0	0	0	0	0	0	0	0	0	0	20.5	2	0	0	0	0	0	0			
1994	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	4	9	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1994	5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	6	
1994	7	1.5	0	11	2	0	3	0	20	2	0	33.5	20	0	5	5	0	81	7.5	15.5	92	24	0	0.5	20	44	0	0	2	3	75	14
1994	8	0	0	0	89	0	0	3	5	0	19	5	0	0	0	0	42.3	1	0	0	0	0	0	158	34	8	6.2	0	0	13	0	0
1994	9	0	0	0	1	0	0	4	0	1	0	0	0	3	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

YEAR	MN	DRF 01	DRF 02	DRF 03	DRF 04	DRF 05	DRF 06	DRF 07	DRF 08	DRF 09	DRF 10	DRF 11	DRF 12	DRF 13	DRF 14	DRF 15	DRF 16	DRF 17	DRF 18	DRF 19	DRF 20	DRF 21	DRF 22	DRF 23	DRF 24	DRF 25	DRF 26	DRF 27	DRF 28	DRF 29	DRF 30	DRF 31
1994	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1994	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	1	0	0	0	0	0	0	0	0	82	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	2	0	0	0	0	0	0	0	0	0	0	0	0	20.8	7	0	0	0	0	0	0	0	0	0	0	0	0	0	12.4			
1995	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	4.6	0	0
1995	4	0	0	0	0	0	0	0	0	0	0	14.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1995	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15.4	40	0	17	0	0	0	0	0	0	15	
1995	7	0	0	0	0	12	0	0	0	0	19.2	0	6	0	0	0	0	0	3.2	1.2	0	0	0	6	0	0	0	37	119.5	3	0	0
1995	8	0	0	19.1	11	5.2	12	6	119	17	7.2	0	0	2	40	0	0	0	0	0	12	11	0	0	1	0	0	21	90	7	225	7
1995	9	6	0	20	56	80	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1995	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1995	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	12.4	0.4	0	0	0	0	6.4	0	0	0	0	0	0	0	0	0
1996	2	0	0	0	0	0	0	0	0	0	40	0	0	0	0	5	0	0	0	0	0	0	0	0	2	0	20	0	0	0		
1996	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	8	0	0	0	0	0	0	0	0	0
1996	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1996	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19.4	20	3	0	0	4	0	36	4	4	58	13	
1996	7	0	0	0	1	0	0	0	0	0	0	0	1	0	0	39	0	0	0	0	0	4	0	0	0	0	19	0	0	0	0	0
1996	8	47	0	15	1	0	0	4	0	0	24	2	0	45	54	7	5	0	0	1	0	32	18	1	24	0	0	0	0	0	1	0
1996	9	0	0	0	0	0	25	19	71	80	5	4	0	0	0	0	2	0	0	13	0	0	0	0	0	0	0	0	0	0	0	
1996	10	0	0	0	10	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1996	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0
1997	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
1997	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0
1997	4	0	11	18	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	17	0	
1997	5	0	0	0	0	2	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	32	0	0	0	25	0	20	21	5	0	0	
1997	7	0	0	0	0	0	0	2	0	0	0	20.3	0	0	0	12	0	1	0	4	0	0	70	0	0	0	0	0	0	0	35	0
1997	8	49	40	92	0	0	0	0	0	0	0	0	0	7	5	0	0	0	0	0	0	0	0	0	0	0	56	22	23	5	3	0
1997	9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1997	10	0	0	0	2	0	0	28	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1997	11	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	
1997	12	4	0	0	0	0	0	0	0	20	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0
1998	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	29	1	0	0			
1998	3	0	0	0	0	9	8	0	0	0	0	0	3	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	0	0	0	0	
1998	5	0	0	0	0	0	0	17	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	6	0	0	0	0	0	0	0	0	0	0	48	22	0	0	0	0	10	53	0	0	0	0	0	0	0	0	0	0	17	15	
1998	7	2	0	0	26	0	2	45	45	1	82	41	0	10	0	0	0	5	3	26	0	2	0	16	0	0	2	0	0	0	0	0
1998	8	1	1	0	28	4	0	0	0	0	13	0	14	0	2	0	10	16	0	0	4	0	0	0	0	0	7	1	54	4	0	0
1998	9	0	0	8	0	0	0	0	0	0	0	4	0	41	19	2	0	0	0	32	0	42	81	8	46	20	0	0	0	0	0	
1998	10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	19	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	11	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1999	1	0	0	0	0	0	0	31	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	14	0	0
1999	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
1999	3	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1999	5	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0
1999	6	0	0	7	0	2	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	56	0	

