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Sanjay Das

Geological Survey of India, Gandhinagar, Gujarat, India

Indra Prakash

Geological Survey of India, Gandhinagar, Gujarat, India

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Sanjay Das
Geological Survey of India
Sector 10A
Gandhinagar 382043, Gujarat
India

Indra Prakash
Geological Survey of India
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Gandhinagar 382043, Gujarat
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ABSTRACT

Jamnagar district of Gujarat is having 355 km long irregular coast line. The district is bounded by Gulf of Kachchh in the north and Arabian Sea in the west and southwest. The precipitation in the area is low and climate is semi arid. Rivers flowing in the area are ephemeral. Ground water occurs in unconfined and semi-confined state. Major central part of the area is occupied by Deccan basalt, western part by marine Tertiary rocks, northern and western coastal area by Quaternary sediments. In general, ground water in Deccan basalt is fresh whereas in Tertiary and Quaternary sediments it is brackish due to inherent salinity as well as sea water intrusion. Miliolite limestone in this area forms good aquifer.

Groundwater hazards in the area are mainly related with the inherent salinity of rocks/ sediments, sea water ingress in the coastal area and chemical pollution. Brackish ground water, toxic element (Pb, Ni) and radicals (SO_4^{--}, NO_3^-, Cl^- and Fluoride) zones have been identified and delineated based on the integrated GIS study. About 181 villages of the district are affected by high TDS, 39 villages by high Fluoride and 2 villages both by high TDS and Fluoride.

INTRODUCTION

The district lies south of the Gulf of Kutch, which is an inlet of the Arabian Sea along the west coast of India, in the state of Gujarat. West coast of the district lies in the open Arabian Sea. The area of the district is 10,900 sq km and coast line is 355 km long. The landscape is marked by flat-topped basaltic (trappean) ridges and a highly varied coastline where a narrow belt of low ridges and cliffs of miliolite limestone and other shore deposits are found. The Holocene high sea earlier submerged a considerable stretch of land including the Okha Rann on the northern coast and isolated patches in and around the river mouths on the southwestern coast.

The Precipitation in the area is low and climate is semi arid. Average annul rainfall varies from 310 to 586 mm and increases gradually from west (Dwarka) to east (Kalavad), respectively. The temperature in the area varies between 15°C (winter) to 40°C (summer). Diurnal temperature variation is fairly high (up to 20°C in the inland areas). Hot ground water (36° to 46°C) has been encountered in the Lalpur area along linear trend parallel and adjacent to NNW-SSE trending fault. In general ground water temperature varies between 25° and 32°C.

Ground water in the area occurs in unconfined and semi-confined state. About 181 villages of the district are affected by high TDS, 39 villages by high Fluoride and 2 villages both by high TDS and Fluoride (GWSSB, 2005). The principal factors which control the distribution of polluted ground water are the porosity and permeability of the country-rocks/ soil, climatic conditions, topography of the terrain, location and type of industries, and location of fresh water and sea water interface in coastal area. Various thematic layers (geology, geomorphology, geo-hydrology and chemical pollution) have been prepared and integrated in the GIS study to identify and assess groundwater hazards.

GEOMORPHOLOGY AND DRAINAGE

The area is having seven geomorphic units namely pediplain, dissected upland and denuded hills, recent tidal flat, beach, flood plain and older tidal flat (Das, 2006), (Fig.1). Pediplain area is developed on the horizontal to sub horizontal basalt flows (Deccan trap) and on the Tertiary sedimentary rocks having gentle slopes (1-2%) mainly towards NW. Within this area low lying ridges and denuded hills are located. Denuded hills aligned in E-W trend are formed along acidic rock intrusion and along basalt ridges in the central and southern

