

CHAPTER - 1

INTRODUCTION

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1.1 General

Water is referred to as the elixir of life in ancient Indian scriptures. It is also described as the life-giving force, protector of environment and earth, nectar, honey, generator of prosperity, sin-cleanser and element that governs the evolution and operation of universe (Manasi S. and Konduru R., 2012). It is ubiquitous and renewable, yet a finite resource with global importance, and is the primary need of all biota. Despite being renewable, many regions on this planet faces severe water scarcity. Globally, one third portion of the planet is occupied by water, however, 97.5 percent of it is saline, while only 2.5 percent exists as fresh water (Te Chow V., 1988). This 2.5 percent fresh water exists as solid and locked in glaciers & ice-caps; as liquid in streams, lakes and sub-surface interstices; and as gas in atmosphere. The maximum volume of fresh water (1.725%) is locked in the polar and non-polar glaciers and ice-caps. It is followed by groundwater (0.76 %), lakes (0.007 %), soil moisture (0.0012%), atmospheric water (0.001%), marshes (0.0008%), rivers (0.0002%) and biological water (0.0001%) (Te Chow V., 1988). Thus, hardly 1% of the fresh water resource is available for utilization. These statistics are a testimony to the classical quote of Edward Keller “the earth is the only suitable habitat we have and its resources are limited (Keller, 2007)”. Therefore, it is of utmost importance to formulate and implement efficient water resource development plan for its sustainability.

India is domicile to 17.7% world’s population, holds only 2.5% of global landmass and only 4% of global freshwater resources (CWC, 2019). Unprecedented population growth, irrigation practices, socio-economic activities and developmental projects have led to increased water demand relative to the existing resources. This escalating water demand has been met with over- exploitation of groundwater (Singh and Singh, 2002, Shankar et al., 2011, Dongare et al., 2022). The impact on the resource is clearly reflected in the declining trend of water tables and early drying of the groundwater structures during summers in various parts of country (Reddy, 1989, Panda et al., 2012, Nath et al., 2021). This condition gives rise to severe domestic water problem and causes discomfort to the population.

1.2 Groundwater in soft and hard rock terrains

Indian sub-continent with a varied geological and geomorphological set-up is characterized by soft and hard rock formations. The areas with soft rock aquifers are categorized as unconsolidated and semi-consolidate sedimentaries (Saha and Ray, 2019); characterized by preponderance of inherent porosity and permeability. Primarily, the inherent porosity and permeability governs the accumulation, movement, distribution and occurrence of groundwater. The storage coefficients and transmissivity of unconfined soft rock aquifers may vary from 5% to 25% and 1000 to 5000 m²/day respectively (Saha et al., 2010 and CGWB, 2012). While, the transmissivity of deeper confined soft rock aquifers may reach upto 12000 m²/day (Saha, 2010). The yield of soft rock aquifers may range from 14 litres per second (lps) to 70 lps. Comparatively, the groundwater occurrence in hard rock terrains comprising of granite, quartzite, gneiss, charnockite, khondalite, basalts and intrusives is poor due to lack of primary porosity and permeability. The transmissivity of these aquifers remains within 100 m²/day and rarely reach above 600 m²/day (Saha and Ray, 2019). Although, the hard rock aquifers have poor groundwater potential than soft rock aquifers, they show a wider aerial distribution and are the major source of freshwater in India. The groundwater occurrences in the hard rocks are rendered by secondary porosity and permeability induced by weathered horizons, regolith, joints and fractures, veins, lithological contacts (Chandra, 2018, Deota et al., 2005, Sarkar et al., 2001).

1.3 Groundwater in the Deccan Trap Province (DTP)

Amongst the hard rocks, the basalts and intrusives dominate in the country with total spread of 5, 12, 302 km² (CGWB, 2012, Chandra, 2018,). Around 5, 00, 000 km² of its total spread is part of Deccan Trap Province (DTP) in west-central India i.e. in Maharashtra, Gujarat and Madhya-Pradesh (Krishnan, 1982, Medlicott et al., 1987, Powar, 1987) (figure 1.1).

The Deccan basalts are volcanic igneous rocks with a number of individual lava flows ranging from few meters to hundreds of meters in thickness (Kulkarni et al., 2000). The groundwater occurrences in Deccan basalts differ from that in other hard rock terrains. Hydrogeologically, the Deccan basalts have been viewed as low-permeability rocks, but the difficulty in finding groundwater in the basalts has been attributed to their high degree of inhomogeneity (Kulkarni et al., 1994, 2000). In phreatic and semi-

confined conditions, the groundwater is found in weathered horizons, fractures, fissures, joints and junctions of lava flow (Deolankar, 1980 and Limaye, 2010). A significant feature of DTP aquifers is that the topographic divide generally matches with the groundwater basin, which restricts groundwater transfer within incarcerares (Limaye, 2010). Groundwater tends to accumulate towards the valley centre of main stream as well as tributary streams in consensus with terrain characteristics. Considering this characteristic, researchers have intensively assessed the terrain characteristics for groundwater exploration, development and management in basaltic aquifers of Maharashtra and Madhya-Pradesh (Sinha et al., 2012, Gupta et al., 2015, Tribhuvan, 2016, Banerjee et al., 2017, Bera, 2020, Berhanu, 2020, Pande, 2020, Ahirwar et al., 2021, Sahu et al., 2022). The assessments aimed to explore groundwater potential and address the year around sustainability of the resource. However, apropos basaltic aquifer system of Gujarat state, the systematic evaluation of groundwater controlling parameters for exploration and sustainable resource management is lacking.

