

CHAPTER - 4

HYDROGEOMORPHOLOGY OF THE KHAPRI WATERSHED

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4.1 Introduction

Hydrogeomorphology¹ is an interdisciplinary science that shows the connection between two significant branches of geology viz. hydrology and geomorphology. It is a combination of three terms viz., *hydro* – refers to surface and groundwater, *geo* – refers to earth and *morphology* – refers to surface characteristics of earth. Scheidegger (1973) first defined it as, “the study of landforms formed by the action of water”. Later with subsequent (Tsukamoto, 1981, Tsukamoto et al., 1982, Tsukamoto and Ohta, 1988, Terajima and Moroto, 1990, Onda, 1992, 1994, Tsuboyama et al., 2000) as well as earlier significant contributions (Hack and Goodlett, 1960, Leopold and Langbein, 1962, Kirkby and Chorley, 1967, Hewlett and Hibbert, 1967, Carson and Petley, 1970, Dunne and Black, 1970), the term has been formally defined as “an interdisciplinary science that focuses on the association of hydrologic processes and landforms or earth materials and the interaction of geomorphic processes with surface and subsurface water in temporal and spatial dimensions” (Sidle and Onda, 2004). The identification, demarcation, and evaluation of hydrogeomorphic features are useful for planning and management of vivid natural resources (Scheidegger, 1972, Sidle and Onda, 2004, Teixeira et al., 2013).

Hydrogeologists have long recognized the importance of hydrogeomorphology in groundwater exploration (Chatterji et al., 1978, Rao, 1978, Roy, 1978, Moore and Dakota, 1979, Bhattacharya and Mankhand, 1979, Chatterji and Singh, 1980, Sahai et al., 1993, Sahai, 1993, Tiwari and Rai, 1996, Shah, 2001, Rathore, 2005, Nag, 2008, Dar et al., 2010), based on the premise that geomorphology allows to characterize and analyse the environmental conditions that controls the water circulation (Verstappen, 1983). The hydrogeomorphological maps represent geomorphic features, drainage characteristics and information on underlying geology to understand its control on water circulation vis-a-vis groundwater occurrence and prospects. Remote sensing data and GIS techniques have offered a powerful means to generate reliable hydrogeomorphological maps for targeting groundwater. These maps when aided by field observations play a decisive role in groundwater exploration in alluvial as well as

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hard rock hydrogeological systems having complex geological and morphological framework (Chatterji et al., 1978, Teixeira et al., 2013).

Roy, (1978) highlighted the importance of LANDSAT image interpretation in small scale hydromorphic mapping for groundwater studies by citing examples from north and Central India. He identified hydrogeomorphic units such as structural and denudational hills, piedmont hill zones, piedmont fan plain, older alluvial plain, younger alluvial plain, intermontane valley, alluvial fans and fan cut-terraces on the basis of image interpretation and utilized it for groundwater exploration.

Sahai et al., (1993) carried out hydrogeomorphological mapping at 1:50000 scale in aeolian landscapes of Jaisalmer and Bikaner districts of Rajasthan using IRS LISS-II and SPOT imagery. The authors discussed the observations made on geomorphic units having significant groundwater prospects such as paleo-channels, valley fills, alluvial plain, buried pediment etc. The workers found that the hydrogeomorphological maps are useful tools for groundwater exploration in desert environment.

Tiwari and Rai, (1996) interpreted Landsat-5 MSS to differentiate varied hydrogeomorphological units and map the trends of lineaments for evaluating groundwater prospective zones in Dhanbad district, Bihar. The vivid geomorphic features demarcated are linear ridges, residual hills, pediplain, buried pediment, dissected pediplain as well as lineaments. The work showed that the pediplain and buried pediments are excellently promising areas for groundwater occurrence.

Das et al., (1997) highlighted the importance of hydrogeomorphological mapping from remotely sensed data in groundwater exploration in the geologically and structurally complex terrain of Keonjhar district, Orissa. Authors used various space borne and airborne data to demarcate various geomorphic features such as flood plain, valley fills, alluvial plain, piedmont plain, lateritic upland etc. and performed qualitative evaluation of groundwater resources. Moreover, the authors carried out resistivity sounding and exploratory drilling, which supported their results on groundwater resource availability in the region.

Raju and Reddy, (1998) showed that groundwater occurrences in hard rock terrain is mainly confined to secondary porosity developed because of joints and fractures. To understand the significance of the fracture pattern the authors made use of

geological, hydrogeomorphological and lineament maps prepared using LANDSAT TM remote sensing data and GIS techniques. The authors concluded that the groundwater potential zones are highly correlated with piedmont plain having high overburden alluvium thickness as well as high lineament density zones.