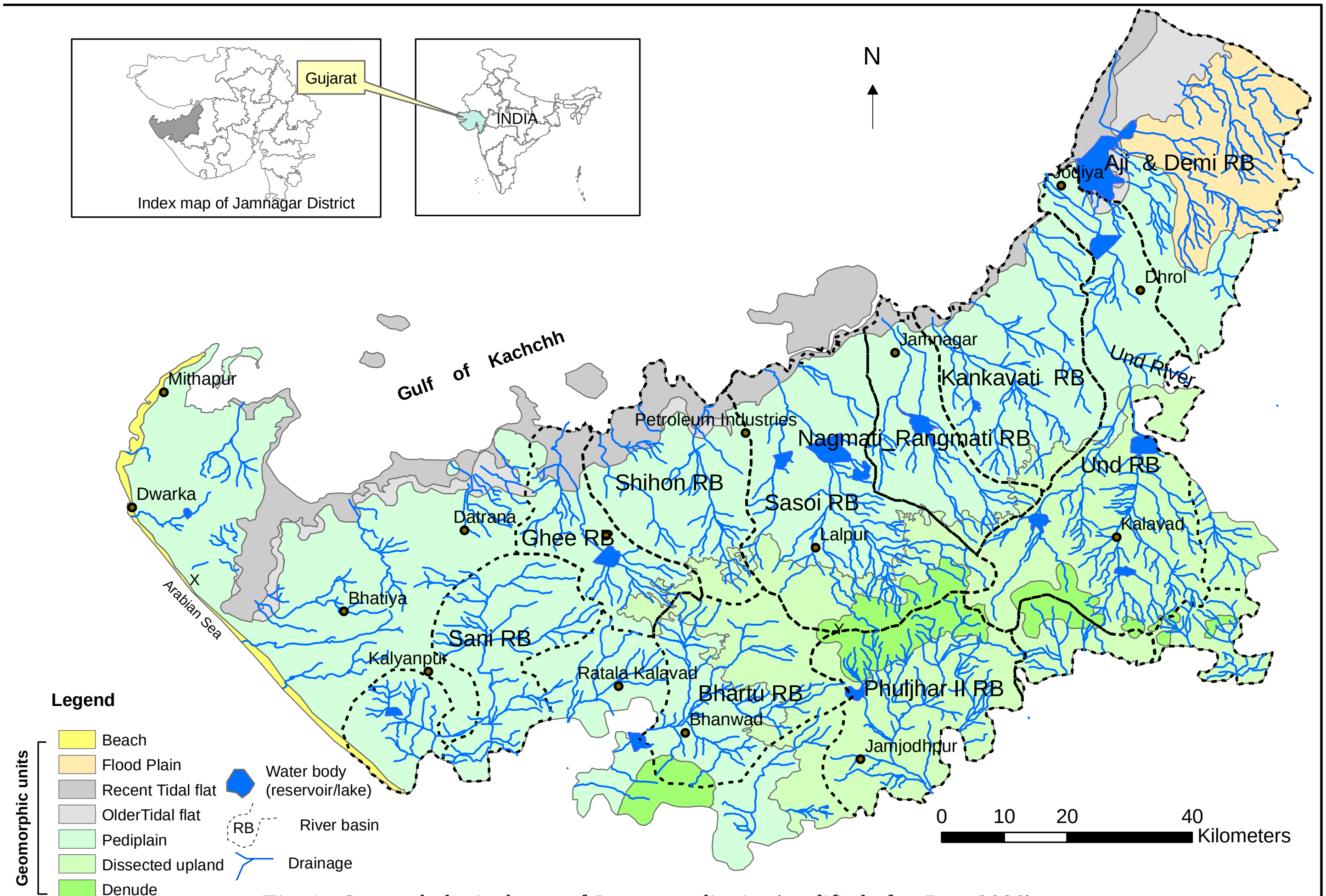

Fig. 1. Geomrphological map of Jamnagar district (modified after Das, 2006)

part between Elevation (El.) 140 and 527m. These ridges are acting as water divide for rivers flowing in northerly and southerly directions. Dissected upland having 2 to 3% slope is formed in the central part between El. 80 and 140 m due to erosion by minor streams. Miliolite limestone is forming ridges along western coast.

Flood plains in the area are poorly developed due to short ephemeral nature of the rivers having low surface discharge. Only Aji River, which traverses relatively longer distance (~120km), is having wider flood plain. The recent (younger) tidal flat is 1 to 8 km wide located within intertidal zone. It is predominantly muddy with isolated outcrops of basaltic rocks. The Older tidal flats are irregular narrow and discontinuous and presently occupied by thorny bushes. Mangrove in coastal belt is occupying parts of the mud covered areas of tidal flat. Sand dunes in the coastal area are partially stabilized. Okha Rann is a major marshy land area located on the north coast in the Gulf of Kutch (Kachchh). Southwestern sea coast of the district is almost straight-fault controlled, rocky-cum sandy beach. Saurashtra west coast fault aligned in NW-SE direction is controlling the coast line.

Drainage in the central part of the area is dendritic and in the western part radial. Drainage in the tidal flat area is of dendritic, trellis and parallel type. The older tidal flat area is dominated by distributary channels. Trellis and parallel type of drainage is confined to deltaic areas of Aji and Sasoi rivers reflecting tectonic control. Geology and drainage are controlling geomorphology of the area.

GEOLOGY

Deccan basalt of Cretaceous Eocene age, Tertiary and Quaternary sediments are exposed in the area (Fig. 2 and 3). Deccan basalt (tholeiite and picrite) intruded by basic dykes and acid volcanics such as granophyres, felsite and rhyolite occupy 77% area (GSI, 2002). Total thickness of basalt is 500m in the west and 1700m in the east. Thickness of individual flow varies from 12 to 22m. Average thickness of individual flow in southern part is estimated as 20 m (Bohra and Sharma, 1990). Acidic plugs are exposed in the southern part. Picrite basalt (Banerjee et al, 1996) is exposed in the western part of the district covering 240 sq km area.

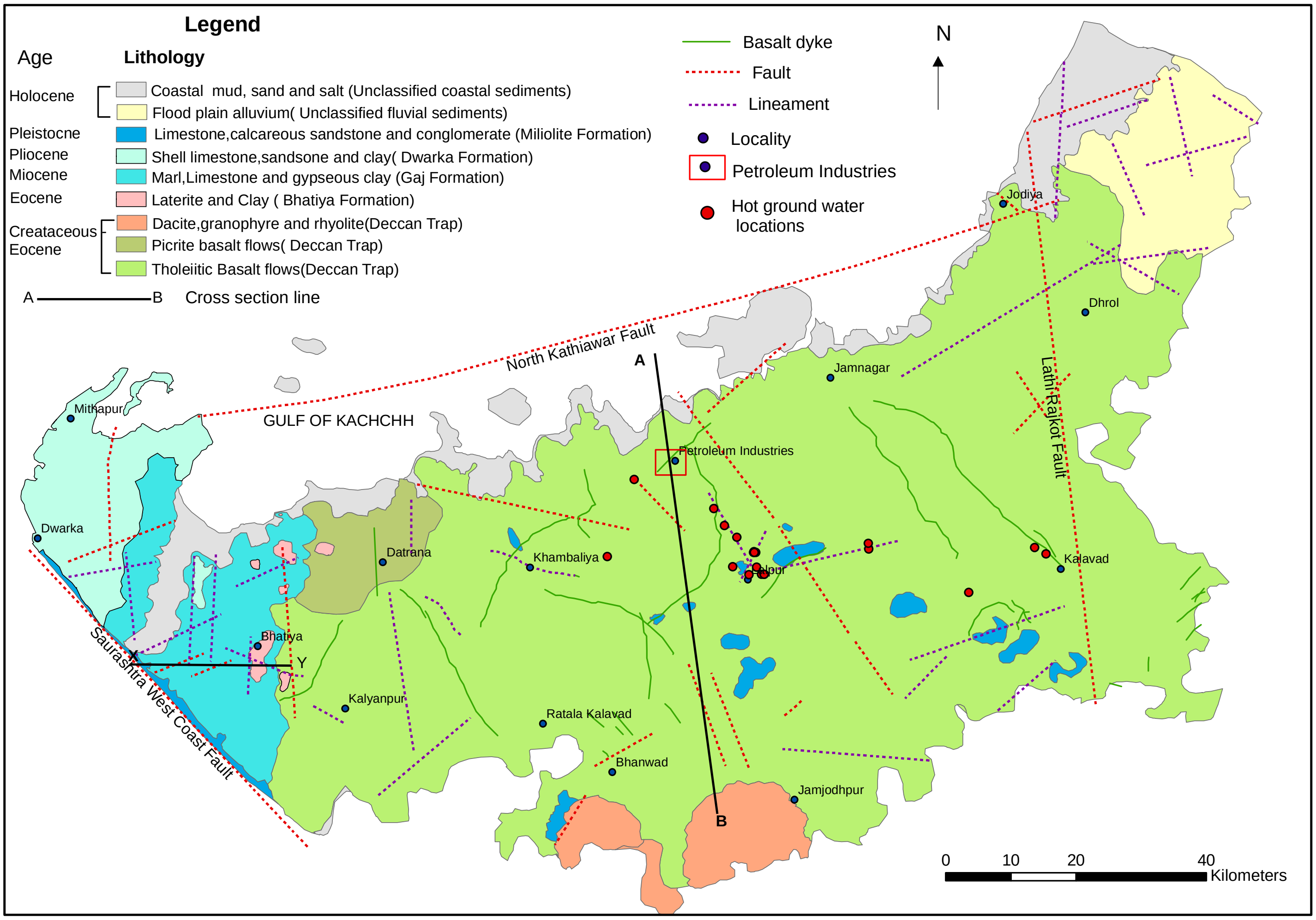

Fig.2. Geological map of Jamnager district (after GSI, 2002)