YE AR	M N	DRF 01	DRF 02	DRF 03	DRF 04	DRF 05	DRF 06	DRF 07	DRF 08	DRF 09	DRF 10	DRF 11	DRF 12	DRF 13	DRF 14	DRF 15	DRF 16	DRF 17	DRF 18	DRF 19	DRF 20	DRF 21	DRF 22	DRF 23	DRF 24	DRF 25	DRF 26	DRF 27	DRF 28	DRF 29	DRF 30	DRF 31
1999	7	9	0	8	0	0	0	0	0	0	0	0	27	12	0	0	0	0	0	1	56	94	93	16	0	0	4	0	0	0	28	18
1999	8	20	0	0	0	0	30	3	0	35	37	28	0	27	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	9	8	0	0	0	2	23	8	0	0	0	2	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1999	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1999	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	1	0	0	0	0	0	0	0	0	0	0	0	1	9	11	0	0	0	0	0	0	0	0	0	0	0	10	2	0	0	0	0
2000	2	0	0	0	0	32	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
2000	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
2000	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2000	5	0	0	0	0	0	16	2	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	2
2000	6	0	0	0	0	13	0	49	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	
2000	7	27	38	0	0	0	0	0	4	17	0	2	0	0	8	0	24	3	123	39	0	0	30	0	0	52	15	0	0	0	0	0
2000	8	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	1	51	4
2000	9	2	0	0	0	9	0	24	0	9	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	
2000	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2000	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	1	8	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0			
2001	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	19	1
2001	4	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	7	3	0	22	0	0	0	0	0	0	0	0	0	0	
2001	5	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	31	9	4	0	0	0	0	0	0	0	0	0	22	4	0	0
2001	6	7	0	0	0	4	0	10	2	0	0	0	0	0	27	5	1	0	0	0	0	1	6	29	0	4	3	0	0	0	0	
2001	7	0	0	0	0	0	0	0	9	0	0	6	0	0	48	34	206.7	13	17	0	0	0	7	0	0	31	0	19	0	0	0	0
2001	8	0	0	0	3	0	35	0	0	12	8	0	0	0	89	49	0	0	4	0	0	0	0	0	33	1	0	0	0	0	0	0
2001	9	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	
2001	10	2	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2001	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
2002	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	2	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	3	0	8	0	0	0			
2002	3	0	68	11	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2002	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	
2002	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	11	0	7	6	0	0
2002	6	0	0	0	0	0	0	1	9	0	0	0	7	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2002	7	0	0	0	0	93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	2	0	0	0
2002	8	0	1	0	0	5	0	0	0	0	0	3	6	27	121	3	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0
2002	9	11	3	9	1	2	0	0	25	8	0	0	15	79	28	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	
2002	10	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2002	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2003	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	11	0	14
2003	2	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	21	0	0	0	0	2	0	0	0	0			
2003	3	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	4	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	
2003	5	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0	0	0
2003	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	14	1	1	0	7	12	0	10	
2003	7	0	0	0	0	55	9	0	0	0	11	22	10	1	5	0	3	0	4	4	0	31	5	0	0	0	15	3	0	0	0	13
2003	8	93	0	0	0	0	0	21	0	18	8	0	0	4	12	0	1	0	0	0	0	0	0	0	0	0	0	3	0	3	81	0
2003	9	0	48	14	0	17	16	0	0	0	0	0	0	1	0	0	16	0	29	0	0	0	0	0	0	0	0	0	0	0	0	
2003	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2003	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2003	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	38	0	0	0	0	0	0	0	5
2004	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

YEAR	MN	DRF 01	DRF 02	DRF 03	DRF 04	DRF 05	DRF 06	DRF 07	DRF 08	DRF 09	DRF 10	DRF 11	DRF 12	DRF 13	DRF 14	DRF 15	DRF 16	DRF 17	DRF 18	DRF 19	DRF 20	DRF 21	DRF 22	DRF 23	DRF 24	DRF 25	DRF 26	DRF 27	DRF 28	DRF 29	DRF 30	DRF 31
2004	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	14	
2004	5	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	5	0	0	0
2004	6	0	14	0	0	0	0	13	0	31	0	0	0	0	0	0	0	0	1	0	8	34	18	0	1	0	0	0	0	0	0	
2004	7	0	0	0	0	0	0	0	9	0	0	3	0	2	13	2	0	1	0	0	0	0	0	0	0	12	8	0	0	0	0	0
2004	8	0	4	131	239	0	5	0	0	9	0	0	7	0	0	37	0	0	59	7	0	0	0	0	96	47	8	0	0	0	0	0
2004	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	17	0	0	0	0	0	0	0	0	5	
2004	10	0	0	7	0	0	0	0	0	0	1	3	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2004	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2005	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	0	12	0	0	0
2005	2	0	0	0	0	0	1	11	23	0	4	0	0	0	0	0	14	0	0	1	0	0	0	0	0	0	0	0	0			
2005	3	0	0	0	0	0	0	0	0	1	9	0	0	0	0	0	0	0	0	0	8	2	17	0	0	0	0	0	0	0	0	0
2005	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	
2005	5	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	20	9	2	0	
2005	7	0	0	0	2	66	70	10	0	0	0	0	41	0	0	0	37	22	25	0	0	18	12	1	11	0	0	3	1	0	0	0
2005	8	43	2	0	28	81	28	5	0	0	0	0	0	0	0	0	0	5	0	0	0	5	0	5	13	0	0	0	0	7	0	0
2005	9	0	0	0	0	0	0	0	0	0	15	0	0	5	2	1	0	28	40	3	0	0	44	0	54	1	0	0	0	0	0	
2005	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2005	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	1	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
2006	3	0	0	0	0	0	0	0	0	0	0	41	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
2006	4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2006	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	21	15	0	4	0	0	13	0	0	0	0	0
2006	6	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	7	0	0	0	0	0	0	0	9	4	5	0	0	0	
2006	7	0	0	0	0	0	0	0	0	0	40	4	0	15	41	3	0	0	0	0	0	0	0	3	6	0	94	13	0	0	0	0
2006	8	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6	37	0	0	2
2006	9	0	6	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2006	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	
2007	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	2	0	0	0	0	0	0	3	0	0	57	34	12	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12			
2007	3	40	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	7	8	0	0	0	0	0	0	0	0	0
2007	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	
2007	5	0	0	0	0	0	6	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	8	21	0	0	0	0	0	0	3	0	15	0	0	0	0	
2007	7	17	0	3	0	8	0	0	0	8	0	0	0	0	7	0	0	0	0	0	0	0	0	0	7	3	0	7	7	5	0	0
2007	8	0	16	0	0	8	0	0	0	0	0	0	3	1	34	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0
2007	9	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	24	0	0	0	0	
2007	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2007	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	1	0	0	0	0	0	0	0	0	9	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
2008	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2008	4	0	0	0	0	7	14	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	
2008	5	0	0	0	0	0	0	0	0	0	9	0	6	0	0	0	0	0	0	7	17	22	0	45	5	0	14	0	0	0	0	0
2008	7	40	0	0	0	9	0	16	0	2	0	0	2	12	1	2	2	25	5	0	0	0	2	0	0	0	0	1	0	0	0	0
2008	8	5	0	0	0	30	0	0	0	48	0	0	7	5	20	17	5	0	10	0	0	0	0	11	0	0	0	0	0	0	0	1
2008	9	0	0	0	2	0	2	8	0	0	0	0	0	0	0	0	0	0	2	9	73	2	0	0	0	0	0	0	0	0	0	
2008	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	
2008	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	0	0	0	0	0	0	0	0	0	0	0	0

