CHAPTER-III

HYDROGEOLOGICAL CHARACTERIZATION OF THE MAHI-NARMADA INTERSTREAM AREA

3.1 INTRODUCTION

Groundwater occurrence distribution and its chemical characters are the functions of geological environment. Assessment of water resources for any area necessitates in depth evaluation of geological parameters viz. geomorphology, lithology and structures. The hydrogeological conditions in the study area vary both laterally and vertically. The western part and central part consist of vast alluvial plains with a gentle dip which, gradually merges with coastal plains. Eastern most part of the study area is characterized by pediment zone underlain by rock formation having thin cover of alluvium and soil. The thickness of alluvium progressively tends to increase westward as the bed rock is moving down under the effect of Cambay Eastern Marginal fault whereas the eastern hinterland comprises varied lithologies of igneous, metamorphic and sedimentary origin predominated by erosional landforms and steep slopes.

3.2 Hydrogeomorphic Characteristic

Geomorphological attributes like landform, drainage, soil, slope and landuse pattern holds vital importance in governing an overall distribution of water in terms of surface runoff and infiltration. A critical evaluation of these geomorphic attributes has greatly facilitated the investigator in identification and delineation of potential zones of groundwater source with the demarcation of recharge boundaries. Various geomorphologic feature of the study area is shown in Fig-3.1. Accordingly, the study area has been divided into four distinct geomorphic classes based on the geomorphic features (Table-3.1) viz.

3.2.1 Coastal Plains/Zone: This geomorphic unit is characterized by low altitude ranging between (±2 to 15m AMSL). Important features identified are intertidal mud flats (low marsh), mud flats (raised marsh), coastal sand dunes, patchy older alluvium and alluvium plain (younger alluvium). The groundwater potential in coastal area is very poor which is due to predominance of silt and clay (mud) composition of sediments. Further, owing to its deposition in estuarine-marine condition, water quality is highly saline thereby groundwater is unfit for any uses. The geographic limit of this zone encompasses parts of Jambusar, Vagra, Amod and Bharuch Talukas.

Fig-3.1 Hydrogeomorphic Map of the Study Area

Table-3.1 Geomorphic Classification of the Mahi-Narmada Interstream Area.

Geomorphic Process	Geomorphic Divisions and Associated Landforms			
	Coastal Plain Zone	Central Alluvium plain Zone	Piedmont Zone	Highland Zone
Depositional or Agradational	Recent mudflats River mouth bars Beach sand dunes	Flood plains Natural Levees Point Bars Buried Channels	River Terraces and Channels fills pluvial and colluvial mounds and low ridges	Valley fills
Erosional or Degradational	Raised Mudflats older alluvium plains and bets	Gullies Cliffs and Scarps	Dyke ridges, Cliffs, Cascades Terraces etc	Eroded land, dissected plateau etc
Environments	Marine	Fluvial	Subaerial Denudation	Aeolian & Fluvial

The landuse pattern of this zone is based on the Census (2001) data almost 5.9% is under irrigation while 58.3% of land is under un-irrigated land category (Fig-3.2).

Fig-3.2 Land use Pattern in the Coastal Area

Important identified landform features identified in this geomorphic zone and their groundwater prospects are described as under with detail description given in Table 3.2.