Sreedevi et al., (2001) studied hydrogeomorphology and lineaments through visual image interpretation of IRS 1B LISS-II satellite data in the Pageru river basin, Cuddapah district, Andhra Pradesh. The authors demarcated various hydrogeomorphic units such as valley fills, floodplains, pediments, shallow buried plain, moderately buried pediplain, mesa, butte, linear ridges etc. and lineaments as well as lineament density through satellite data. The various geomorphic units are characterized as favourable, moderately favourable and poor for groundwater occurrences. The authors concluded that the hydrogeomorphology and lineament architecture of the study area strongly controls the shallow groundwater occurrences.

Bahuguna et al., (2003) investigated the influence of landforms and lineaments on assessment of groundwater availability in Deccan traps of Madhya Pradesh. The authors described the usefulness of IRS LISS-II data for hydrogeomorphological mapping, zoning of the area into different groundwater prospects and evaluation of zones through discharge data of groundwater structures in the study area. The authors concluded that the fractured and weathered rocks are highly productive in terms of groundwater discharge. Moreover, the study showed that the better groundwater prospects are limited to lower elevation zones of micro-watersheds in the region.

Rathore, (2005) discussed about the groundwater exploration and efforts for the resource augmentation in Rajasthan. The author stated that development and recharge of aquifers is controlled by the geomorphic characteristics such as slope, drainage pattern and nature of thickness of unconsolidated and semi-consolidated layers on the basement rock of the terrain. According to the author, hydrogeological properties of non-hard rock areas are strongly dependent on the geomorphic properties of the terrain. Moreover, geomorphic features can be identified through visual interpretation techniques of remote sensing data and ground truth verification, it is possible to identify potential aquifers and narrow down the areas suitable for groundwater recharge.

Nag, (2008) applied integrated approach to assess the groundwater potential zones by considering various thematic layers of lithology, hydrogeomorphology and

lineament prepared using remote sensing and GIS techniques. The author opined that groundwater resource in any terrain is affected by the factors such as climate, physiography, drainage, geological setup and hydrogeomorphological maps provides a better understanding for watershed management, and are useful for groundwater exploration. Moreover, the analysis of remotely sensed data in conjunction with SOI topographical map, secondary information and ground-truth verification is useful in developing a baseline information for groundwater exploration in any terrain.

Dar et al., (2010), evaluated groundwater prospects of Kancheepuram district, Tamil Nadu essentially based on the hydrogeomorphology. The authors emphasized the role hydrogeomorphological units mapped from IRS P6 LISS-III data in groundwater storage. The authors concluded that study area exhibits varied hydrogeomorphological environment where the groundwater regime is dependent on geology and topography.

Nag and Ghosh, (2013), demarcated groundwater potential zones with an aim towards proper management of groundwater resources for sustainable use hydrologically complex terrain of Chhatna block, Bankura district, West Bengal. The authors analysed the influence of hydrogeomorphology, slope, and lineaments on groundwater occurrences by using remote sensing and GIS techniques. IRS–LISS-III satellite data and DEM with collateral data sets such as topographic maps and field data have been used to obtain information on the hydrogeomorphic features viz., valley fills, buried pediment moderate, buried pediment shallow and structural hills, lineament density and slope. The study provided promising results on groundwater prospects of the area.

Khadri and Pande, (2015), investigated the hydrogeomorphology of Mahesh river basin in Akola and Buldhana districts of Maharashtra for groundwater assessment and management. The hydrogeomorphological map prepared using IRS LISS-III satellite data helped authors to assess the groundwater prospects zones in the Mahesh river basin. The authors concluded that among the various hydrogeomorphic units the slightly dissected and moderately dissected plateaus are the better areas for groundwater exploration as well as for the construction of groundwater recharge structures.

Roy et al., (2020), performed a groundwater potential assessment at micro-level in drought prone area of West Bengal, India. To assess the groundwater potential the authors considered parameters like hydro-geomorphology, slope, lineament, drainage density, land use/land cover and fractional impervious surface. The authors compared

their results with earlier studies in same area and concluded that their study addressed two aspects viz. (i) for groundwater potential mapping drainage density, land use-land cover and fractional impervious surface are important to be considered and (ii) the accuracy of the map is substantiated by groundwater depth data.

The present chapter highlights, the hydrogeomorphic characteristics of landforms and slope of the Khapri watershed. The spatial distribution of geomorphic indicators is assessed to understand their control on occurrence, distribution and movement of the groundwater.

4.2 Datasets and methodology

Primary datasets such as Open Series Topographic Maps (OSM) from Survey of India (SOI) (1st edition, 2011), IRS – LISS III satellite data of May – 2019 from NRSC Bhuvan and Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM-2011) from USGS earth explorer are utilized to map hydrogeomorphology (table 4.1).