YE AR	M N	DRF 01	DRF 02	DRF 03	DRF 04	DRF 05	DRF 06	DRF 07	DRF 08	DRF 09	DRF 10	DRF 11	DRF 12	DRF 13	DRF 14	DRF 15	DRF 16	DRF 17	DRF 18	DRF 19	DRF 20	DRF 21	DRF 22	DRF 23	DRF 24	DRF 25	DRF 26	DRF 27	DRF 28	DRF 29	DRF 30	DRF 31
2009	2	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
2009	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	4	2	0
2009	4	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2009	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	
2009	7	36	23	0	0	0	0	0	0	0	0	6	0	0	3	0	0	7	0	0	0	5	0	0	0	0	0	0	7	40	20	8
2009	8	0	0	0	17	0	0	0	0	0	0	0	3	0	0	14	1	0	7	10	3	0	0	0	0	0	0	0	0	0	0	0
2009	9	5	0	0	2	0	0	0	0	0	9	66	62	30	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2009	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2010	1	0	0	0	3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	2	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0			
2010	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2010	5	0	0	0	0	0	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	6	0	0	0	0	5	0	0	23	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	4	2	0	
2010	7	3	5	0	0	97	77	104	0	0	0	0	42	4	2	0	0	0	0	0	0	24	0	21	0	0	0	4	0	0	0	0
2010	8	12	7	0	0	0	2	0	0	0	0	0	2	0	0	0	0	2	0	17	3	2	4	0	1	0	0	0	0	0	0	0
2010	9	0	0	5	0	3	0	0	2	5	1	1	67	0	0	0	0	0	0	0	13	0	0	20	0	0	0	0	0	0	0	
2010	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2010	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	24
2011	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	2	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
2011	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
2011	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2011	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	20	0	0	0	0	0	0	0	0	2	0
2011	6	34	27	0	0	0	0	0	0	0	5	0	0	0	0	8	11	0	32	0	0	0	0	0	0	3	3	5	0	0	0	
2011	7	0	0	0	0	0	0	0	40	23	13	0	0	0	0	0	38	2	0	0	0	0	0	4	56	0	0	0	0	0	5	0
2011	8	0	0	0	0	5	0	0	0	0	6	2	0	0	0	14	27	0	0	0	6	0	0	0	8	3	0	23	0	0	0	12
2011	9	2	0	0	0	0	0	0	0	15	3	4	0	0	0	0	62	4	0	0	0	0	0	0	0	0	0	0	0	0	0	
2011	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2011	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	1	0	0	0	0	0	0	3	16	0	0	0	0	0	0	0	2	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
2012	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	4	0	0	0	0	0	0	0	0	0	5	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2012	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
2012	6	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2012	7	0	0	0	0	0	0	17	39	0	0	2	0	14	0	0	0	0	0	0	0	9	0	0	0	12	0	0	0	0	0	0
2012	8	3	0	8	0	0	0	0	0	0	4	9	0	0	0	0	0	0	0	0	0	40	24	7	0	3	3	10	23	62	1	0
2012	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2012	12	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	5	0	0	0	0	0	0	0	0	0	0	0	0
2013	2	0	0	0	2	6	11	0	0	0	0	0	0	0	0	0	8	7	0	0	0	0	6	5	13	0	0	2	0			
2013	3	0	0	0	0	0	0	0	0	0	0	0	0	0	10	6	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
2013	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	
2013	5	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	6	0	0	0	0	0	0	17	0	0	0	0	2	0	26	0	16	24	0	0	0	0	0	14	0	12	2	2	4	6	20	

Annexure-4

Gauge and Discharge Data of Site No. 5, River Tangri Ambala-Shahbad Road crossing near Shahpur

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
2001																								
1	-	-	-	-	-	-	-	-	-	-	-	-	3.34	2.55	2.28	1.96	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	0.47	-	1.19	1.07	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	236.74	0.84	0.62	-	4.08	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	17.62	9.76	-	-	1.11	0.86	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	2.36	1.82	3.04	2.37	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	0.69	-	1.94	1.26	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	1.85	1.45	1.76	0.95	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	36.69	16.78	5.72	5.21	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	8.18	7.07	95.38	25.59	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	2.64	5.5	13.89	16.73	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	23	26.42	4.91	4.45	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	15.22	5.25	3.39	3.02	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	2.9	13.62	2.52	4.45	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	3.11	1.2	82.68	98.66	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	5.82	7.81	71.8	62.67	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	55.3	394.04	30.97	28.07	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	149.84	259.2	10.65	29.22	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	118.11	41.4	11.61	10.58	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	19.6	10	4.26	3.77	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	47.99	47.94	3.35	2.91	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	23.7	81.6	2.66	1.98	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	20.55	13.11	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	7.3	5.04	2.45	1.91	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	1.85	1.57	6.82	4.77	3.36	2.82	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	1.47	1.02	5.84	3.91	2.37	2.26	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	22.51	2.01	3.85	3.38	1.63	1.41	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	0.72	0.64	7.98	3.9	1.19	0.97	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	5.17	4.73	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	5.02	4.67	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	3.9	3.11	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	2.77	2.54	-	-	-	-	-	-	-	-	-	-
2002																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34.68	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.51	6.05	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.5	4.15	-	-	-	-	-	-
4	-	-	-	-	2.35	1.26	-	-	-	-	-	-	-	-	-	-	1.33	0.96	-	-	-	-	-	-
5	-	-	-	-	0.67	0.51	-	-	-	-	-	-	2.94	1.21	-	-	13.87	8.23	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.29	5.33	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.88	2.68	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.84	7.48	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34.68	12.06	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13.95	9.73	-	-	-	-	-	-