Tholeiitic basalts are of amygdular, porphyritic and aphanitic type. Amygdules are generally infilled with calcite, zeolite and chloropheiite glass. Sizes of the amygdules and geoids vary from few mm to 40 cm. Upper part of the amygdular basalt is weathered and permeable. The porphyritic basalt is also weathered at places where large plagioclase phenocrysts are present. Aphanitic basalt is relatively less weathered. Contacts of basaltic flows are sheared and weathered, at places and or marked by red boles and inter-trappean volcano-sedimentary beds.

Laterite of Bhatiya Formation (Eocene age), occurring as isolated patches underlain by Deccan basalt, forms low lying ridges in the western part of the district. Tertiary sediments comprising Gaj and Dwarka formations are also exposed in the western part. Gaj Formation (Miocene age) covering 11% area consists of limestone, marl, clay, sandstone with occasional gypsum layers and soft sands with well rounded grains. Clay dominated layers contain intercalated sand lenses. Both sandstone and clay are associated with gypsum at places. Secondary solution cavities are also present in this limestone. Rocks of Dwarka Formation of Pliocene age are forming elevated grounds. This formation comprises of flaggy sandy limestone, calcareous sandstone and gypseous- calcareous clay and occurs as isolated outliers within the Gaj Formation.

Miliolite Formation of Pleistocene age comprising limestone and calcareous sandstone of Pleistocene age occurs in the western coastal tract with an average outcrop width of 200 m and maximum thickness of 30 m. It also occurs as isolated patches along the slopes of the denuded hills and dissected upland. Miliolite formation near coast is consolidated calcareous beach-sand associated with foraminifers and marine shell fragments whereas inland it is having fluvio-aeolian character. Both types are having clastic nature with coarse grained and cross stratification. Miliolite limestone is porous and permeable. Holocene sediments in the coastal zone comprise well sorted sand along the western beach coast and fluvial sand, silt and clay in the flood plain area. Columnar and sheet joints are common in the basalt. It is also affected by tectonic joints aligned in the direction of major lineaments and faults. Joints in the limestone are widely spaced vertical. The Deccan trap area is profusely intruded by basaltic dykes trending mainly in NNW-SSW, NE-SW and dykes are 30 km long and150 m wide.

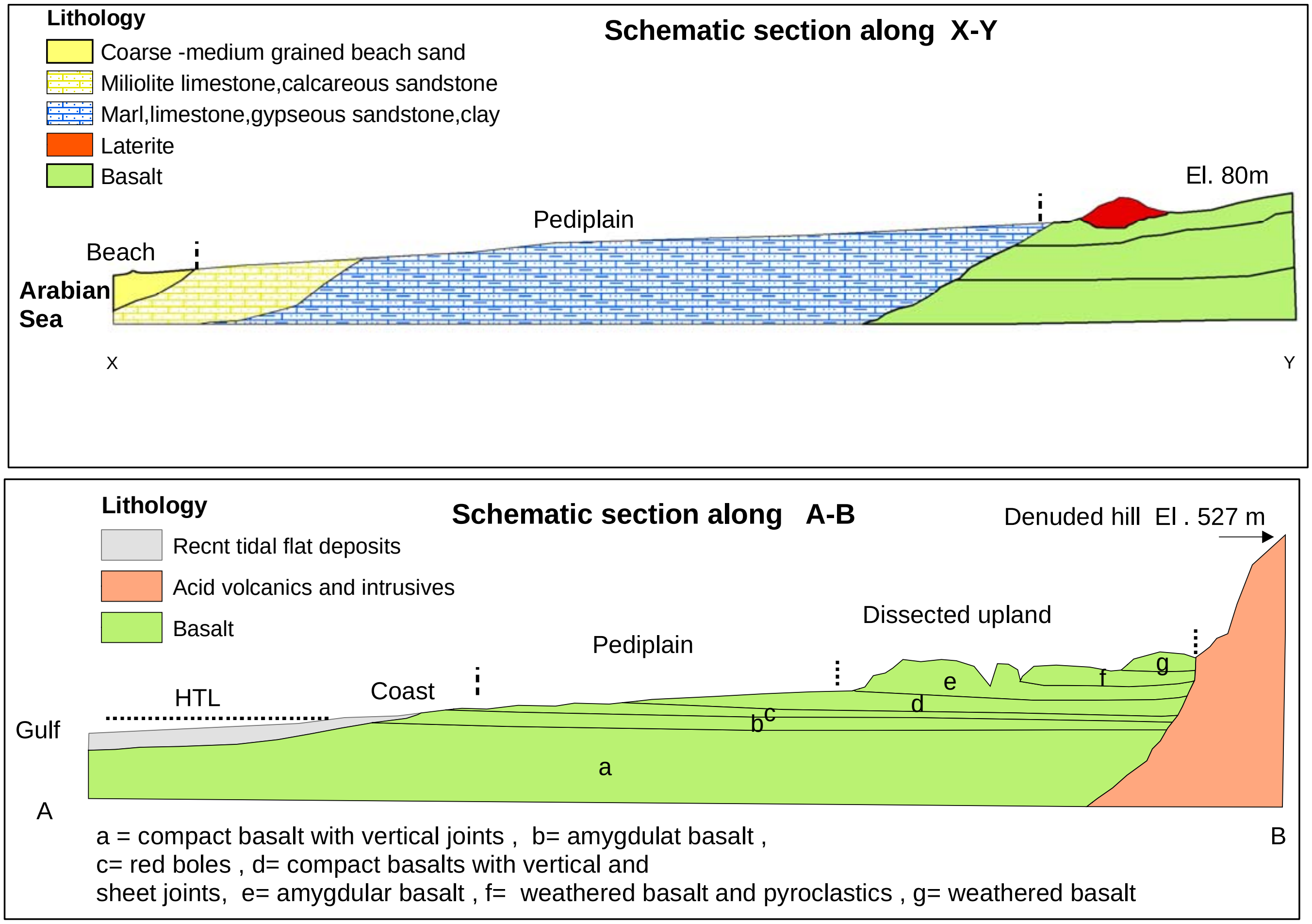

Fig. 3. Schematic geological cross sections of northern (A-B) and western(X-Y) coast and part of mainland