Table -3.2 Hydrogeomorphological Features of the Coastal Tract of the Study Area

Geomorphic Feature	Material Composition	Terrain Characterization	Genesis	Hydrogeomorphic significance
Mud Flats	Fine silt mud	Relatively level area or fine silt along shore covered or uncovered by the tide or covered by shallow water. A muddy tidal flat devoid of vegetation	Depositional features formed by the marine environment	The TDS value is very high falling in brackish –saline water category. Area not suitable for any purpose
Raised (Palaeo) mud flats	Composed of fine clay and silt	Gently sloping area mudflats formed due to marine action in the past, normally cultivated	Erosional features formed under regressive phase of sea	Aquifers are patchy, brackish to saline. Pockets of older alluvium have potable water with restricted yield
River mouth bars	Varying from sand to silt & clay	Formed due to action of tidal wave and fluvial current	Depositional features formed due to sediment accumulation due to check in water current	They are under the influence of estuarine environment hence saline
Alluvial plain	Constitutes gravel, sand, silt	Level or gently sloping tract produced by deposition of alluvium	Depositional features formed by the fluvial activity except relict alluvial plains which are erosional features	In alluvial deposits the water at shallow depth is generally good quality wherein it tends to deteriorate at deeper level due to long residence time
Coastal sand Dunes	Mainly composed of sand silt	Undulating gentle to moderate slope, vegetated at places	Depositional features formed by the Aeolian process	Stabilized dunes are important source of potable water. Groundwater mounds are developed as phreatic aquifers but with depth water becomes saline

- Mudflats: These are the features formed by the deposition of clay and silt under the effect of tides. These mud flats are characterized by a very gentle slope. Due to its inherent salinity the groundwater prospects are almost nil. They are further divided into two categories viz. recent mudflats and raised mudflats that have been deposited in the past under high strand line.

- River mouth Bars: The study area has a broad estuarine mouth of river Mahi, Narmada and Dhadhar. The tidal influence of sea is seen inland deep inside the estuary. During high tide the sea water intrude into inland side and during low tide phase depositing extensive mud to form such features. These features are common in all the three estuaries of Mahi, Dhadhar and Narmada Rivers. The mouth bars of Mahi and Narmada are predominantly sandy while that of Dhadar river is clay and silt dominating (Yousef, 1989). These sandy bars are ideal repositories of fresh groundwater. However, their potential is meager.

- Coastal dunes: these are the features formed by the aeolian process. These dunal sands are not continuous all along the coast but shows patchy occurrences. These unconsolidated features mainly composed of fine sand-silt. Topography of dune covered surface has gentle to moderate slope and at times they are vegetated. At times thin mounds of phreatic aquifer system are developed within the dunal sands which is potable and do provides fresh water supply. However, groundwater prospect of this landform unit is moderate to poor.

3.2.2 Central Alluvium Zone: Vast stretch of central alluvium is characterized by a moderate relief and has been extensively used for agricultural, urbanization and industrialization. The important landform features associated with this unit are attributed to the processes of erosion and deposition are viz. alluvial plains, palaeo/buried channels, flood plains, valley fills, ravine land and old meanders. The genetic attributes of these landforms along with groundwater prospects are given in Table-3.3.

Salient characteristics of identified landforms of this unit and their groundwater prospects are described as under:

- Flood Plain: These are depositional feature of a river system associated with the major rivers. They are generally composed of sand gravel, pebble, boulders, clay and silt. Groundwater prospects of flood plain are very high, which is attributed to high

Table -3.3 Hydrogeomorphological Features of the Central Tract of the Study Area.

Geomorphic feature	Material Composition	Terrain Characterization	Genesis	Hydrogeomorphic significance
Palaeo channel	Sand and gravel	Old fluvial channels includes buried as wells as abandoned channels and meander loops, normally cultivated, gentle sloping	Depositional features formed by the river	Groundwater potential in terms of quality and quantity is excellent
Ravine land	Predominantly silty to fine sand	Dissected, with steep slopes, usually barren	Erosional feature formed along the river banks. Due to rill erosion surface runoff is high and recharge is poor	Moderate to good groundwater potential with potable quality
Recent Flood plain	Composed of sand gravel, pebble, boulders, clay and silt	Surface or strip of relatively smooth land adjacent to river channels, covered with water when rivers overflow their banks, gentle slope, normally cultivated	Depositional features by fluvial activity	Generally such sites are the best site for groundwater prospecting because of fluvial deposits, good quality groundwater is available. Such sites are also good for groundwater recharge
Alluvial plain	Constitutes gravel, sand, silt or varying lithology	Level or gently sloping tract produced by depositional of alluvium	Depositional features formed by the fluvial activity except relict alluvial plains which are erosional features	In alluvial deposits the water at shallow depth is generally good quality wherein TDS content is less but water at deeper level are saline due long residence time and interaction of water with sediments
Plains	Composed of fine clays	Flat, normally cultivated landform	These are depositional features by fluvial activity	Because of the presence of clay the recharge in such area is less as a results water quality deteriorate with time and depth
Valley fills	Constitute boulders, cobbles, pebbles, gravels, sand silt, clay etc	Unconsolidated sediment deposited as to fill or partly fill a valley, more thickness at the centre and tapering at the periphery, normally cultivated	These are depositional features formed by the fluvial processes	These are excellent site for groundwater prospecting as both quality and quantity are good to very good, subjected to depth of filled material. Such sites are also favorable for water recharge
Old meanders	Mainly sand and gravel	Old fluvial meanders	These are erosional features formed by the fluvial process	Such sites are excellent for water availability and recharge point of view