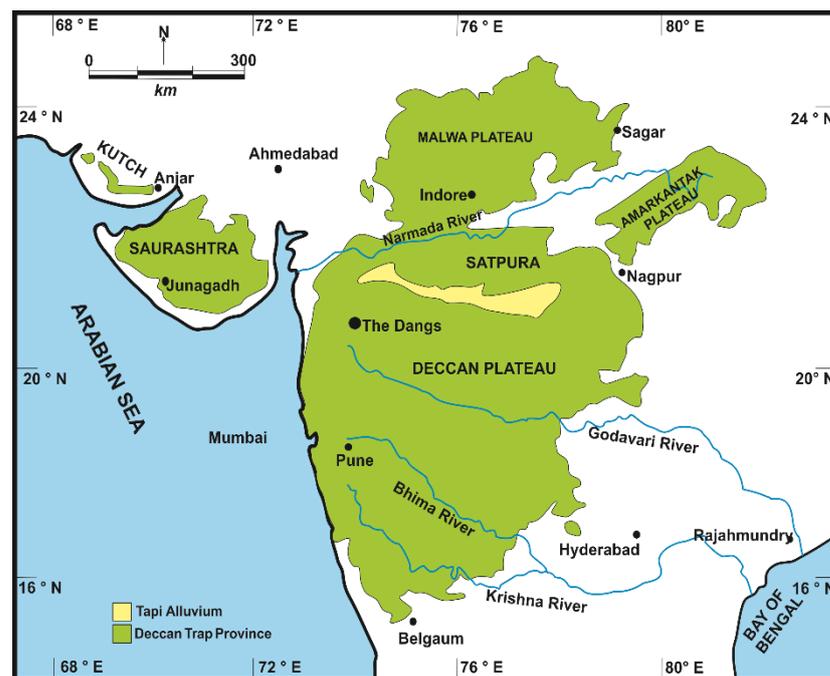


Figure 1.1 Spatial distribution of Deccan Trap Province in west-central India (Modified, after Deshmukh 1988).

1.4 Groundwater in Deccan Trap Province (DTP) of Gujarat

The aerial extent of Gujarat state is 1,96,024 km², of which around 50 % is occupied by hard rocks having major rock type as basalt (31%) belonging to DTP (Chandra, 2018). These Deccan basalts are exposed in all three physiographic divisions

of Gujarat viz. (i) Kachchh (ii) Saurashtra (iii) Mainland Gujarat and constitute the basaltic aquifer system of the state (figure 1.2).

In the Kachchh rift basin the DTP forms a continuous narrow linear outcrop extending from Anjar in east to Matano Madh in northwest. The groundwater occurrence in the region is restricted to weathered mantle and along interflow zones, joints and fissures with meagre groundwater development. The range of depth of dug wells varies from 11 to 15 m with depth to water levels varying between 5 to 9 m below ground level (bgl). Moreover, high salinity in groundwater occurs particularly in western and central areas due to sea water ingress (CGWB, 2013a).