The individual OSM are geo-referenced following the World Geodetic System (WGS-1984) considering minimum 4 uniformly distributed Ground Control Points (GCP) in Arc GIS 10.4. The geo-referenced OSM are re-projected into Universal Transverse Mercator (UTM) projection, WGS 84, North Zone 43. False Colour Composite (FCC) of IRS LISS-III satellite data is prepared by combining Bands 432 (NIR, Red and Green). The mosaic of individual geo-coded OSM and FCC satellite data tiles is generated using mosaic tool. The mosaic is used for masking the extent of Khapri River watershed. The geomorphic features and slope have been mapped and evaluated for Khapri watershed. The geomorphological map has been prepared by considering the elements of visual image interpretation viz. tone, texture, shape, size and association, from IRS LISS-III FCC (B-432) data. From the geomorphological map the areal coverage of each landform is quantitatively estimated in GIS environment and is represented through pie diagram. The SRTM DEM (2011) is used to generate the slope map using slope tool (spatial analyst) of Arc GIS 10.4. The slope is further reclassified using reclassify tool on the basis of natural breaks in slope observed during ground truth verification (Dongare et al., 2022).

Table 4.1 Datasets used for mapping hydrogeomorphic indicators.

Sr. no.	Details of dataset	Source of dataset
1	SOI OSM 1:50,000 scale (46H/5, 46H/9, 46H/10, 46H/13 and 46H/14)	Survey of India Nakshe Portal (https://soinakshe.uk.gov.in/)
2	IRS – LISS III satellite data, 24 m resolution (May-2019)	bhuvan.nrsc.gov.in
3	SRTM 1 Arc-second Global DEM, 30 m resolution (2011)	https://earthexplorer.usgs.gov/

4.3 Hydrogeomorphic features of the Khapri watershed

The significant influence of landforms and slope characteristics on groundwater occurrence and distribution is highlighted in the following sub-sections.

4.3.1. Landforms

The Khapri watershed is characterized by unique assemblages of landforms having varying capacity of runoff-infiltration and thereby groundwater occurrence and distribution. In view of this, the geomorphic features of Khapri watershed have been identified (1:50,000) through visual image interpretation of IRS LISS-III FCC satellite data (B-432) (figure 4.1). SRTM DEM and google earth images are used as reference data to verify the demarcated geomorphic features. Overall, the Khapri watershed is characterized by nine landforms such as escarpments, highly dissected plateaus, moderately dissected plateaus, low dissected plateaus, planation surfaces, pediments, pediplains, alluvial plains and valley fill deposits from south-east to north-west directions (figure 4.2). The aerial coverage of these landforms is represented in the form of pie diagram (figure 4.3). The morphological character of landforms, its spatial distribution and the groundwater characteristics are highlighted in sub-sections to follow.

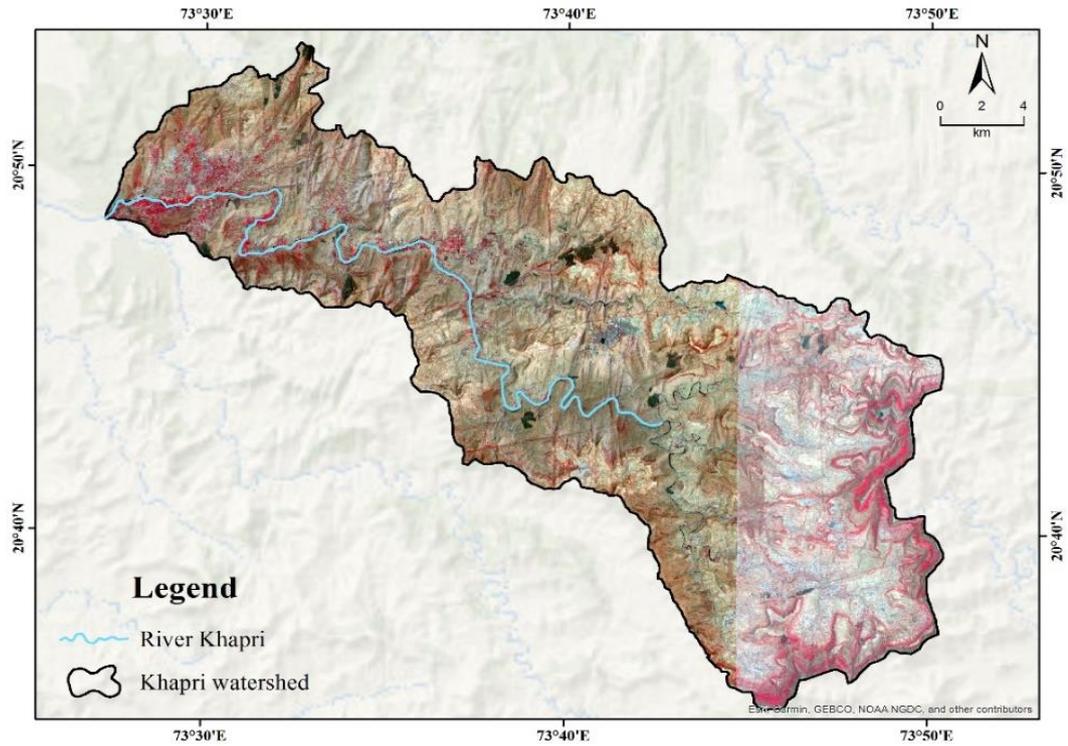


Figure 4.1 IRS LISS-III (May-2019) FCC image of Band-432 representing the extent of the Khapri watershed.