porosity and permeability thereby constitutes an ideal repository for groundwater of good quality.

- Paleo-channels: This includes buried as wells as abandoned channels. They are generally formed because of lateral shifting of river courses. They are gentle sloping and consist of sand and gravel, an ideal repository for groundwater with very high potential.

- Gullies: The gully formation is characterized by head way erosion forming steep slopes. The rivers of the study area especially Mahi, Dhadhar and Narmada rivers shows extensive ravine formations. Aerial distribution of ravine land (CS&WCR&TI, 1981) along the major river system are Mahi (61888 ha); Dhadahr (12086 ha); and Narmada (58142 ha). These gullied sediments are characterized by silty nature with high vertical permeability and low lateral permeability and considered to be ideal sites from groundwater prospect point of view.

3.2.3 Eastern Piedmont Zone: This zone represents transitional phase between highlands and alluvial plains and is characterized by both erosional and depositional landforms. Surface is generally covered with alluvium but at shallow depth rock is exposed. This is clearly visible in some of the open wells present in this area. The zone can be traced from Savli taluka in the north through Waghodia and finally Tilakwada in the south. Some of the significant depositional features identified in this zone are alluvial plains, valley fills, low terraces, bad land (especially along the rivers) etc. whereas erosional features mainly formed by fluvial and aeolian processes are scarps, cliffs, residual bedrock terraces and features visible in rivers like cascade and rapids. The sediment characteristics of this zone show mixed character of coarse grained materials which is poorly sorted i.e. colluvium. Broad characterization of this geomorphic unit along with its groundwater prospects is given in Table - 3.4.

3.2.4 Eastern Highland Zone: This zone is characterized by undulatory hilly rock terrain with intermittent pockets of valley filled alluvium. The rocky terrain encompasses a variety of landforms viz. Deccan plateau, moderately dissected plateau, highly dissected plateau, dissected hills, residual hills dissected by joints, fractures, faults etc. summary of various geomorphic attributes of this unit along with their hydrogeological significance is furnished in Table -3.5.

Table -3.4 Hydrogeomorphological Features of the Eastern Pedimont zone.