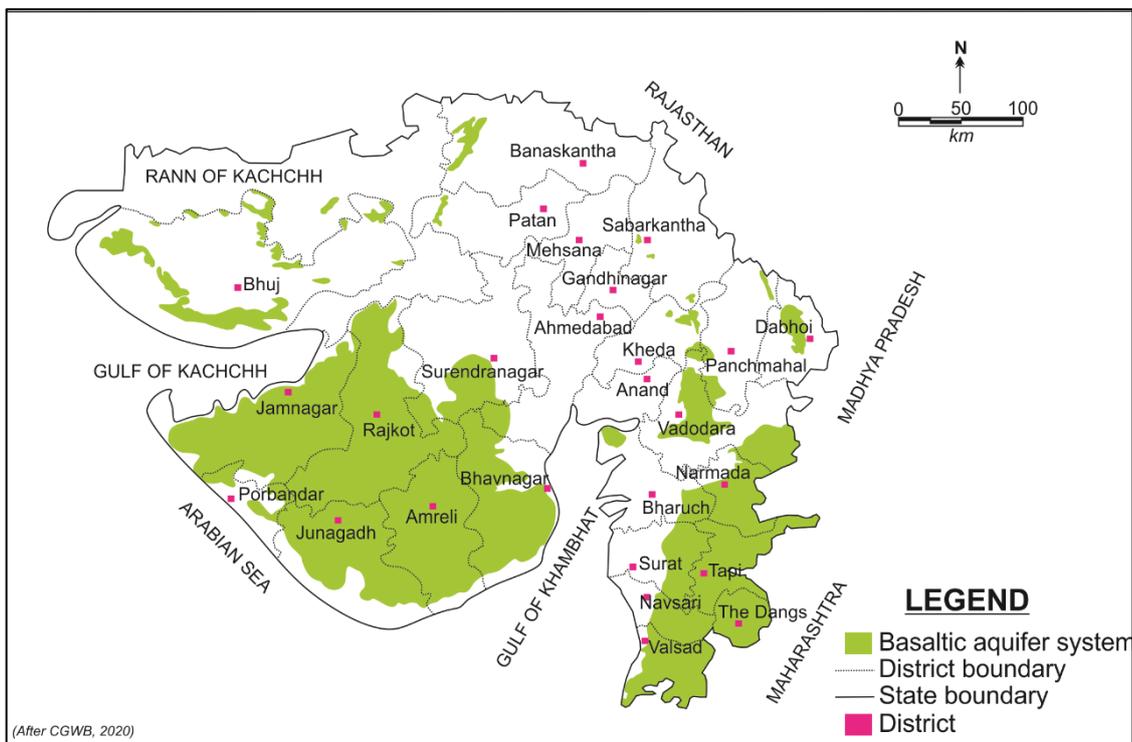


Figure 1.2 Basaltic aquifer system of Gujarat (after CGWB, 2020).

The DTP in Saurashtra covers the peninsula except along its fringes, where rocks of Mesozoic & Tertiary age and Quaternary sediments are exposed (Merh, 1995). The Deccan basalts form the major aquifer system in Rajkot, Amreli, Junagadh, Jamnagar, Bhavnagar and Surendranagar districts. The groundwater is mainly in phreatic to confined conditions (CGWB, 2013b). The basalts form a poor aquifer system due to compactness and negligible primary porosity. However, the upper weathered parts, which at places are up to 20 m thick, form good aquifer systems. At deeper levels, the secondary porosity developed because of tectonic activities, in the form of joints,

fractures and shear zones form good groundwater repository at many locations (CGWB, 2013b). The dykes particularly in the southern part, influence the occurrence and movement of groundwater. The dykes with high degree of weathering, form potential aquifers or serve as carrier dyke for groundwater. While, the compact dykes act as subsurface barrier for the groundwater flow, due to which the groundwater structures only on the particular side of these dykes possess good to excellent yields (CGWB, 2013b). The groundwater in this region is generally tapped through dug wells varying in depth from 10 to 50 m. At places, dug-cum-bored wells are also constructed below the bottom of dug wells. The dug and dug-cum-bored wells yield is limited to 100 m³/day (CGWB, 2013).

The Deccan basalt in mainland Gujarat, towards north occur as outliers in Dahod, inliers in Vadodara, Panchmahal and Sabarkantha districts and volcanic rock suit around Pavagadh hill. Whereas towards south, the basalts occur as trappean rocks of Vadodara district between Unch and Narmada River in east and the uplands and highlands of Narmada, Tapi, Valsad and Dangs district (Merh, 1995).

Groundwater in Panchmahals district occurs in trappean and intertrappean rocks which forms unconfined and confined aquifers (CGWB, 2014a). In trappean rocks, groundwater is rendered by the weathered mantle, joints, fractures and interflow zones. While, granular sediments of intertrappean rocks locally give rise to good aquifers system. The vesicular basalts here possess the primary porosity, but are not permeable due to lack of vesicle interconnection (CGWB, 2014a). However, the joints and fractures aid in connecting the vesicles and thus give rise to more permeable aquifer. The overall depth to water level ranges from 4 to 12 m bgl (CGWB, 2014a). In case of Narmada district, the individual flows of DTP comprise of two distinct units, viz., upper vesicular basalt and lower massive basalt. The latter is hard and compact with no inherent porosity and permeability while the former exhibits porosity due to vesicles. The groundwater flow is governed by secondary porosity induced by joints and fractures. The depth to water level here varies from 5 to 25 m bgl (CGWB, 2014b). In the southern Sabarkantha district, groundwater occurs in weathered portion, fissures and joints of the unconfined aquifers of basalts. The water table in traps is deeper (20 to 40 m) and the depths of dug wells and dug-cum-borewells extends 30 and 60 m bgl (CGWB, 2014c).