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.25	3.05	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.79	2.81	2.49	8.23	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.62	2.55	55.82	34.68	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	925.81	995.39	11.62	5.54	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	166.28	55.82	5.07	4.12	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.78	11.87	7.15	4.65	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.89	2.4	2.95	5.93	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	1.05	2.6	1.99	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.46	34.64	2.22	1.85	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.84	3.03	1.55	1.28	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.31	0.77	1.37	1.16	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.86	0.71	1	0.82	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.76	0.66	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.79	1.44	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.64	0.56	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.7	1.94	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.81	0.68	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6	1.3	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.01	1.56	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	2.85	1.54	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2003																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	1.87	1.38	-	-	7.12	6.12	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.13	7.66	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26.62	294.31	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	107.78	82.91	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	1.28	-	-	55.82	26.62	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	2.01	1.51	-	-	26.62	26.62	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55.82	26.62	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.3	6.86	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.38	4.83	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	4.12	5.21	-	-	5.67	4.53	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	2.7	1.82	-	-	4.51	3.9	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.64	3.37	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	6.11	4.72	-	-	2.81	2.61	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	7.68	4.81	-	-	2.34	2.16	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	7.21	-	-	1.93	1.75	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	0.83	0.57	-	-	5.25	4.6	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.74	3.4	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	6.72	3.46	-	-	12.56	7.78	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	0.74	0.58	-	-	4.14	3.61	-	-	-	-	-	-
20	-	-	3.6	1.98	-	-	-	-	-	-	-	-	-	4.25	-	-	2.16	1.96	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	6.11	4.72	-	-	1.84	1.63	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	5.08	3.18	-	-	1.57	8.72	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	0.76	0.65	-	-	2.63	2.05	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	1.05	3.94	-	-	1.84	1.37	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	7.81	5	-	-	1.8	1.53	-	-	-	-	-	-

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
26	-	-	-	-	-	-	-	-	-	-	-	-	4.77	2.94	-	-	1.59	1.46	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	1.00	0.82	-	-	1.45	1.36	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	0.57	0.57	-	-	1.17	1.08	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	1.55	-	-	0.99	0.81	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	82.91	-	-	0.63	0.47	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	34.68	139.98	-	-	-	-	-	-	-	-	-	-
2004																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	255.1	1081.36	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	557.58	140.23	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67.42	34.62	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.69	10.29	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.15	0.86	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	67.42	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.12	6.78	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.01	5.03	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.52	3.64	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.55	7.97	-	-	255.1	331.9	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.73	3.01	-	-	91.37	34.62	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.45	1.23	-	-	5.6	3.37	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.29	1.1	-	72.83	2.78	2.36	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.47	0.33	6.83	6.2	1.68	1.39	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.14	7.02	7.26	5.29	1.26	1.08	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.95	4.4	2.41	2.15	1.26	0.78	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.45	1.96	1.86	1.52	0.99	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.32	1	0.69	0.56	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.88	0.73	0.58	3.51	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.46	0.33	4.1	3.33	-	-	-	-	-	-
23	0.33	4.58	-	-	-	-	-	-	-	-	-	-	-	-	0.48	1.19	2.87	2.52	-	-	-	-	-	-
24	2.16	2	-	-	-	-	-	-	-	-	-	-	-	-	6.57	5.82	4.37	3.47	-	-	-	-	-	-
25	1.8	1.5	-	-	-	-	-	-	-	-	-	-	-	-	34.62	8.32	1.68	1.51	-	-	-	-	-	-
26	1.54	1.37	-	-	-	-	-	-	-	-	-	-	-	-	7.26	4.35	0.86	0.63	-	-	-	-	-	-
27	0.84	0.6	-	-	-	-	-	-	-	-	-	-	-	-	4.1	3.41	0.39	0.25	-	-	-	-	-	-
28	0.28	0.22	-	-	-	-	-	-	-	-	-	-	-	-	2.22	1.84	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.12	0.98	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	0.47	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-			-	-	-	-	-	-	-	-
2005																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.2	6.35	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.18	0.93	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.39	2.32	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	1.46	1.1	2.35	3.77	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	26.62	663.48	0.98	0.77	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	77.69	26.62	3.5	15.43	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	16.87	11.61	4.46	77.69	-	-	-	-	-	-	-	-

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
8	-	-	-	-	-	-	-	-	-	-	-	-	5.58	3.99	15.43	4.8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	1.5	1.2	1.54	2.08	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	0.46	0.43	0.97	0.72	-	0.57	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	26.62	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	3.21	2.24	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	1.6	1.16	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	77.69	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	1.84	1.52	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	4.3	136.48	-	34.68	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	5.86	3.57	15.43	6.3	-	15.43	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	15.43	5.44	34.68	6.36	2.19	1.6	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	3.8	2.58	6.12	4.9	2.87	2.48	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	1.77	1.23	4.96	3.39	1.11	0.92	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	5.88	3.78	2.64	2.01	0.57	0.41	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	4.21	0.09	3.42	2.8	4.85	4.68	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	2.44	1.64	2.22	1.81	2.31	1.76	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	1.67	1.28	1.18	0.92	4.67	15.43	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	3.88	2.42	0.73	0.62	5.61	4.67	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	1.21	5.53	-	-	15.43	6.5	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	2.3	15.43	-	-	15.58	4.08	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	3.77	2.87	-	-	1.78	1.39	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	2.7	1.56	2.11	0.91	0.96	0.74	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	1.85	1.28	-	-	0.84	0.74	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	5.7	4.73	-	-	-	-	-	-	-	-	-	-
2006																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.21	0.63	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.47	2.85	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.46	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	15.43	2.71	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	2.46	15.43	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	3.73	2.44	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	2.97	1.51	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	2.26	26.62	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	1.08	0.98	1.45	0.75	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	1.88	0.85	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.38	1.52	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	4.92	15.43	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	1.95	3.97	4.97	1.57	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	3.86	2.65	1.84	1.12	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	2.26	1.64	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	1.16	0.84	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.85	1.85	-	-	-	-	-	-	-	-
2007																								
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1	-	-	-	-	2.55	1.85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	1.8	0.96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.21	1.61	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.98	22.83	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.61	2.56	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.47	1.82	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.81	1.57	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	253.17	107.78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	166.28	55.82	-	-	-	-	-	-	2.9	1.62	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	6.67	-	-	8.32	-	-	-	-	2.75	1.67	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	2.21	1.45	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	1.08	0.75	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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26	-	-	-	-	-	-	-	-	-	-	2.04	1.36	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	2.59	1.93	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.24	1.74	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.61	1.19	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2008																								
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1	-	-	-	-	-	-	-	-	-	-	-	-	3.44	0.92	40.58	7.12	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.77	1.29	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.03	21.6	-	-	-	-	-	-	-	-