Geomorphic feature	Material Composition	Terrain Characterization	Genesis	Hydrogeomorphic significance
Valley fills	Constitute boulders, cobbles, pebbles, gravels, sand silt, clay etc	Unconsolidated sediment deposited as to fill or partly fill a valley, these are characterized by low relief and gentle topography, normally cultivated	These are depositional features formed by the fluvial processes	These are excellent sites for groundwater development but in piedmont zone the extent of such features is not much hence occurrence of groundwater is limited to small extent
Low terrace	Sand, silt, kankar etc	These are characterized by low relief, vegetation growth at times being used for agriculture purpose with good development of soil	These are depositional features formed by the fluvial processes	Because of presence of unconsolidated material and low relief these are excellent sites for groundwater development and prospecting
Alluvial veneer on badland	Alluvium material with intermittent exposure of Deccan traps	These areas are dominated by moderate relief, at times shows development of weathered profile and soil	These are depositional features formed by the action of fluvial and Aeolian processes	Because of presence of rock at shallow depth and its weathering at times may produce site for groundwater development
Residual bedrock terraces	Deccan trap	These areas are dominated by moderate relief and at times development of weathered profile is also common phenomena	These are erosional features	Due to erosional processes rock is exposed and development of weathered profile is almost absent. Groundwater may occur along fractures and lineaments.
Scarps and cliffs	Deccan trap	These shows undulatory topography with steep slopes and high relief. Soil development of weathered profile is almost absent	These are erosional features	Because of high relief the surface runoff is more and recharge is less hence not good sites for groundwater development
Hilly rock terrain	Deccan trap	These are dominated by high relief, dissected by fractures with no soil cover	These are erosional features	In such areas the surface runoff is high and infiltration is less hence such site are not good from groundwater development point of view

Table -3.5 Hydrogeomorphological Features of the Eastern Highland.

Geomorphic feature	Material Composition	Terrain Characterization	Genesis	Hydrogeomorphic significance
Eroded land	Sand, gravel, kankar etc	Dissected, with steep slopes, usually barren.	These are erosional feature formed along the river banks.	Due to erosion surface runoff is high and recharge is poor.
Deccan Plateau	Basaltic lava flows	Low relief, undulating topography normally cultivated.	Such areas are criss crossed by fractures and joints as a result feasible for groundwater development.	These are good sites for groundwater recharge. But due to rolling topography, formation of black cotton soil and hard surface, runoff is more and infiltration is less.
Moderately dissected plateau	Basaltic lava flows	Comparatively low to moderate relief, moderately jointed and fractured with thin weathered cover.	Such areas are criss crossed by fractures and joints as a result feasible for groundwater development.	Due to moderate dissection the groundwater availability is less and if present mainly confined along lineaments and weathered zones.
Highly dissected plateau	Basaltic lava flows	High relief, steep slopes and high runoff.	These are erosional features formed by processes of fluvial and Aeolian activities.	Such sites for poor from groundwater availability point of view. Due to high relief and steep slopes the surface runoff is very high and infiltration is less. Groundwater is mainly confined to lineaments and weathered zone.
Dissected hills (sedimentary)	Composed of sandstone, limestone & shale	High relief, steep slopes, barren, dissected by fractures no soil cover.	These are erosional features formed by processes of fluvial and Aeolian activities	Due to high relief and steep slopes the groundwater infiltration is less and surface runoff is high. Groundwater is mainly confined along intersection of lineaments.
Dissected hills (Metasedimentaries)	Consists of Precambrian quartzite, phyllite & schist	High relief and steep slopes.	These features are formed by erosional processes which continuous modifies the landscape.	Due to high relief and steep slopes the groundwater prospecting is less and confined only to lineaments

Continued--

Geomorphic feature	Material Composition	Terrain Characterization	Genesis	Hydrogeomorphic significance
Pediplains (Metasedimentary)	Mainly comprises of Precambrian metasediments like quartzite, phyllite & schist.	Broad gently sloping rock floor erosional surface of low relief covered with thin veneer of detritus sparsely vegetated.	These are formed by the processes of Aeolian and fluvial activity.	Such areas are criss crossed by fractures, faults, axial traces etc and groundwater availability as such is poor but moderate along lineaments.
Pediplain (Sedimentary)	Mainly comprises of Tertiary sediments composed of sandstone , shale etc	Broad gently sloping rock floor erosional surface of low relief.	These are erosional features developed depending upon the structure & lithology of the area.	Such areas are criss crossed by fractures as a result is good site for groundwater prospecting and favourble for groundwater recharge also.
Residual hills	Precambrian Crystallines	High relief, steep slope, isolated hills, jointed and weathered.	They are formed by erosional processes comprising of Aeolian and fluvial activity.	Due to high relief and steep slope infiltration is poor as a result availability of groundwater is less, at times groundwater is confined along lineaments and in weathered zone
Valley fills	Constitute boulders, cobbles, pebbles, gravels, sand silt, clay etc	Unconsolidated sediment deposited as to fill or partly fill a valley, more thickness at the centre and tapering at the periphery, normally cultivated.	These are depositional features wherein sediment formed by erosional processes gets deposited in low relief area or where there is sudden drop in topographical relief/slope.	These are excellent site for groundwater prospecting as both quality and quantity are good to very good, subjected to depth of filled material. Such sites are also favorable for water recharge.
Lineaments	Cut across various lithounits	Linear topography, features of regional extent believed to reflect crustal structure, represents fractures/faults/ joints/shearzone/litho contact zone etc., indicate secondary porosity.	These are either syn or post genetic or formed by the tectonic processes due to redistribution of stresses.	The possibility of good quantity of groundwater in such areas is along intersection of lineaments. Water quality is generally good and are responsible for groundwater reserves in hard rock terrain