CHARACTERISTICS OF SOIL

Low soil permeability impedes infiltration, percolation, and ground-water recharge and enhances surface runoff whereas high soil permeability enhances these factors. Recharge is likely higher where the permeability of soils remains high to greater depths. In the study area clayey loam soil is developed over the pediplain and dissected upland underlain by basaltic rock (MOA, 1970). The soil developed over basaltic rocks is generally insitu soil. High drainage density over the basaltic country rock may be ascribed to the least permeable clayey loam soil (montmorillonite rich) developed over them. Thickness of soil varies from 15 to 45 cm over pediplain and 5 to 15 cm over dissected upland. The basaltic terrain has thin soil followed by thin weathered rock zone (Fig. 4). The soil over basaltic rocks is dominated with montmorillonitic clay showing high swelling indices (50 to 80%) and very low permeability. Sandy loam soil is developed over the older tidal flat and parts of the pediplain underlain by Tertiary sandstone and limestone. Calcareous sandy loam of 10 to 30cm thick is developed in the western part of the pediplain occupied by Tertiary limestone. Sandy clayey loam is developed on the foot hill region of denuded hills derived from acid igneous rocks. This soil has higher effective permeability.

SURFACE WATER

Natural surface water in the area is limited as monsoonal precipitation is the only source of the surface water. Therefore, earth dams and a number of check dams on the effluent rivers have been constructed to store the surface water. Kankavati and Und river basins cover about 1100 sq km area. Other river basins (Sasoi, Nagmati-Rangvati, Phuljhar II, Bhartu) area varies between 385 to 756 sq km. Area of the dam reservoir varies from 10 sq km to 18 sq km. Pipli is the largest reservoir (18 sq km) on Sasoi River in the area.

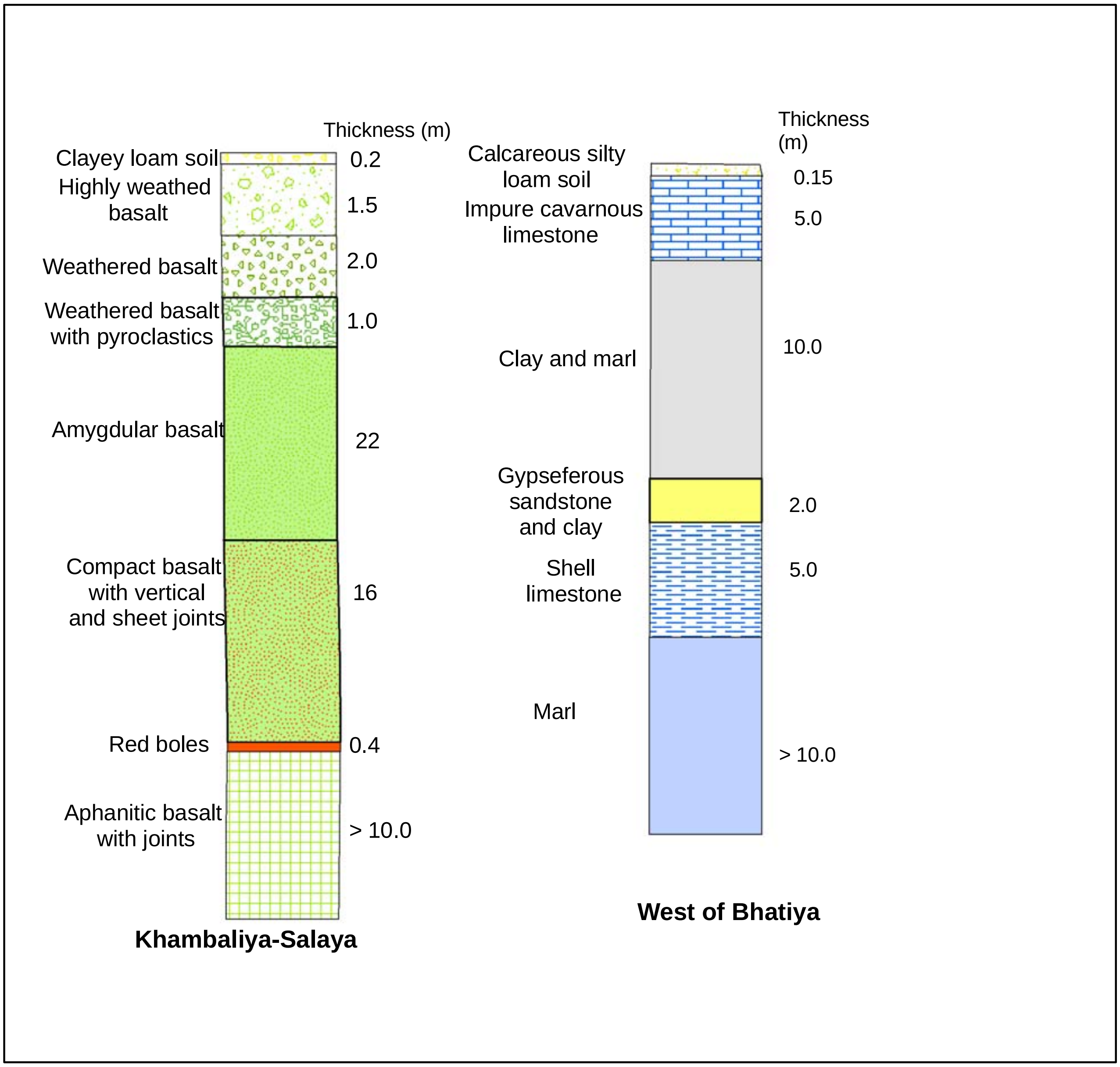

Fig. 4. Typical geological sections of Deccan Trap (Khambaliya) and Gaj Formation(West of Bhatiya) .