The district Dangs marks the southernmost boundary of mainland Gujarat. It is completely characterized by basalts of DTP which constitutes the major aquifer system. Groundwater in Dangs is under water table conditions in weathered, jointed, fractured and vesicular horizons in traps. The depth of open wells ranges from 18 to 20 m with water levels ranging from 2 to 12 m bgl (CGWB, 2014d). In the adjacent district Valsad, the groundwater occurs in phreatic and in confined conditions in fissured formations. The groundwater level ranges from 3 m to 9 m bgl (CGWB, 2014d).

Amongst the aforementioned regions with basaltic aquifer systems, specifically the district Dangs has atypical water scarcity. District Dangs is endowed with 2000 mm average annual rainfall received mostly in just the four months of summer monsoon. The surface water resources almost go extinct and the region reels under water scarcity with scorching summer heat during non-rainy period. Moreover, the Dang is the tribal district of Gujarat and the livelihood largely depends on agriculture, because of which groundwater holds the utmost importance and hence year around groundwater sustainability is expected. However, the area faces acute shortage of water resources and the population has to walk miles to collect water from wells. The overall trend of groundwater level is declining on account of excess exploitation for irrigation purposes, due to which groundwater development falls under semi-critical category (GWRDC 2006, Dabral, 2009). Over the years, several efforts for developing surface and groundwater resources in the district by non-government organizations (NGOs) are still not able to ease the agony satisfactorily. The frequent failures of biasedly built groundwater structures (either proximal to residences of higher officials or with view to spendthrift the grants), silted check-dams/percolation tanks and their position clearly depict that groundwater controlling parameters are overlooked. Thus, it will not be an exaggeration to say that, proper knowledge of geo-environmental parameters (GEPs) (geology, geomorphology, lineament, slope, drainage, land use and soil) governing groundwater occurrence and its sustainability is lacking in the region. This knowledge gap is the base for the present work on the systematic evaluation of GEPs for exploration and proposing sustainability measures in basaltic aquifer system of district Dangs, Gujarat.



Figure 1.3 *Hardworking homemakers bringing water from a well located around 2 km away from their residence, village Chankhal and Temburgartha, Dangs.*

1.5 Problem statement

The district Dangs marks the extension of Western Ghats in Gujarat state, western India. It is characterized by uniformly spread less transmissible basaltic rocks, rugged trappean highlands and moderate to very steeply sloping surfaces. These critical terrain conditions give rise to higher runoff than infiltration, leading to water crisis during non-rainy period. The occurrence, distribution, recharge and quality of groundwater is dependent on variations in spatial distribution of vivid GEPs such as geology, drainage, geomorphology, slope, lineaments, soil and land-use and thus requires in-depth understanding. In case of Dangs district, no systematic work, except the regional scale studies of National Remote Sensing Centre (NRSC) on groundwater prospects under Rajiv Gandhi National Drinking Water Mission (2015) exists. The groundwater structures in the region have failed due to lack of watershed-based assessments of GEPs. Watershed based assessments are opportune for evaluating the hydrological processes as it coincides with the boundary of groundwater basin and thereby influence the groundwater potential (Limaye, 2010). Khapri watershed cover the maximum area of district Dangs and experiences acute shortage of groundwater as compared to other regions of the district. *Hence, the present study focuses on assessment of GEPs for determining the sustainable groundwater potential zones through remote*

sensing and GIS, recharge patterns through stable isotope tracer technique and status of groundwater quality in the Khapri watershed.

1.6 Objectives

In the light of afore discussed research gaps, the objectives of the present study are:

- 1) Identification and demarcation of the groundwater potential zones in the Khapri watershed.
- 2) Assessment of groundwater quality and its suitability for drinking and irrigation purposes.
- 3) To decipher the groundwater recharge patterns and suggest suitable locations for the groundwater recharge structures.

1.7 Methodology

Outline of the methodology adopted to achieve the aforesaid objectives is represented in flow chart (figure 1.4 and 1.5), while the detailed methodology is discussed in chapters to follow. As shown in the flow chart, the study involved three components viz. literature survey, field studies and lab studies.

- Extensive review of scientific literature pertaining to the study area was carried out for identification of research gaps, understand the physiographic, geological and climatic setup, natural resources, demographic profile and selection of suitable approach to address the research gap.
- Collection and analysis of Survey of India (SOI) topographic maps, remote sensing and ancillary data to generate thematic maps of identified geo-environmental parameters controlling the groundwater occurrences and accumulation (Geology, Drainage, Geomorphology, Slope, Lineaments, Land-use, Soil, Rainfall) at 1:50000 scale in Arc GIS 10.4.
- Drainage morphometric analysis with view to understand the hydrological setup of the study area.
- Fieldwork for ground truth verification and preparation of well inventory to monitor seasonal groundwater levels, sample collection for groundwater quality during pre-(2022 and 2023) and post-monsoon seasons (2021 and 2022).
- Application of Weighted Overlay Analysis (WOA) and multi-criteria decision method (MCDM) – Analytical Hierarchical Process (AHP) in Arc GIS 10.4 for

identification of the groundwater potential zones and their validation with the field data.