3.3 Hydrolithology

Sediment nature and its composition hold vital bearing on the mode of occurrence and distribution of groundwater resource of an area. Geomorphic attributes of the area significantly influences overland flow and infiltration processes and facilitates in demarcating the area of recharge and discharge. However, the infiltration and infiltration capacity of the medium is solely governed by the medium through which water flows.

From the groundwater occurrence point of view sediments are divided into classes (Davis & De Wiest, 1967) viz.

1. Unconsolidated: loose sediments of Recent – sub recent.
2. Semi-Consolidated: Sedimentary rocks and low grade metamorphic rocks.
3. Consolidated: High grade metamorphic and igneous rocks.

The overall groundwater potential trends to decrease from unconsolidated to consolidated sediments.

The study area is characterized by all the three hydrogeological units and the unconsolidated sediments constitute a major chunk of the area and by and large occupy central and western parts of the study area.

Further, assessment of groundwater potential is dependent of subsurface geological information. In order to study the subsurface geology of the study area occupied by Quaternary-Holocene sediments (unconsolidated) the author has referred available bore holes logs drilled by the state and central groundwater departments. Moreover, exposed Quaternary sediments along the vertical cliffs of major river systems have also been studied. Based on available lithologs, author has developed 03 subsurface hydrogeological profiles (Fig 3.3 – 3.5). Section lines have been shown in Figure 3.2.

The subsurface hydrogeological section (A-A') between Alamgir (Vadodara Taluka) and Malod (Karjan Taluka) covers a distance of 33 km. The sediments mainly comprised of clay & sand with subordinate layer of gavel and kankar (Fig-3.3). The clay starts immediately below the soil hence this area is not good from recharge point of view. Further, the top soil is of vertisol type (black cotton soil) which impedes groundwater movement. Maximum aquifer thickness (±70m) is observed in Nasaria borehole wherein the lower aquifer is confined

within the clayey aquiclude. As the recharge source is in further east, the aquifers are having very good potential.

Fig.3.3 Index Map for Hydrogeological Sections.

Fig-3.4 Sub-surface Hydrogeological Cross Section along Alamgir – Bamangam – Nasaria – Malod (After CGWB, 93-94)

The second section (B-B') between Mobha (Padra Taluka) and Maleth (Sinor Taluka) stretches for almost 45km and shows development of top unconfined and lower confined aquifers (Fig 3.4). The phreatic aquifer is developed within sand and kankar whereas thick confined aquifer is in gravely material. The section clearly depicts that between Timberva and Maleth village sand is exposed just below the soil layer which acts as a zone of recharge. Moreover, at 200m depth there is a confined aquifer, the thickness tends to increase in Southeasterly. The thickness of gravel deposits is more than 150m. The base of these loose sediments is Deccan trap encountered inbetween the depth of 296 to 302m bgl at Maleth.