Repeated drying of these reservoirs within a period of 5 to 8 months leads to formation of salt encrustation on the upper surface of the reservoir beds such as at Ghee, Sani and Bhratu II dams. This encrusted salt enters the shallow aquifer after the precipitation enhancing salinity of groundwater locally.

OCCURRENCE OF GROUND WATER

Underground water occurs and flows along pore-spaces, cracks, fissures, shears, faults, cavities and other openings within the country-rocks and its availability for the water supply depends mainly on the porosity and permeability of the rocks in which they occur. The distribution of ground water in a region depends on the nature and structure of rocks and soils forming the country. Recharge of ground water depends on the drainage basin area, precipitation and infiltration rate. Infiltration rate depends on the lithology, slope and drainage characteristics. The area is having low precipitation (310 to 555 mm /year), limited drainage length and poor infiltration rate. Basalt in general is poor ground water aquifer but at places due to secondary permeability it forms good groundwater potential zones. Deccan basalt province generally yields fresh ground water. In this area at shallow depth ground water occurs in weathered tholeiite basalts, dissected by joints and having interconnected vesicular cavities. It also occurs at deeper levels along the sheared and weathered permeable contacts of basaltic flows (Cook, 2003). Picrite basalt forms relatively poor aquifer. The acid igneous rocks (granophyre, granite porphyry and rhyolite) are relatively less weathered and jointed, therefore, form poor ground water source in the area. Storage capacity of basalt is very less. Ground water at depth occurs along major discontinuities (shears, joints and faults). Ground water in Bhatiya Formation occurs at shallow depth along the contact of basalt and overlying laterite. This water is not potable due to its brackish nature.

Gaj Formation (limestone, marl and gypseous clay) is having multiple aquifers. In general groundwater in this formation is brackish due to the inherent salinity of rocks. However, ground water at shallow depth (4 to 6 m) is fresh generally after monsoon due to displacement and replenishment of saline water by the rain water along joints and shears. The discharge rates in this formation are poor.

Ground water in Dwarka Formation (flaggy and well jointed limestone) is potable but the discharge rates are poor. Rocks of Miliolite Formation (porous and permeable limestone and calcareous sandstone) form good aquifers with moderately high discharge rates (2000 to 5000 lph). Ground water in this formation occurs along porous and permeable rock mass and interconnected cavities. Miliolite limestone patches occurring in inland areas yields good quality of water whereas near coast it is brackish due to sea water intrusion.

Hot ground water (36° to 46° C) has been encountered in the Lalpur area parallel and adjacent to NNW-SSE trending fault for a distance of about 15km indicating thermal effect. In general, temperature of ground water varies between 25° and 32°C.

DISCHARGE RATE

Discharge rate of ground water depends on storage capacity of rocks, precipitation and size of river basin. Low discharge rate (<2000 lph) has been observed in the western part of the area occupied by Tertiary sediments and Picrite basalt. A few isolated zones of low discharge area are also located within the tholeiitic basalt area.

Moderate (2000 to 5000 lph) to high discharge rate (>5000 lph) rates (litre per hour) have been noticed in the wells located in tholeiitic basalt whereas the area covered by picrite basalt is having low discharge rate indicating that picrite basalt is relatively less permeable. Unusual high discharge rate (~7000 lph) around Ratala Kalavad area is observed where large size inter connected amygdules and vesicles are present in the tholeiitic basalt. Different discharge zones are superimposed on the geological map to show the relation between discharge rate and lithological characteristics (Fig. 5).