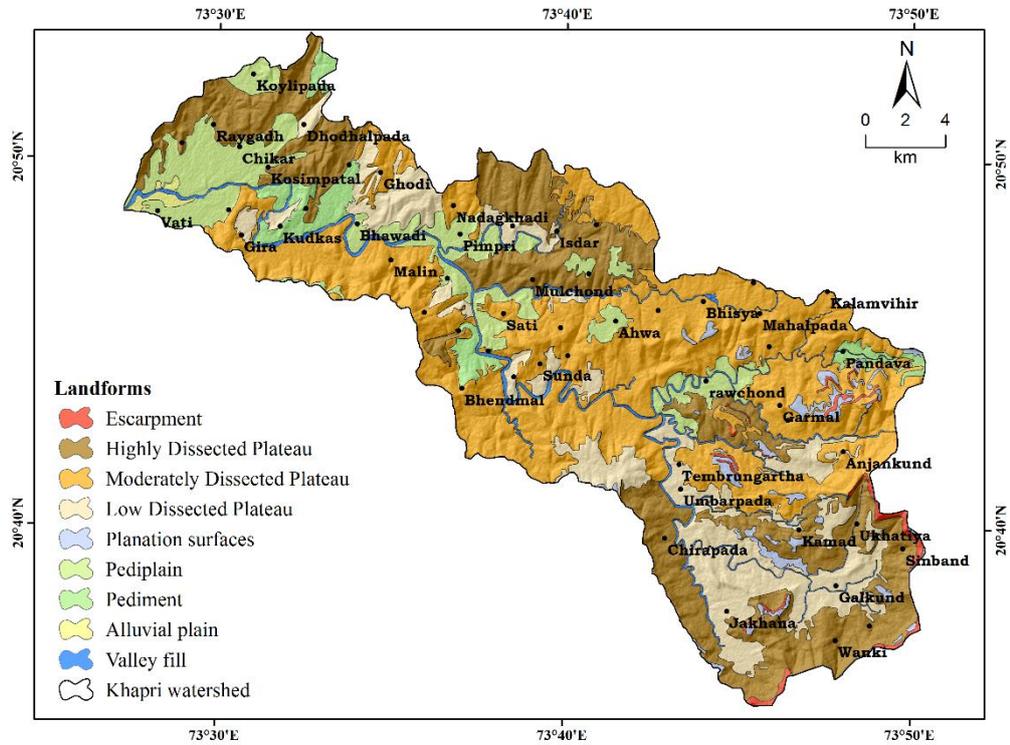


Figure 4.2 Geomorphological map representing the vivid landforms of the Khapri watershed.

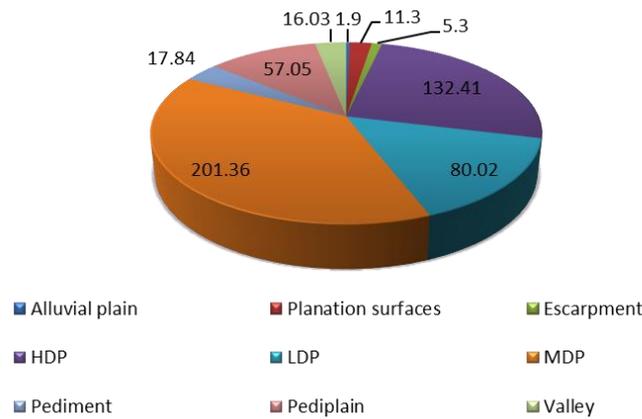


Figure 4.3 Pie-diagram representing the aerial coverage (km²) of the landforms.