- Hydro-chemical characterisation of groundwater samples through Indian Standard (IS) techniques.
- Application of GIS techniques to map the spatial distribution of groundwater physicochemical characteristics and determine its suitability for drinking and irrigational purposes.
- Isotope Ratio Mass Spectrometry (IRMS) studies for isotope systematics of collected water samples.
- Comprehensive assessment of all geo-environmental parameters in GIS to recommend location specific recharge structures, to ensure sustainability of the groundwater resource.

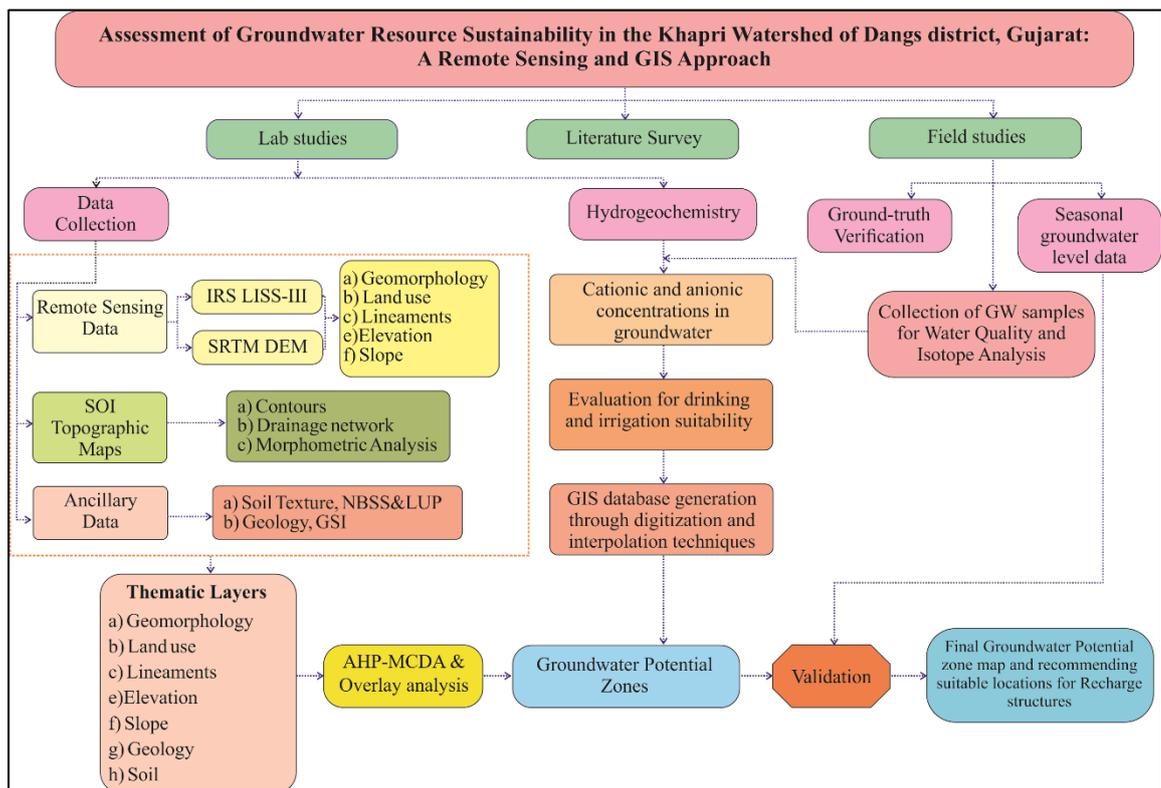


Figure 1.4 Work flow of the present study.