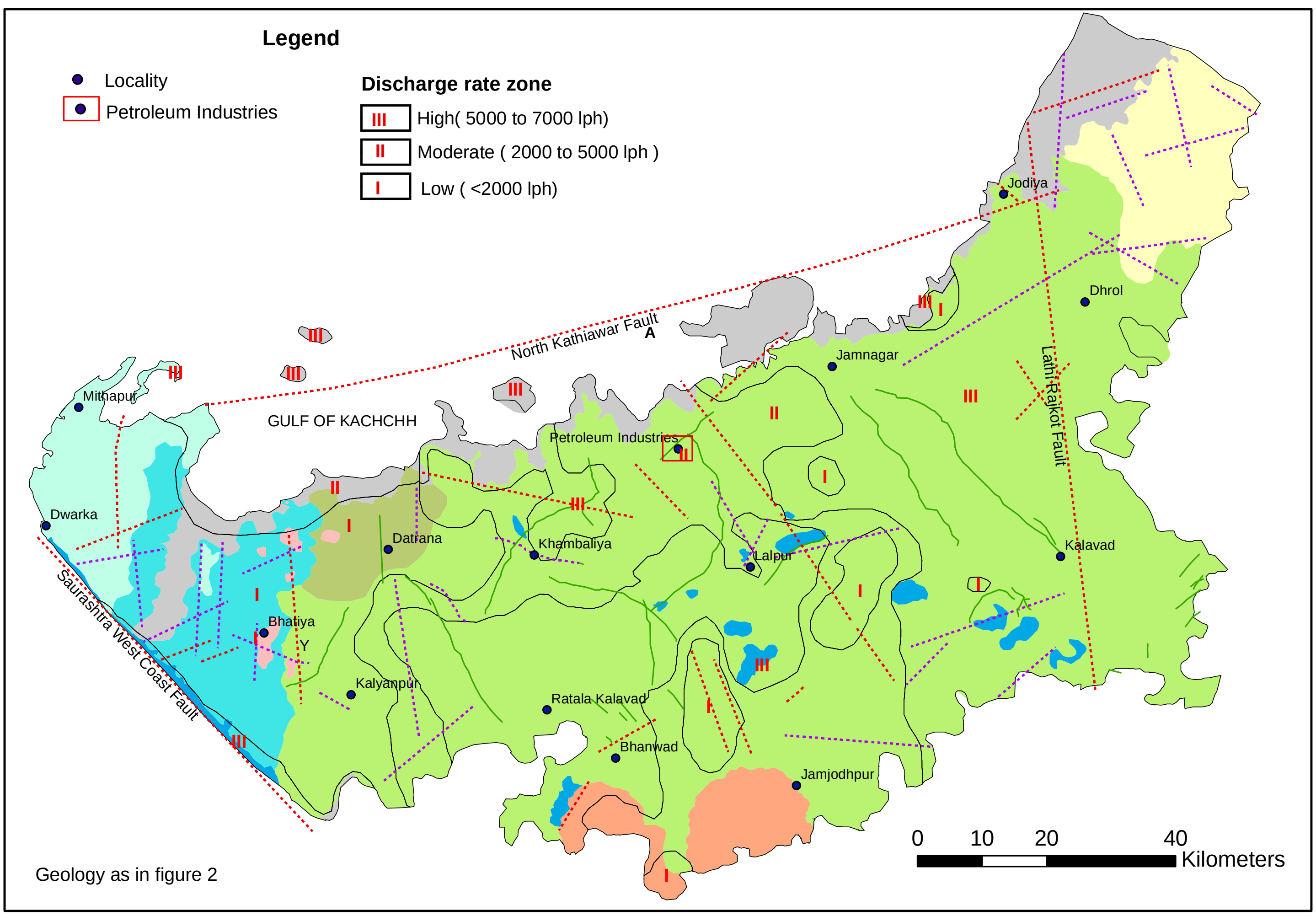

Fig. 5. Map showing discharge rate zones of ground water.

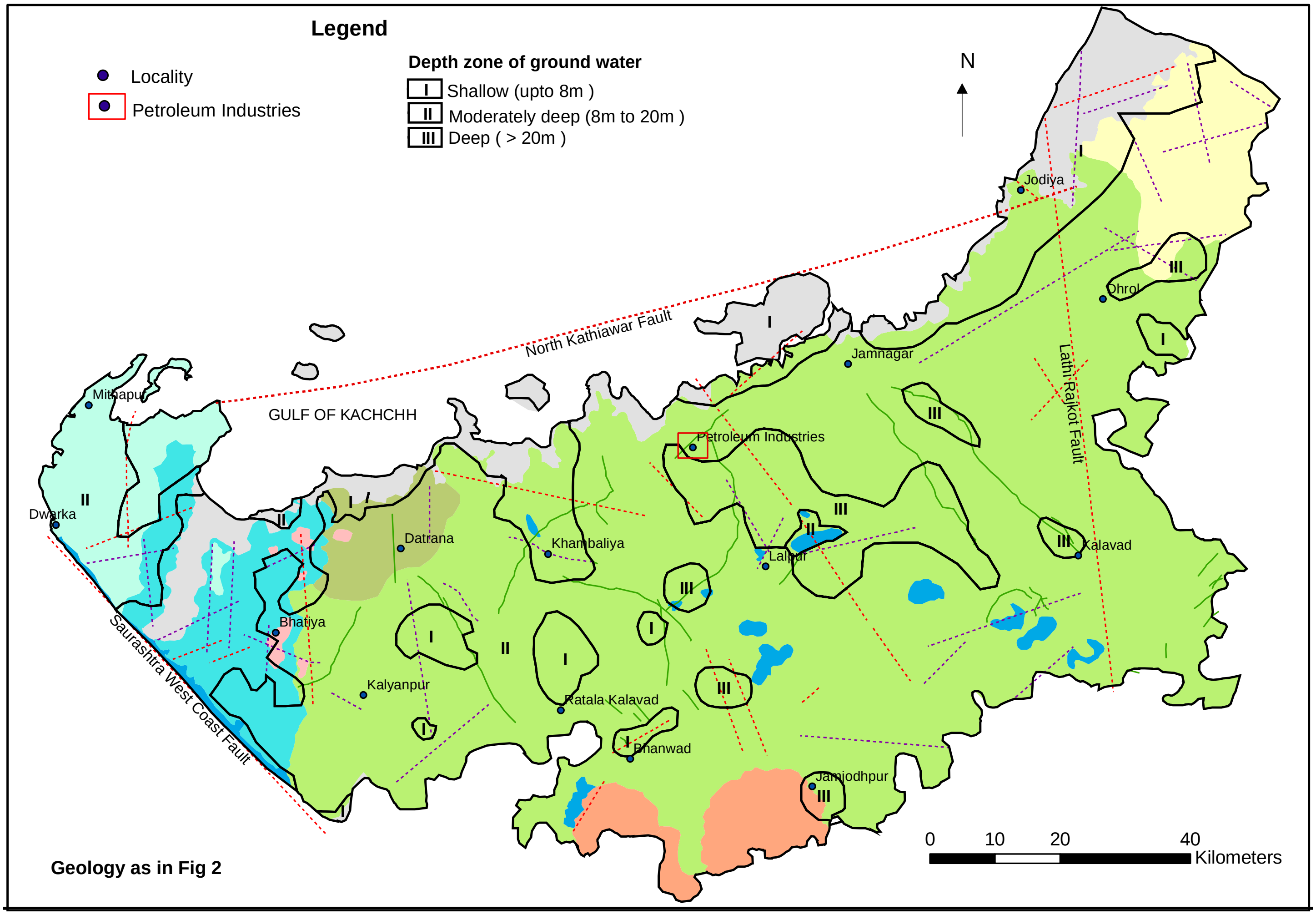

Fig. 6. Map showing depth zones of ground water.

The Gaj and Dwarka limestone overlying the Deccan basalt are having low discharge rate (< 2000 lph). Sharp change from high to low discharge rate is noticed from basaltic terrain to the limestone terrain. Contrary to this Miliolite limestone along coast and in isolated patches in river valleys show high discharge rate due to its permeable nature. Holocene non marine sediments are having high discharge rate (~ 7000 lph) and form good aquifer.

An elliptical zone of low discharge rate between Bhanwad and Jamjodhpur along and adjacent to fault has been observed indicating tight/ healed fault zone which acts as a barrier to ground water movement.

DEPTH OF GROUND WATER

Ground water in the area is being tapped up to 100m depth. However, in general it is being exploited up to 50m depth. Depth wise occurrence of ground water has been classified into three zones namely shallow (< 8m), moderately deep (8 to 20m) and deep (> 20m). These zones have been collated and correlated with the geology of the area.

Ground water occurs at shallow depth near coast in the Holocene sediments, Miliolite limestone, Dwarka and Gaj limestone. Landward ground water occurs at moderate depth in Deccan basalt, and also in Dwarka and Gaj limestone. Ground water at deeper level in pockets is encountered in the Deccan basalt area along the major lineaments, dykes and faults due to deep percolation of water (Fig. 6). These features are aligned in NNW-SSE direction. Prominent fault in the area is traversing along Sasoi River and dyke is traversing between Kalavad and Jamnagar. Other major Lathi-Rajkot fault aligned in N-S direction is not showing any influence in the distribution of ground water.