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70.94	508.76	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	1.02	0.83	40.98	7.07	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27.48	461.74	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	2.64	1.66	273.54	47.16	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21.55	12.79	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9.38	5.84	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	4.8	1.73	1.14	0.85	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	5.38	3.56	40	8.1	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	47.16	7.93	34.62	6.84	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21.39	20.58	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	47.16	7.87	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	70.94	47.16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21.91	8.49	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.55	6.05	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.02	4.53	4.73	40.58	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.83	2.21	508.76	995.39	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58.42	20.46	373.23	72.83	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	31.47	18.85	116.33	67.42	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.38	9.9	26.57	17.76	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.44	2.26	20.3	15.73	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.23	1.04	14.06	8.95	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.85	4.98	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.47	1.15	-	-	-	-	-	-
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30	-	-	-	-	-	-	-	-	-	-	2.4	4.08	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	6.46	23.4	-	-	-	-	-	-	-	-	-	-
2009																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
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10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	116.33	47.16	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	866.66	660.53	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	608.19	750.3	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	373.23	165.89	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67.42	40.58	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25.92	15.34	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.2	7.34	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.1	0.99	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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29	-	-	-	-	-	-	-	-	-	-	-	-	5.85	19.63	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	40.58	11.13	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	7.24	4.23	-	-	-	-	-	-	-	-	-	-
2010																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.53	9.67	-	-	6.38	5.42	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.41	11.37	4.91	3.93	4.32	3.76	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.60	6.71	40.58	34.62	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.59	769.22	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	461.74	-	-	72.83	34.62	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	508.76	995.39	-	-	34.62	15.80	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	866.66	557.58	-	-	128.05	202.29	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	67.42	58.42	-	-	116.33	995.39	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	5.78	3.97	-	-	165.89	218.42	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	2.21	6.23	-	-	91.37	47.16	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	4.37	13.91	5.88	47.16	34.62	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	1.75	140.33	11.16	6.11	152.84	82.15	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	47.16	5.10	10.23	8.24	72.83	58.42	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	4.07	2.99	10.68	70.94	67.42	47.16	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	116.33	331.90	47.16	34.62	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67.42	34.62	22.86	19.52	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	461.74	58.42	19.14	16.91	13.57	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	6.03	3.10	14.37	34.62	13.98	10.96	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	660.53	1081.36	9.29	8.70	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	12.32	12.10	331.90	202.29	9.68	8.76	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	5.34	-	218.42	608.19	8.42	7.81	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	12.90	140.23	67.42	508.76	508.76	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	10.10	4.10	58.42	15.11	1127.00	557.58	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34.62	40.58	140.23	72.83	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	218.42	116.33	16.34	13.13	70.94	58.42	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	17.07	8.22	12.08	9.23	40.58	34.62	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	11.70	7.54	7.61	5.60	24.41	19.27	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	7.01	4.96	5.40	4.53	13.05	10.27	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.91	3.29	12.44	9.08	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.87	2.40	8.01	6.52	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2011																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	25.20	20.16	5.07	5.00	3.68	3.68	3.62	3.62	3.43	3.43	4.20	3.81	18.99	15.97	12.91	12.00	40.04	40.04	12.00	12.00	9.56	9.56	6.86	6.86