The occurrence of groundwater is mainly in sand, gravel and kankar. The clay act as a confining layer for aqueous media. The depth of occurrence of groundwater in top phreatic aquifer in this area is maximum i.e. 15-20m bgl.

Fig 3.5 Sub-surface Hydrogeological Cross Section along Mohba – Kurai – Timberva – Maleth (After CGWB, 93-94)

The third section (C-C') runs for almost 40km along NE-SW transect between Kurai and Akotadar. The subsurface sediments consist of intercalated sequence of clay and sand with intermittent bands of gravel (Fig3.5). At Chatral Deccan traps occurs below the depth of 265m as the bed rock (CGWB, 93-94). This area also shows good development of top unconfined aquifer. The litholog of Bamangam reveals multiple aquifers of semi-confined to confined nature.

Fig-3.6 Sub-surface Hydrogeological Cross Section along Kurai – Bamangam – Chatral – Akotadar (After CGWB, 93-94)

Good cliff sections of about 40m exposing basal clay are observed in the Mahi and Narmada River sections. The basal or blue clay exposed in the river section and also in the mainland occurs at varying depth ranging from 75m at Gotri and 90m at Sevasi (*GWRDC, 1987*). On an average, it occurs at a depth of 60m. This 60m sedimentary sequence is very important because good potable water is available above blue clay which acts as maker horizon and delimits the vertical extent of potable water. Below blue clay layer though the potential of aquifer is high but the quality wise, water is highly saline.

3.4 Geohydrological Characteristics:

An overall evaluation of various sub-surface hydrogeologic profiles of central alluvium zone has conclusively established the presence of top phreatic aquifer and deep multi-tired aquifers of confined and semi-confined nature. CGWB (1994) based on the subsurface exploration has identified five different aquifer zones in the alluvial deposits. Though all five aquifers are not present throughout and not forming regional aquifers, but towards eastern side upper three aquifers are hydrologically interconnected and coalesce in to single aquifer. The thickness of these aquifers also varies spatially and there is difference in their hydraulic properties. Brief information about the identified multi-tired aquifers is given as under:-

Table-3.6 Detail about Aquifer System in the Study Area.

No. of aquifer	Status of aquifer	Depth range (mbgl)
I	Unconfined	Upto 40
II	Semiconfined to confined	62.0 – 81.5
III	Confined	96.5 – 116.0
IV	Confined	135.0 – 148.0
V	Confined	165.0 – 202.0 and below 207

(CGWB 1994)

Further, summary of estimated hydraulic characteristics through field pumping tests is given as under:-

Table 3.7 Aquifer Parameters of the Study Area.

Sr. no.	Aquifer characteristic	Aquifer type		
		Unconfined	Confined	Hard rock
1.	Specific Conductivity $m^3/min/mt$	0.010 to 0.7983	NA	0.0307 – 0.485
2.	Transmissibility m^2/day	12.52 – 475	541 – 5800	19.64 – 213
3.	Specific Yield %	2 - 11	NA	1.7 – 2.9
4.	Storage Coefficient	NA	3.56×10^{-3} 5.56×10^{-4}	NA

The upper unconfined aquifers are being used by means of open or dug wells. But due to lowering of water table, the phreatic aquifers have gone to much deeper level especially in the central part. The eastern and northern part of the study area is characterized by hard rock terrain therefore large diameter open dug wells tapping phreatic aquifers is more prevalent. In the western part of the study area though phreatic aquifers are occurring at shallow depth but they are by and large saline. In the coastal plain area because of salinity problem most of the wells are on the periphery of man made ponds. These ponds get filled during rainy season and provide potable water to dug wells, handpumps and to some extent tube wells. They also create subsurface groundwater mound pushing saline water due to density contrast.

Overall hydrogeological characterization of the study area based on various geomorphic, lithologic and structural attributes has greatly facilitated the author in identifying the recharge and discharge areas as well as assessment of overall potential. The spatial information generated through this has been further utilized for micro and mega level characterization of the area on GIS environment. Same has been dealt in proceeding chapters.