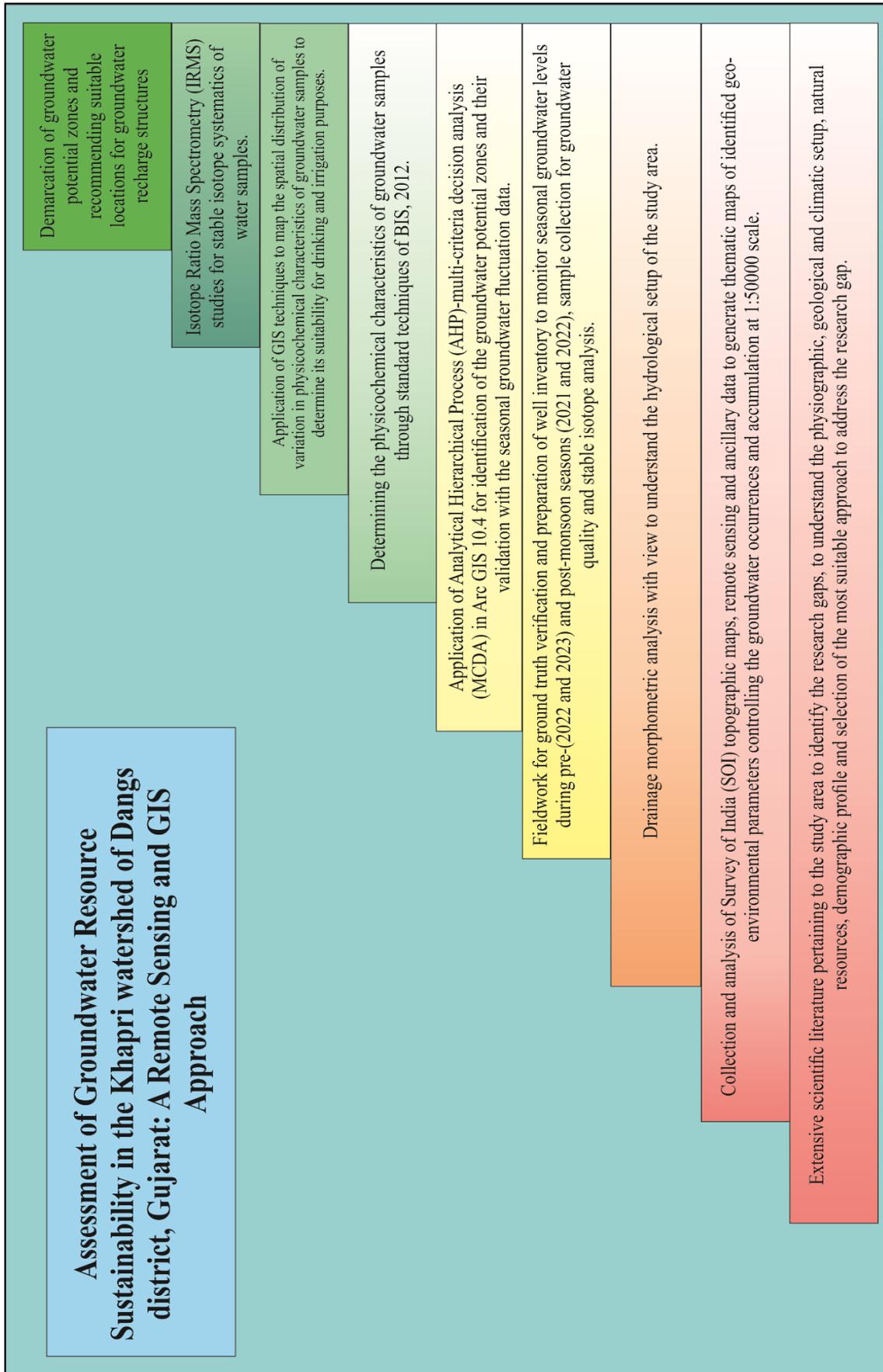


Figure 1.5 Generalized methodology.

1.8 Study area

1.8.1. Location and extent

The Dangs district marks the southernmost part of trappean highlands of mainland Gujarat (figure 1.2). It is drained by four important rivers viz. Ambica, Purna and their major ephemeral tributaries Khapri and Gira respectively. Present study focuses on the river Khapri which originates near village Vanar on the western slope of trappean highlands and drains almost the central portion of the district covering Ahwa and Waghai Talukas. To the south it is bounded by river Ambica and to the north by river Purna. The longest stretch of river Khapri lies in NW direction and continues its journey through villages viz., Galkund, Anjankund, Umbarpada, Tembrungartha, Ahwa, Khapri, Kutarnachiya, Dhulchond, Pimpri, Bhawadi, Kudkas, Dabdar and finally meets to river Ambica near village Vati. The prominent high standing trappean flows marks the watershed divides with an elevation varying from 86 m amsl at the confluence of river Ambica and Khapri near village Vati to 1083 m amsl near Saputara hill station (figure 1.7). The Khapri watershed is located between $73^{\circ} 27' 12.42''$ E and $73^{\circ} 50' 13.53''$ E longitude and $20^{\circ} 53' 27.52''$ N and $20^{\circ} 35' 6.91''$ N latitude (figure 1.6) of Survey of India (SOI) topographic maps 46H/5, 46H/9, 46H/10, 46H/13, 46H/14 and covers the aerial extent of 523 km².

1.8.2. Communication

The study area is well connected by road network and partially by rail network (meter gauge) from Billimora, Navsari district up-to village Dungarda. The nearest airport is Surat International Airport, situated at distance of 141 km from the district centre and head quarter, Ahwa. National Highway (NH) 350 passes through the Waghai block of the district. The Gujarat State Highway (SH) 14 connects Ahwa to NH 350. The villages of the district are well connected to each other and towns through internal good metalled roads and state highways.