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
2	15.12	15.12	5.00	5.00	3.65	3.65	3.62	3.62	3.42	3.42	4.02	3.81	13.96	13.96	12.00	12.00	30.78	30.78	11.90	11.90	9.46	9.46	6.74	6.74
3	15.12	12.50	4.91	4.91	3.65	3.65	3.58	3.58	3.35	3.35	3.68	3.68	13.08	12.52	12.00	11.50	52.33	52.33	11.60	11.60	9.46	9.46	6.78	6.78
4	11.38	11.35	5.82	4.82	3.62	3.62	3.58	3.58	3.35	3.35	3.65	3.65	11.65	9.81	11.17	15.39	27.00	27.00	11.60	11.60	8.73	8.73	6.78	6.78
5	10.20	10.20	4.75	4.75	3.58	3.58	3.54	3.54	3.32	3.32	3.58	3.58	9.81	9.40	15.39	15.39	22.50	22.50	11.50	11.50	9.46	9.46	6.74	6.74
6	6.93	5.95	4.64	4.64	3.58	3.58	3.54	3.54	3.42	3.42	3.54	3.54	9.63	9.63	12.00	11.50	20.52	20.52	11.50	11.50	9.35	9.35	6.66	6.66
7	6.16	6.16	4.50	4.50	3.62	3.62	3.50	3.50	3.32	3.32	3.42	3.42	9.56	43.20	11.50	11.50	40.04	27.00	11.17	11.17	9.35	9.35	6.57	6.57
8	6.03	6.03	4.50	4.50	3.65	3.65	3.54	3.54	3.35	3.35	3.35	3.35	21.60	133.00	11.17	11.17	27.00	27.65	11.17	11.17	9.24	9.24	6.57	6.57
9	6.13	6.13	4.34	4.34	3.68	3.68	3.58	3.58	3.32	3.32	3.42	3.42	44.29	47.88	12.85	11.60	40.04	40.04	11.07	11.07	9.13	9.13	6.51	6.51
10	6.03	6.03	4.20	4.20	3.81	3.81	3.62	3.62	3.35	3.35	3.43	3.43	25.70	21.00	15.39	15.39	27.00	25.65	11.07	11.07	9.16	9.16	6.51	6.51
11	5.95	5.95	4.20	4.20	3.81	3.81	3.68	3.68	3.32	3.32	3.42	3.42	21.60	21.60	27.00	27.00	35.91	41.04	11.17	11.17	9.16	9.16	6.57	6.57
12	5.76	5.76	4.09	4.09	3.89	3.89	3.65	3.65	3.26	3.26	3.54	3.54	36.31	27.93	22.50	46.68	35.91	27.00	11.17	11.17	9.13	9.13	6.57	6.57
13	5.76	5.76	4.09	4.09	3.81	3.81	3.62	3.62	3.32	3.32	3.50	3.50	101.00	36.31	27.00	27.00	22.50	22.50	11.07	11.07	9.01	9.01	6.51	6.51
14	5.95	5.95	4.02	4.02	3.99	3.99	3.62	3.62	3.26	3.26	3.43	3.43	27.93	52.33	22.50	20.52	41.04	31.50	11.07	11.07	9.13	9.13	6.51	6.51
15	5.76	5.76	4.34	4.20	3.94	3.94	3.68	3.68	3.26	3.26	3.54	3.54	30.78	120.00	46.68	52.33	27.00	167.63	10.95	10.95	9.01	9.01	6.36	6.36
16	5.69	5.69	4.20	4.20	3.89	3.89	3.68	3.68	3.23	3.23	3.54	3.54	120.00	61.56	70.97	80.37	56.94	52.33	10.95	10.95	9.01	9.01	6.44	6.44
17	5.57	5.57	4.09	4.09	3.89	3.89	3.71	3.71	3.26	3.26	5.69	5.37	52.00	52.33	52.33	46.68	40.04	35.91	10.60	10.60	8.98	8.98	6.36	6.36
18	5.69	5.69	4.02	4.02	3.81	3.81	3.89	3.89	3.23	3.23	11.35	11.35	46.68	52.33	46.68	46.68	27.00	24.30	10.27	10.27	8.98	8.98	6.36	6.36
19	5.57	5.57	3.99	3.99	3.80	3.80	3.81	3.81	3.23	3.23	6.93	6.93	46.68	40.04	61.56	52.33	22.50	22.50	10.27	10.27	9.01	9.01	6.29	6.29
20	5.37	5.37	3.94	3.94	3.80	3.80	3.68	3.68	3.18	3.18	6.93	5.95	35.91	35.91	89.77	84.13	28.52	19.49	10.00	10.00	9.98	9.98	6.21	6.21
21	5.32	5.32	3.94	3.94	3.81	3.81	3.65	3.65	3.42	3.42	5.69	5.69	52.33	46.68	70.97	52.33	18.47	18.47	10.00	10.00	8.95	8.95	6.29	6.29
22	5.37	5.37	3.89	3.89	3.80	3.80	3.65	3.65	3.42	3.42	5.37	5.37	40.04	35.91	46.68	46.68	15.39	15.39	9.89	9.89	8.86	8.86	6.21	6.21
23	5.32	5.32	3.89	3.89	3.76	3.76	3.62	3.62	3.32	3.32	5.12	5.12	31.50	70.97	70.97	52.33	14.71	13.34	10.00	10.00	8.71	8.71	6.21	6.21
24	5.32	5.32	3.81	3.81	3.71	3.71	3.58	3.58	3.18	3.18	4.82	4.82	46.68	40.04	52.33	61.56	13.34	13.25	9.89	9.89	8.36	8.36	6.15	6.15
25	5.24	5.24	3.76	3.76	3.71	3.71	3.54	3.54	3.11	3.11	11.35	11.35	35.91	27.00	46.68	40.04	13.34	13.25	9.78	9.78	7.36	7.36	6.21	6.21
26	5.24	5.24	3.65	3.65	3.68	3.68	3.54	3.54	3.09	3.09	78.15	113.40	23.94	21.60	35.91	30.78	12.85	12.00	9.67	9.67	7.21	7.21	6.15	6.15
27	5.16	5.16	3.71	3.71	3.68	3.68	3.50	3.50	3.03	3.03	50.40	37.80	21.60	21.60	531.90	89.92	12.00	12.85	9.67	9.67	7.06	7.06	6.09	6.09
28	5.12	5.12	3.68	3.68	3.65	3.65	3.50	3.50	3.58	3.58	25.20	18.90	19.95	18.62	70.96	61.56	15.39	13.34	9.78	9.78	7.06	7.06	6.15	6.15
29	5.24	5.24	-	-	3.65	3.65	3.43	3.43	3.43	3.43	7.08	78.15	18.62	46.68	52.33	46.68	13.25	12.84	9.67	9.67	6.98	6.98	6.09	6.09
30	5.24	5.24	-	-	3.68	3.68	3.42	3.42	3.42	3.42	11.30	18.99	19.95	18.95	40.04	35.31	12.58	12.10	9.56	9.56	6.86	6.86	6.06	6.06
31	5.16	5.16	-	-	3.65	3.65	-	-	3.35	3.35	-	-	15.39	15.39	35.91	30.78	-	-	9.46	9.46	-	-	6.09	6.09
2012																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.53	9.67	-	-	6.38	5.42	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.41	11.37	4.91	3.93	4.32	3.76	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.60	6.71	40.58	34.62	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.59	769.22	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	461.74	-	-	72.83	34.62	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	508.76	995.39	-	-	34.62	15.80	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	866.66	557.58	-	-	128.05	202.29	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	67.42	58.42	-	-	116.33	995.39	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	5.78	3.97	-	-	165.89	218.42	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	2.21	6.23	-	-	91.37	47.16	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	4.37	13.91	5.88	47.16	34.62	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	1.75	140.33	11.16	6.11	152.84	82.15	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	47.16	5.10	10.23	8.24	72.83	58.42	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	4.07	2.99	10.68	70.94	67.42	47.16	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	116.33	331.90	47.16	34.62	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	67.42	34.62	22.86	19.52	-	-	-	-	-	-