4.3.1.1 Escarpments

The escarpments are near vertical or almost vertically sloping faces formed on account of erosion or faulting (Deota, 1992, Babar, 2005). According to Johnson (1939) “a young scarp is likely to be situated near the fault that produced it, but a mature or old fault scarp may have receded from its originating fault”. The later may be true in case of escarpments of Khapri watershed. However, much more detailed studies are required to determine the development of the escarpments. On IRS LISS-III FCC (B-432) satellite data, the escarpments exhibit dark grey to brown colour, rough texture and are more or less irregular to curvilinear in shape. During ground-truth verification, a nearly vertical cliff with exposed bare rock surface is observed with Deccan grass around the visible joints and fractures (figure 4.4). The total area occupied by escarpments in the Khapri watershed is around 5 km² (figure 4.3). The escarpments are mainly restricted to the upper reaches along the watershed divide and nearby areas (i.e., near village Javtala, Sinbandh, Ambalia, Kotamdar, Ukhatiya, Chinchpada and Bilmal) above elevation of 600 m with slope greater than 45°. The morphological characteristic of this landform makes it a heavy runoff zone leading to very poor to negligible groundwater potential. However, at the base where there is a break in slope, i.e., where the steep slope is followed by gentler slope, runoff from the vertically sloping faces accumulates at the base and hence increases the possibility of groundwater occurrence and recharge (Sarkar et al., 2001).



Figure 4.4 Escarpment near village Ukhatiya.

4.3.1.2 Highly dissected plateau

The basaltic flows of Deccan traps in the study area are horizontally disposed as plateaus. The formation of a dissected plateau typically begins either with the uplift of a landmass, which creates a large, elevated plain or plateau or by exogenous processes such as scarp retreat (Twidale, 1976), erosion by rivers and streams, which carve deep valleys and gorges into the landscape. In the present study, depending upon the severity of drainage dissection, the plateaus have been classified as highly dissected plateaus (HDP), moderately dissected plateaus (MDP) and low dissected plateaus (LDP). On IRS LISS-III FCC (B-432) satellite data, these are characterized by light reddish brown and faint reddish grey colour and moderate to rough texture due to numerous stream dissections. In the field, the HDP is characterized as highly rugged terrain with development of serrated margins, mesa and butte hills, deep valleys and steep slopes with presence of dense bushes, trees and Deccan grasses (figure 4.5). The total area occupied by HDP in Khapri watershed is 133 km² (figure 4.3). HDP mostly covers the south-western part of the Khapri watershed in the upper reaches, but few patches are also present in the middle reaches which inhabit villages such as Nilsakiya, Mulchond,

Chikatiya, Bhavandagadh, Gaurya, Isdar and in north-western part of lower reaches near villages such as Raygadh, Amania, Kosimpatal and Dhadhra. Dug wells in this geomorphic unit range from 8 to 20 m in depth, with water level varying from post-monsoon to pre-monsoon by 3 to 20 m below ground level. These regions indicate high runoff-zones due to the less transmissible nature of underlying rocks and high drainage density leading to fine drainage texture (Dongare et al., 2022). Hence, these areas generally have poor groundwater potential.



Figure 4.5 Highly dissected plateau near village Isdar.

4.3.1.3 Moderately dissected plateau

The moderately dissected plateaus (MDP) are characterized by moderate drainage densities, relatively shallow valleys separated by moderate slopes and less rugged topography compared to HDP. On IRS LISS-III FCC (B-432) satellite data, MDP is characterized by dark reddish-brown colour to faint reddish grey and moderate texture on account of stream dissections. The total area occupied by this landform in Khapri watershed is 201 km² (figure 4.3). During ground truth verification, it is found that the moderately dissected plateaus exhibit relatively less serrated ridges with wide spacing of drainages, shallow valleys accompanied by moderately steep slopes. It is covered by dense vegetation, bushes and Deccan grasses (figure 4.6). MDP mostly covers the middle reaches of the Khapri watershed and inhabits villages such as Mahalpada, Bhisya, Bhandmal, Songir, Kasavdahad and Ghoghli. However, significant patches of MDP are

also found covering villages such as Kosambiya, Garmal, Pandava, Chaukiya, Anjankund in upper reaches and Malin and Gira in lower reaches. Dug wells in this geomorphic unit range from 7 to 20 m in depth, with water level varying from post-monsoon to pre-monsoon by 1 to 16 m below ground level. Due to the inherent morphological characteristics, the landform indicates a moderate runoff zone and hence groundwater potential is characterized as good to moderate.

4.3.1.4 Low dissected plateau

The low dissected plateau (LDP) is characterized by moderate to low drainage densities, coarse drainage texture, gentle slopes, uniform topography and flat-topped ridges followed by shallow valleys (figure 4.7). On IRS LISS-III FCC (B-432) satellite data, LDP exhibits brownish red to bluish grey tone and mottled texture due to agriculture and mixed built-up land. The total area occupied by LDP in Khapri watershed is around 81 km² (figure 4.3). Ground-truth verification of LDP highlights the presence of gentle slopes, shallow valleys, less drainage dissections and exhibits agriculture as well as mixed built-up land-use. The LDP covers the upper reaches of the Khapri watershed and inhabits villages such as Galkund, Nirgudmal, Dhumkhal, Lahandabhas, Jakhana, Temburgartha and Wasurna. Few patches of LDP are also found in the middle reaches near villages Khapri, Kasavdahad, Sunda, Dhulchond, Gaurya and in lower reaches, village Kudkas, Kukadnakhi and Dhodhalpada. Dug wells in this geomorphic unit ranges from 10 to 20 m in depth, with water level varying from post-monsoon to pre-monsoon by 2 to 19.3 m below ground level. The morphological characteristics indicate low- to moderate runoff zone, suggesting increased possibility of infiltration and thereby groundwater occurrence and recharge. Overall, the groundwater potential of the landform is characterized as moderate.