Ground water is being extracted from deeper levels of Sasoi River basin (Lalpur-Jamnagar belt) along its longer axis traversed by NNW-SSE trending fault. ENE-WSW trending dyke are acting as barrier for ground water movement in the east of Lalpur area.

GROUNDWATER HAZARD

Ground water hazards in the area are related with the natural causes and anthropogenic activities affecting ground water potential. In general, ground water potential in the area is low due to poor storage capacity of Deccan basalt and saline nature of Tertiary and Quaternary sediments. Over exploitation of ground water for the agriculture and industrial use without adequate recharge is responsible for enhancement of the salinity ingress in the coastal area and lowering of inland ground water table. Groundwater hazards identified in the area are due to inherent salinity of rocks, sea water ingression and chemical pollution of groundwater.

Salinity hazard

There is a problem of fresh ground water turning saline. The reasons contributing to this problem are manifold namely excessive withdrawal of ground water, less natural recharge, sea water ingress in lower aquifers, tidal water ingress in upper aquifers and poor land management.

Inherent salinity of rocks/ sediments.

Rocks of Gaj formation comprising limestone, marl and gypseous clay of Miocene age were formed in marine environment. The Gaj Formation exposed in the western part of the district in Okhamandal area is having multiple aquifers due to intercalation of clay layer in limestone. In general, groundwater in this formation is brackish (Fig.7) due to the inherent salinity of rocks. However, a few pockets of fresh ground water are available at shallow depth (4 to 6m) after monsoon due to flushing/ displacement of saline water from joints and shears by percolating rain water. Ground water in Quaternary sediments also occurs as saline water in the Jamnagar, Jodiya, Kalayanpur, Okhamandal, Khambaliya and other talukas due to its formation in marine environment and location near coast.

Sea water ingress.

Problem of salinity ingress is mainly confined along coast. With the advance in agriculture techniques people switched over from conventional techniques of lifting water with Mhot, to pumping sets. The electrification of rural areas gave further impetus to pumping of ground water with the help of electric

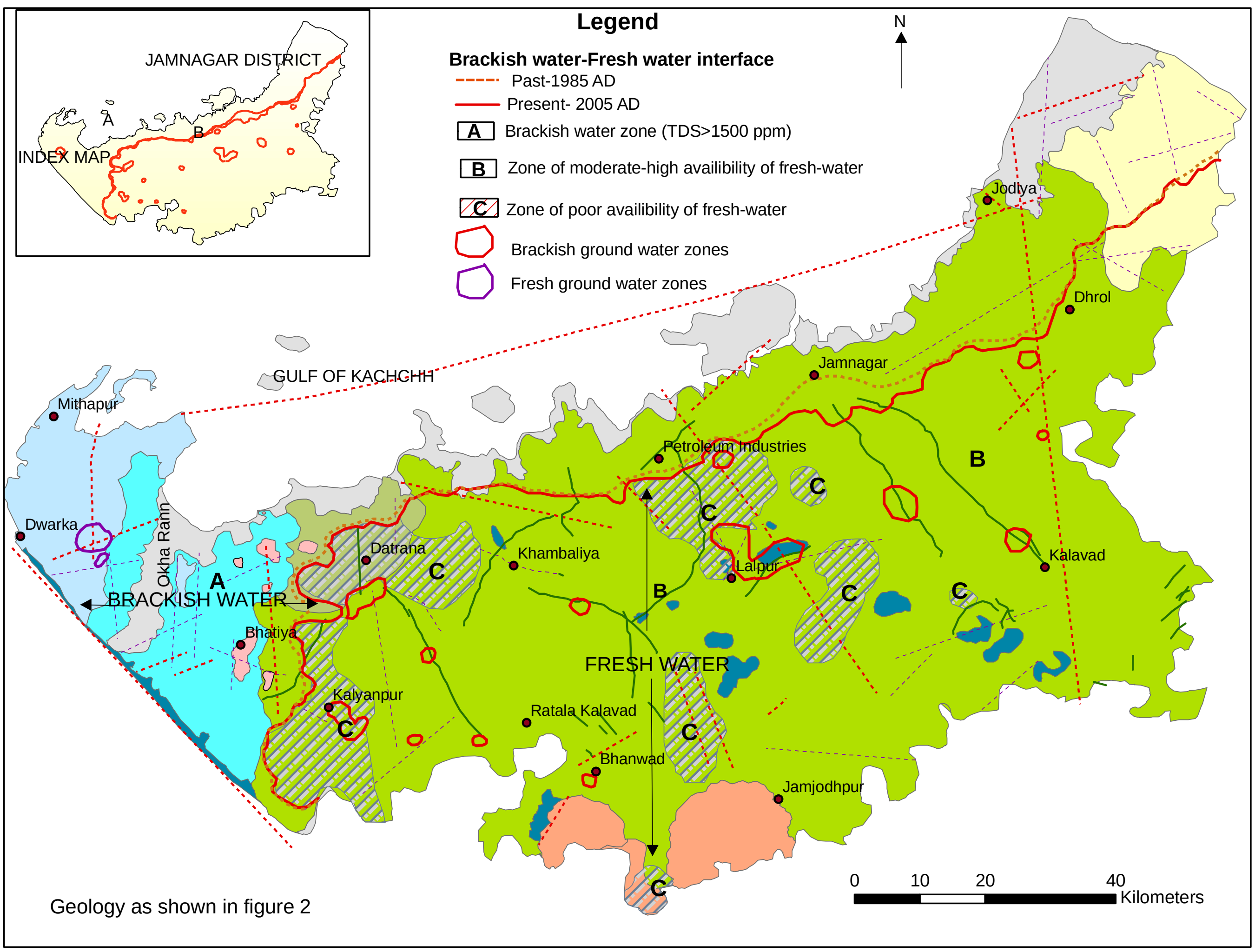

Fig. 7. Map showing brackish and fresh water zones and availability of ground water.