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
17	-	-	-	-	-	-	-	-	-	-	-	-	-	461.74	58.42	19.14	16.91	13.57	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	6.03	3.10	14.37	34.62	13.98	10.96	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	660.53	1081.36	9.29	8.70	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	12.32	12.10	331.90	202.29	9.68	8.76	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	5.34	-	218.42	608.19	8.42	7.81	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	12.90	140.23	67.42	508.76	508.76	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	10.10	4.10	58.42	15.11	1127.00	557.58	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34.62	40.58	140.23	72.83	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	218.42	116.33	16.34	13.13	70.94	58.42	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	17.07	8.22	12.08	9.23	40.58	34.62	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	11.70	7.54	7.61	5.60	24.41	19.27	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	7.01	4.96	5.40	4.53	13.05	10.27	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.91	3.29	12.44	9.08	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.87	2.40	8.01	6.52	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	373.24	-	-			-	-	-	-	-	-
2013																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	7.40	4.48	4.80	3.84	4.90	4.77	4.32	2.01	0.66	0.60	1.27	1.18	7.20	7.04	47.48	34.56	47.48	39.83	24.23	24.23	9.07	9.07	9.46	9.46
2	3.87	2.56	4.90	4.77	6.18	5.92	2.01	1.64	1.27	1.20	1.23	1.16	6.92	6.40	29.44	24.23	34.56	29.44	29.44	29.44	9.07	9.46	9.46	9.46
3	5.36	4.86	6.18	5.36	5.84	5.52	0.72	0.60	1.25	1.15	1.23	1.13	9.36	9.07	24.23	19.33	34.56	29.44	34.56	29.44	8.06	8.06	9.26	9.26
4	7.36	5.36	3.62	10.30	5.36	4.80	3.64	2.56	1.29	1.16	1.45	1.34	8.16	8.06	24.23	19.33	34.56	29.44	34.56	29.44	8.16	8.16	9.26	9.26
5	7.92	6.40	13.28	11.24	5.12	4.96	3.88	2.64	1.23	1.15	1.37	1.27	9.36	8.64	19.33	29.44	34.56	29.44	29.44	29.44	9.07	9.07	9.36	9.36
6	6.18	5.03	10.96	9.86	6.18	5.92	3.36	2.00	1.23	1.16	2.41	2.28	7.92	12.25	24.33	29.44	47.48	34.56	24.23	24.23	9.07	9.46	9.36	9.36
7	6.18	3.64	5.78	4.18	6.18	3.64	2.56	1.44	1.26	1.13	2.25	2.17	34.56	210.24	29.44	24.23	34.56	29.44	24.23	24.23	8.64	8.64	9.46	9.46
8	5.13	3.36	5.16	4.00	4.72	4.12	3.87	1.76	1.24	3.20	1.99	1.89	20.27	69.20	69.20	34.56	47.48	69.20	19.33	19.33	9.26	9.26	9.46	9.46
9	7.92	6.40	7.04	4.51	5.36	4.66	3.64	1.28	1.96	1.67	1.84	1.71	20.27	19.33	60.75	47.48	34.56	29.44	157.49	47.48	9.07	9.07	9.26	9.26
10	5.84	3.64	6.18	5.92	5.12	4.96	2.56	1.88	1.64	1.48	1.79	1.71	8.80	8.64	34.56	29.44	34.56	29.44	69.20	47.48	9.07	9.07	9.07	9.07
11	6.18	5.92	8.16	6.24	5.84	3.88	3.60	2.12	1.56	1.43	1.60	1.52	9.36	9.07	47.48	47.48	29.44	24.23	24.23	24.23	9.26	9.26	9.07	9.07
12	5.84	3.64	6.18	5.03	6.20	3.64	3.31	1.87	1.45	1.37	1.54	1.46	9.46	9.07	34.56	47.48	29.44	24.23	19.33	19.33	9.26	9.26	9.07	9.07
13	5.84	3.64	6.18	3.64	6.18	5.36	3.60	1.20	1.38	1.30	1.34	1.28	9.46	34.56	560.36	210.24	24.23	24.23	19.33	19.33	9.07	9.07	8.64	8.64
14	6.18	3.64	6.18	5.36	4.90	4.77	3.36	1.44	1.37	1.28	1.37	1.28	12.25	7.20	86.10	69.20	24.23	19.33	15.36	15.36	9.46	9.46	8.64	8.64
15	12.25	6.80	7.04	5.52	4.80	3.84	4.80	1.60	1.34	1.28	1.23	1.15	8.40	7.98	69.20	86.10	24.23	19.33	9.36	9.36	9.46	9.46	7.92	7.92
16	7.04	5.52	6.18	3.64	5.43	3.36	2.80	0.70	1.32	1.23	2.40	1.27	86.10	69.20	69.20	60.75	19.33	19.33	24.23	24.23	9.26	9.26	7.92	7.92
17	9.36	20.27	6.18	4.96	6.80	3.64	2.40	1.27	1.34	1.27	2.14	0.50	47.48	34.56	47.48	39.83	19.33	16.88	24.23	19.23	9.26	9.26	8.16	8.16
18	14.32	13.60	8.40	4.48	5.84	3.64	2.14	0.50	1.30	1.21	2.01	0.36	24.35	39.83	60.75	47.48	16.88	16.88	19.33	24.23	9.07	9.07	8.16	8.16
19	13.74	11.36	6.18	3.64	4.24	2.56	3.88	0.84	1.32	1.24	2.08	0.36	24.23	24.23	69.20	47.48	16.88	15.36	29.44	24.23	9.07	9.07	7.92	7.92
20	12.48	10.30	7.76	5.92	5.84	3.69	2.56	0.56	1.28	1.21	1.28	0.48	47.48	34.56	34.56	29.44	15.36	15.36	24.23	24.23	8.64	8.64	8.16	8.16
21	7.92	3.64	5.43	3.36	5.13	3.36	2.01	0.36	1.30	1.20	4.24	3.64	23.44	24.23	69.20	60.75	15.36	34.56	15.36	19.33	8.64	8.64	8.64	8.64
22	6.18	3.64	5.30	4.96	7.92	6.40	1.64	0.30	1.64	0.30	3.31	3.21	210.24	133.68	60.75	47.48	34.56	29.44	7.92	12.25	9.07	9.07	8.64	7.92
23	6.18	5.92	5.43	4.96	5.36	4.86	2.08	0.36	1.29	1.16	2.95	2.83	34.56	29.44	34.56	29.44	29.44	29.44	8.64	8.64	9.07	9.07	8.16	7.92
24	6.18	3.84	6.18	3.64	3.87	8.56	2.56	0.32	1.23	1.15	2.83	3.36	24.23	133.68	34.56	29.44	29.44	24.23	9.46	9.46	9.07	9.07	8.06	8.06
25	4.24	2.56	7.44	6.80	4.90	4.77	2.14	0.40	1.96	1.57	4.90	4.86	47.48	69.20	34.56	29.44	29.44	29.44	15.36	15.36	9.26	9.26	8.06	8.16
26	7.44	6.80	6.18	3.64	5.12	4.96	2.12	0.32	1.64	1.48	6.18	6.80	34.56	24.23	34.56	29.44	24.23	24.23	9.46	9.46	9.26	9.26	8.16	8.16
27	6.18	3.64	4.90	4.77	5.84	5.52	2.40	0.72	1.45	1.37	6.92	6.80	24.23	16.88	34.56	29.44	24.23	24.23	9.36	9.36	9.07	9.07	7.92	7.92
28	5.43	3.36	6.18	3.64	6.20	3.38	2.00	0.45	1.37	1.28	7.20	6.92	19.33	24.23	42.48	39.83	34.56	29.44	9.07	9.07	9.07	9.07	8.64	8.64
29	7.92	6.40	-	-	4.90	4.77	1.28	0.48	1.32	1.23	7.44	7.20	24.23	29.44	34.56	29.44	34.56	29.44	9.46	9.46	9.26	9.26	9.07	9.07
30	7.44	6.80	-	-	5.36	3.64	1.44	0.28	1.64	0.30	7.44	7.20	24.23	24.23	34.56	29.44	29.44	29.44	9.36	9.36	9.26	9.26	9.07	9.07
31	6.18	3.64	-	-	4.24	2.56	-	-	2.08	0.36	-	-	24.23	19.33	47.48	39.83	-	-	8.16	8.06	-	-	8.64	8.64