4.3.1.5 Planation surfaces

The planation surfaces are defined as widespread and nearly level topographic surfaces having low slope gradient, with occasional residual relief (Goudie, 2004). Two or more planation surfaces may exist at different elevations giving a step-like appearance to the landscapes. The flat top surfaces of the linear ridges and plateaus in the Khapri watershed are marked as planation surfaces (figure 4.2). On IRS LISS-III FCC (B-432) satellite data, the planation surfaces exhibit mainly light grey to light brown colour due to sparse vegetation and settlements, medium texture and irregular shape.

These planation surfaces are seen to be covered by thin veneer of blackish brown coloured soil during ground-truth verification (figure 4.8). The total area occupied by planation surfaces in the Khapri watershed is around 10 km² (figure 4.3). It is mainly found in the upper reaches of Khapri watershed near villages Bhisya, Chaukiya, Morzira, Javtala, Garmal, Linga, Bimal, Lahancharya, Motacharya, Saputara, Pipalpada and Vanar. This geomorphic unit is characterized by dug wells ranging from 8 to 15 m in depth for drinking and subsistence farming purposes. The water level varies from post-monsoon to pre-monsoon as 4 to 12 meters below the ground level. The flat to very gentle slopes of this landform increase the time duration of surface contact of water and facilitate the groundwater recharge. The infiltration potential enhances wherever these planation surfaces are dissected by negative lineaments. Overall, this geomorphic unit is characterized by moderate groundwater potential.



Figure 4.6 Moderately dissected plateau as seen from Waghai-Ahwa state highway.



Figure 4.7 Low dissected plateau near village Jakhana.



Figure 4.8 Planation surfaces with sparse vegetation near Morzira.

4.3.1.6 Pediments

Pediments are defined as gentle to moderately sloping surfaces that develop at the base of mountains or the steep uplands and mainly consist of veneer of detrital material eroded from the surrounding (Gopinath and Seralathan, 2004). The gentle to moderate sloping surfaces of pediment and relatively permeable nature on account of detrital material makes them potential areas for groundwater recharge (Jawed and Wani, 2009). On IRS LISS-III FCC (B-432) satellite data, the pediments are characterized by light grey and red tones, medium texture, irregular shape and sharp contact with the adjacent plateau and hills. These units are consisting of weathered zones ranging from 5 to 8 m as observed from the length of lining in dug wells. The total area occupied by the pediments in the Khapri watershed is around 18 km² (figure 4.3). The pediments are mainly found along the villages Kudkas (figure 4.9), Chichinagavtha, Kutarnachiya and Pandava occurring as narrow strip adjacent to the plateau and hills. The dug-wells in this geomorphic unit range from 5.2 to 20 m in depth with water level varying from post-monsoon to pre-monsoon by 2.3 to 13.5 m below ground level. This geomorphic unit is characterized by good to moderate groundwater potential.

4.3.1.7 Pediplains

Pediplains are defined as gently sloping undulating surfaces with large aerial extent formed because of continuous process of weathering and coalescence of pediments (King, 1950, Spark, 1960, Agarwal and Garg, 2000). Pediplains are characterized by high porosity, permeability, and infiltration rate and hence the groundwater potential is very good (Babar, 2005, Shah, 2001). On IRS LISS – III FCC

(B-432) satellite data, the pediplains exhibit light grey and red tones, mottled texture, irregular shape and associated with river channel. During ground-truth verification, pediplains are characterized by flat to gentle slope, with extensive agriculture and mixed built-up land-use. These units are consisting of weathered zones ranging from 5 to 6 m as observed from the length of lining in dug wells and supports infiltration. The total area occupied by pediplains in the Khapri watershed is around 57 km² (figure 4.3). These pediplains are found near villages Borkhel (figure 4.10), Rawchond, Chaukiya, Mulchond, Sati, Halmudi, Aamonnia, Chikar and Ahwa town. The dug-wells in this geomorphic unit ranges from 8 to 20 m in depth with water level varying from post-monsoon to pre-monsoon by 1.6 to 6.3 m below ground level. Due to the inherent morphological characteristics, the groundwater potential of the landform is characterized as good.



Figure 4.9 Pediment near village Kudkas.