1.8.3. Topography

The topography of Khapri watershed is rugged in nature, such that it rises to several hundred meters above mean sea level (m amsl). The overall elevation ranges from 86 m amsl in north-western end to 1083 m amsl in south eastern end (figure 1.7). Numerous tributary streams cut deeply into the basalt and join the Khapri River. In general, the slope of Khapri watershed is towards northwest direction. The summits of east-west trending sub-parallel ridges are made up of serrated tops of conical or rounded

hills, or linear stretches of elongated rectangular, square and triangulated hills. The Ahwa plateau marks the central portion of the Khapri watershed (figure 1.7). To the south of Ahwa plateau Khapri River continues its course through village Pimpri. The north, east and west sides of Ahwa plateau are bounded by hills and dense forests. Towards Saputara from the Ahwa plateau, there is presence of high hills forming part of eastern highland belt. This eastern highland belt attains semi-circular shape in the south-eastern part of the watershed and shares boundary with Maharashtra. Towards Waghai from the Ahwa plateau, the region is identified as pediment plateau, because on one side it is flanked by high mountains and other side it faces the plains of south Gujarat.

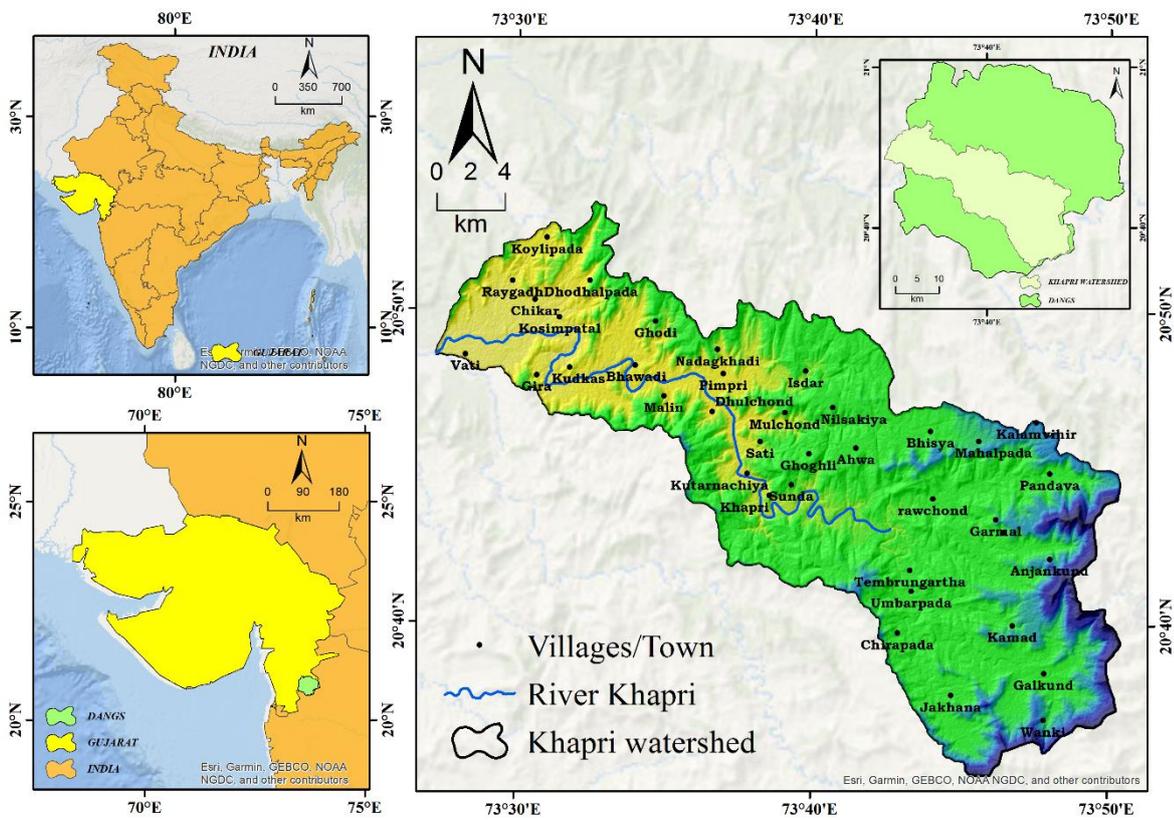


Figure 1.6 Location map of the Khapri watershed.

1.8.4. Climate

Climate plays a significant role in governing the landscape and natural resources of any region. It has a decisive effect on the different aspects of any area such as cropping pattern, floral and faunal distribution and water resources. The Khapri watershed enjoys the sub-humid climate with four seasons viz. the summer from March-May; monsoon from June-September, while months of October-November are regarded as post-monsoon and December to February as the winter season. It receives highest

average annual rainfall (2000 mm) in the entire state, which decreases from west to east. The precipitation predominantly occurs during south-west monsoon months, marking July as the rainiest months. Sporadic showers may prevail during the October-January months. The eastern winds prevail during the cold seasons, while south-west winds for the rest of the year. The temperature begins to rise from latter half of the February. Month of May turns to be the hottest month with average daily maximum temperature of about 40° C and the average daily minimum is about 26° C. The summer heats are intense on some days and could reach up-to 44° C. The relative humidity is as low as 30 percent during summer season to about 70 percent during monsoon season (Gujarat State Gazetteer: Dangs District 1971).