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
2014																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	71.69	8.87	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	7.44	1.94	1.13	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	87.03	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22.32	1.91	96.87	17.75	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	239.96	2.04	1.29	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22.32	12.00	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37.80	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13.10	8.00	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.82	1.06	-	-	-	-	-	-	12.00	3.31
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	103.58	-	-	-	-	-	-	1.85	0.96
17	-	-	-	-	-	-	-	-	-	-	-	-	14.20	9.11	2.60	1.42	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	42.55	357.10	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	236.28	317.80	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	223.60	99.29	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	24.82	8.00	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	1.57	1.05	-	-	-	-	-	-	-	-	-	-
23	-	16.61	-	-	-	-	-	-	-	-	-	-	15.91	1.80	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2015																								
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1	-	-	-	-	37.80	20.37	-	-	-	-	-	-	-	-	-	176.00	-	-	-	-	-	-	-	-
2	-	-	-	-	14.80	5.97	-	-	-	-	-	-	-	-	3.38	2.28	-	-	-	-	-	-	-	-
3	-	-	-	-	3.72	3.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	15.91	23.64	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	11.52	2.06	-	45.22	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.20	2.15	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.85	1.50	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	37.80	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	67.50	48.38	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	74.04	35.71	369.85	350.12	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	36.08	23.65	117.47	85.15	-	-	-	-	-	-	-	-

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
14	-	-	-	-	-	-	-	-	-	-	-	-	15.36	4.99	35.84	79.21	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	1.09	0.96	33.89	25.98	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	86.81	55.91	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	74.52	231.15	14.07	2.94	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	53.99	48.08	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	33.26	10.08	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	2.14	1.50	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	32.85	10.08	-	81.36	31.52	Leakage	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	140.80	76.27	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50.95	29.23	239.96	420.27	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24.96	12.85	228.38	163.75	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.56	2.83	86.51	48.22	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	27.59	1.92	1.51	28.72	20.83	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	2.03	-	-	-	Leakage	Leakage	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.14	Leakage	Leakage	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2016																								
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1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	124.80	85.24	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	95.21	109.52	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.95	-	31.83	21.49	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.29	4.25	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	74.05	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36.06	49.12	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58.79	12.54	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.54	6.29	33.77	15.06	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.02	4.95	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.29	5.06	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.29	16.9	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	61.4	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1081.36	279.46	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.93	16.37	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21.27	42.32	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24.91	15.72	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	354.89	6.02	4.15	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	455.47	259.97	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51.33	29.87	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.34	6.29	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.02	5.07	-	-	-	-	-	-	-	-

Date	January		February		March		April		May		June		July		August		September		October		November		December	
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.95	4.25	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.41	5.18	124.80	85.24	-	-	-	-	-	-
2017																								
	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630	0830	1630
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	124.80	85.24	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	95.21	109.52	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.95	-	31.83	21.49	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.29	4.25	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	74.05	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36.06	49.12	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58.79	12.54	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.54	6.29	33.77	15.06	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.02	4.95	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.29	5.06	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.29	16.9	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	61.4	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1081.36	279.46	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.93	16.37	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21.27	42.32	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24.91	15.72	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	354.89	6.02	4.15	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	455.47	259.97	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51.33	29.87	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.34	6.29	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.02	5.07	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.95	4.25	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.41	5.18	124.80	85.24	-	-	-	-	-	-

Note:
The discharge is being measured by way of float and sounding system.
R.L. 267.60 m

Notes