Figure 4.10 *Pediplain near village Borkhel.*

4.3.1.8 Alluvial plains

Alluvial plains are gently sloping depositional surfaces, formed by river and consist of unconsolidated sediments characterized by high primary porosity and permeability. On IRS LISS-III FCC (B-432) satellite data, it dominantly exhibits red tone and mottled texture due to extensive agricultural fields as observed during the ground-truth verification (figure 4.11). Total extent of alluvial plains in Khapri watershed is only about 2 km² (figure 4.3). The dug-wells in this geomorphic unit range from 8 to 18 m in depth with water level varying from post-monsoon to pre-monsoon by 0.6 to 9 m below ground level. These are significantly observed on the either bank of river Khapri near its confluence with river Ambica at village Vati. This geomorphic unit is characterized by very good groundwater potential.

4.3.1.9 Valley fills

Valley courses filled with loose unconsolidated sediments deposited at the base of valley slopes under the action of gravity and fluvial processes are defined as valley fills (Thornbury, 1954). On IRS LISS-III FCC (B-432) satellite data, it exhibits light blue and occasionally red colour due to agricultural fields, fine to medium texture, irregular to linear shape, occupying low-lying areas associated with river channel. In field, weathered and erosional products of rocks with heterogeneous size characterize the valley fills (figure 4.12). The topographic location and unconsolidated nature of the deposits allow the water to infiltrate significantly and constitute a good groundwater reserve. The total area occupied by valley fills in Khapri watershed is 17 km² (figure 4.3). The dug-wells in this geomorphic unit ranges from 8 to 16 m in depth with water level varying from post-monsoon to pre-monsoon by 1 to 7.5 m below ground level. The

overall possibility of groundwater accumulation in this geomorphic unit is good to very good.



Figure 4.11 Alluvial plains near village Vati.



Figure 4.12 Valley fill deposits near village Vati.

4.3.2. Slope

Slope is one of the significant geomorphic indicators that remarkably governs runoff and infiltration capacity of the watershed (Nassif and Wilson, 1975, Deota and Desai, 1995). In general, the gentle slopes allow water to remain in contact with the surface for longer durations and increase the probability of infiltration to sub-surface compared to the moderate and steep slopes. However, the effect of slope may be modified with respect to landforms and drainage characteristics. In the study area, slope is intimately associated with elevation, which increases with an increase in elevation

from west to east as well as from north to south. The slope of Khapri watershed varies from 0° to 67° and is classified into seven classes (Dongare et al., 2022 and Dongare and Deota, 2023) viz. flat (0° - 3°), very gently sloping (3° - 6°), gently sloping (6° - 10°), moderately sloping (10° - 18°), moderately steep sloping (18° - 35°), steeply sloping (35° - 45°), very steeply sloping ($>45^{\circ}$) (figure 4.14). The pie diagram (figure 4.13) shows that around 36 percent area of the Khapri watershed falls in flat to gently sloping category, while more than 63 percent falls in the steep to moderate sloping categories. Only around one percent area of watershed falls in steep to very steep category of slope. High degrees of slope are observed mainly along the ridges which act as a watershed divide at sub-watershed level. These steeper slopes of Khapri watershed are responsible for closely spaced drainage channels and elongated shape (Schumn, 1956). Ground truth verification is also carried out at multiple locations to verify the slope map (figure 4.15). The slope is inversely related to the infiltration hence, the areas with flat to gently sloping categories generally possess good to excellent ability of groundwater infiltration and thereby groundwater potential. On the other hand, the areas with moderate to steep slopes reduce the ability of infiltration and thereby lead to poor groundwater potential.