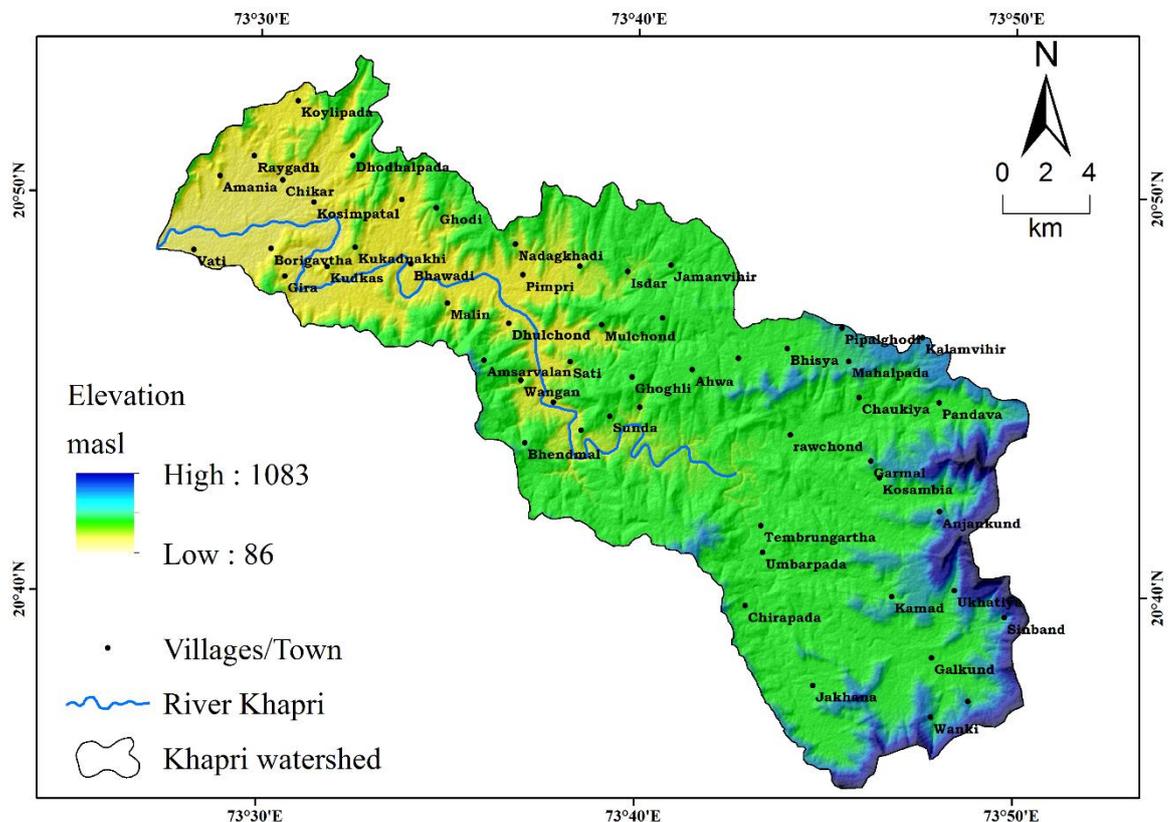


Figure 1.7 Digital Elevation Model of the Khapri watershed.

1.8.5. Flora and fauna

The forest of Dangs falls in 'south Indian moist deciduous forests' sub-group and are further classified as 'moist teak forest' (Champion and Seth, 1968). As per the holistic classification of Puri et al. (1983), the forests are categorized as deciduous teak forest of intermediate type falling between dry and moist categories. These are also referred to as Tectona-Terminalia-Adina-Anogeissus series and are found in Valsad,

Nasik and Thane districts and Nagar-Haveli. The occurrences of *Tectona grandis* (Teak) are ubiquitous in the study area. Jain (1963), Shah and Yadav (1979) and Shah et al. (1981) identified these forests as the richest in Gujarat and house abundant economically and medicinally important species such as Khakro (*Butea monosperma*), Sadad (*Terminalia crenulata*), Umbero (*Ficus racemosa*), Khair (*Acacia catechu*), Rayan (*Manilkera hexandra*), Mardasingi (*Helicteres ixora*) & bamboo and Baheda (*Tecoma stans microcarpa*) respectively. The fauna of Dangs is more or less similar to that found in northern Western Ghats. The pristine forest cover is a suitable habitat to wild animals due to availability of food and water. However, many mammal species are very sensitive to the civic disturbances due to which some are already extinct or are found in low numbers. The significant fauna found in the forests of Dangs are sambar, hyena, chital, monkey and barking deer.