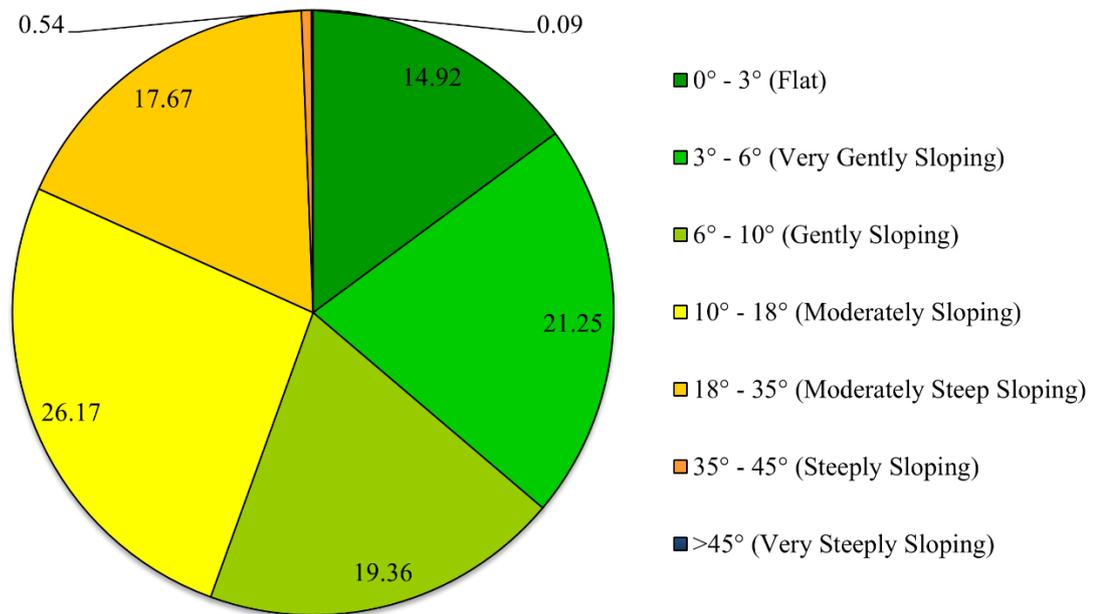


Figure 4.13 Pie diagram representing the percent aerial coverage of different slope classes in Khapri watershed.

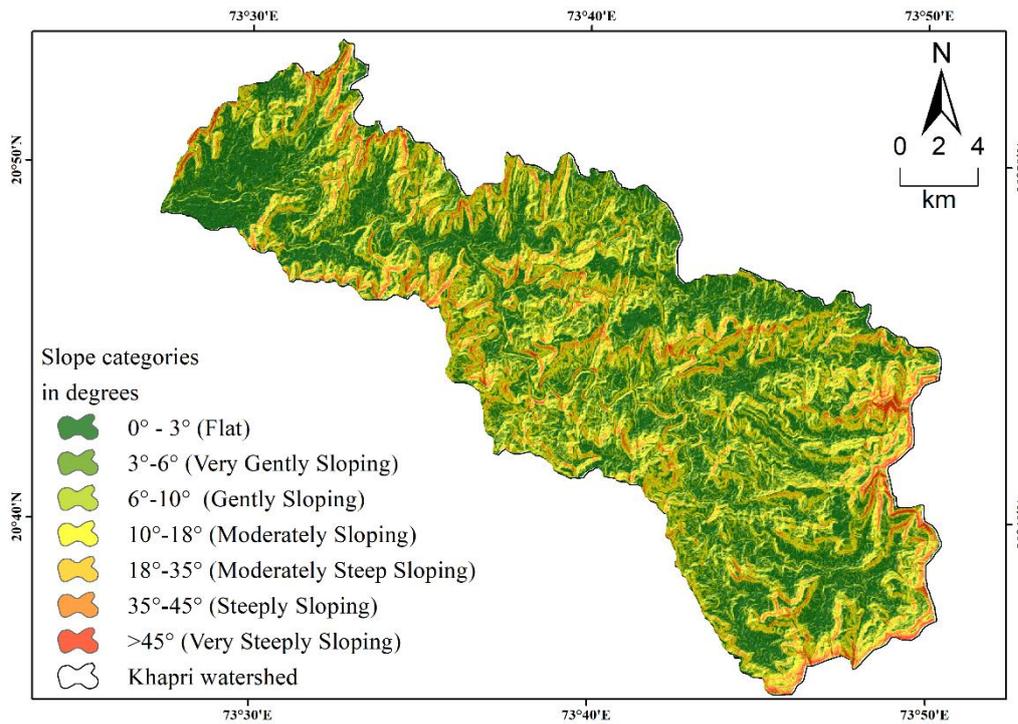


Figure 4.14 Map exhibiting seven categories of slope increasing from west to east as well as from north to south in the Khapri watershed. (After Dongare et al. 2023).



Figure 4.15 Ground truth verification of slope near Jakhana.

4.4 Epilogue

The landforms and slope shows significant contribution in groundwater occurrence and distribution. The nine geomorphic features are demarcated in the Khapri watershed and are analysed with respect to runoff-infiltration capacity. The escarpments are near vertical or almost vertically sloping faces with negligible groundwater potential. Highly dissected plateau (HDP) regions characterized by high drainage density indicate high runoff-zones and poor groundwater potential. On the other hand, the low dissected plateau (LDP) with gentle slopes, low to moderate drainage densities leads to moderate groundwater potential. In between, the moderately dissected plateau (MDP) having moderate drainage density exhibit good to moderate groundwater potential. The flat top surfaces of the linear ridges and plateaus mark the planation surfaces and is characterized by moderate groundwater potential. Pediments are gently sloping surfaces with veneer of weathered and colluvial material characterized by good to moderate groundwater potential which is enhanced on account of high lineament density. Pediplains are gently sloping undulating surfaces marked by moderate to good groundwater potential. Alluvial plains are gently sloping depositional surfaces with unconsolidated sediments having very good to excellent groundwater potential. Valley fills are mainly consisting of weathered products of the surrounding basaltic rocks, gravels, pebbles, sand and silt sized particles deposited by the action of stream transport and gravity resulting in good to very good groundwater potential.