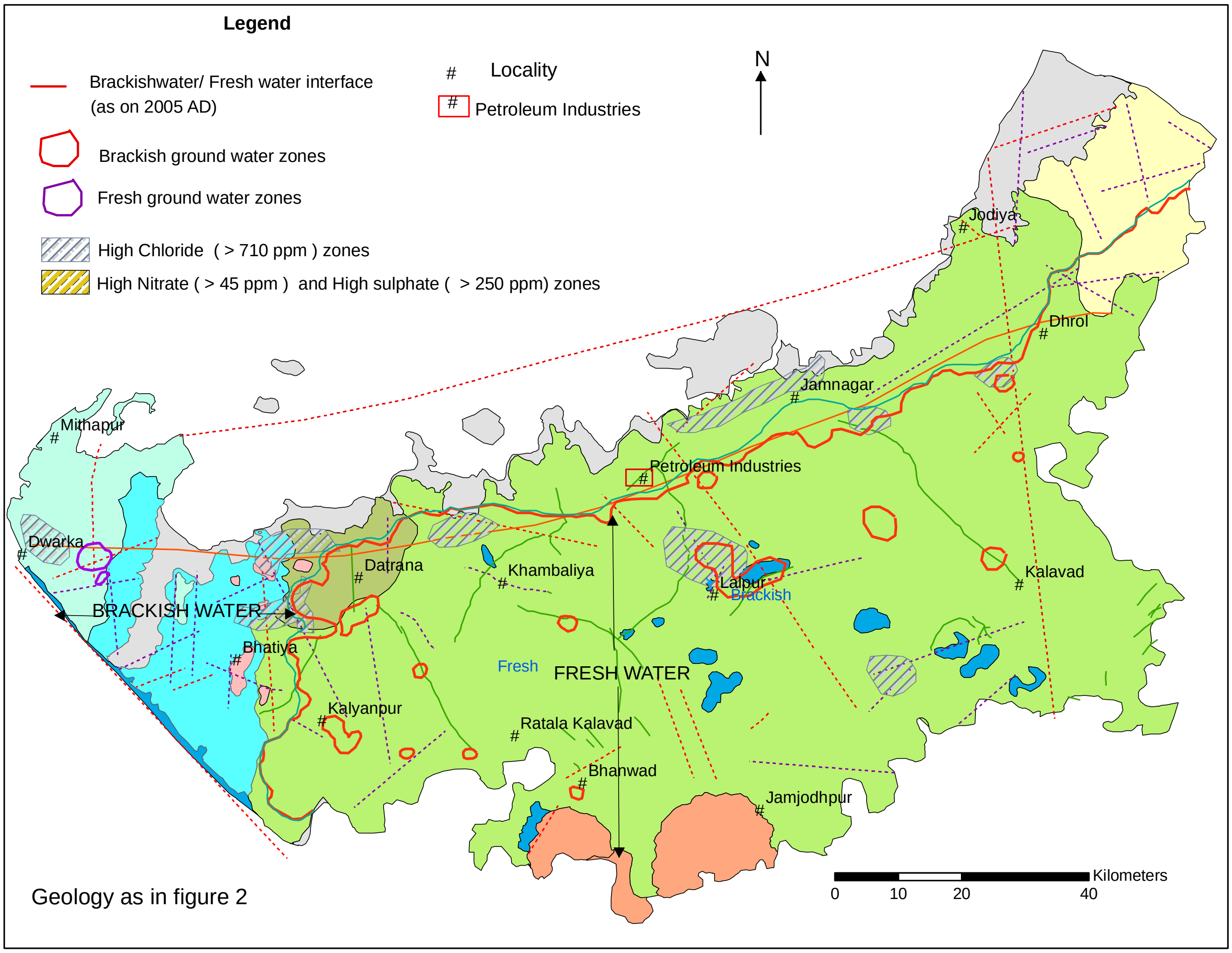

Fig.8. Chemical hazard map of ground water showing high chloride, sulphate and nitrate zones.

motors. The extraction rate of water from a well increased 5 to 10 times with the use of pumps. Excessive pumping of fresh water has lowered the ground water table in the area. This has resulted in sea water intrusion due to reversal of hydraulic gradient. Excessive withdrawal of ground water without proper recharge has led to rapid deterioration of quality of ground water. In addition, the tidal water traveling upstream along river channel has not only contaminated surface water but also affected the quality of ground water due to downward percolation of saline water.

The chloride is the dominant cation in sea water and normally occurs in small amounts in fresh ground water. On the other hand, bicarbonate is usually the most abundant negative ion in ground water and occurs only in minor amount in sea water. The higher ratio, therefore, indicates larger proportion of sea water. Ratio of chloride to carbonate plus bicarbonate [Cl/(CO_3+HCO_3)] in the ground water in the coastal belt area is about 50 indicating sea water intrusion. There is a gradual increase in the ratio on continuous pumping of wells in the affected areas. This indicates drawal of sea water when wells are pumped. The width of brackish water (>1500 ppm TDS) zone has increased up to 7.5 km within last 20 years (Fig. 7). The maximum landward movement of brackish water is around Jamnagar urban complex area which has expanded 35% within five years. Enhancement of mining activities for bauxite and high alumina clay in Limdi and Mevasa area (Kalyanpur Taluka) have also increased the salinity in this area due to over pumping from deeper mining pits causing movement of saline water form coast towards land.

In general, enhanced anthropogenic activities in the area have increased problem of ground water salinity affecting agricultural, industries and human lives. Based on the salinity, area has been demarcated as brackish water and fresh water zones. Within fresh water zone, area has been further divided into low, moderate and high potential zones depending on the depth of ground water and discharge rate. Low potential water scarcity and brackish water zones have been demarcated (Fig. 7).

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Chemical hazard

Based on the synthesis of geochemical, geological and geohydrological data various chemical hazard zones showing higher values of NO_3, SO_4, Ni, Pb, Co, Cl and Fluoride have been delineated in the area.

Chloride hazard.

High Chloride value zones of ground water (>710 ppm) detrimental for human consumption and for vegetative growth have been identified along the zones of brackish and fresh water interface (Fig 8). Isolated pockets of high chloride ground water also occur within basaltic area around Lalpur and Kalavad and in Dwarka limestone.

Fluoride hazard.

High fluoride (>1.5 ppm) in ground water occur in Dwarka limestone area. The southwest area of Jamjodhpur occupied by acid igneous rocks is also affected by high fluoride in ground water (Fig 9). Granophyres associated with felsite veins may be the source rock for fluoride in this area.

Chemical hazard in Industrialized Coastal Zone (ICZ).

Higher values of NO_3 (> 45 ppm) and SO_4 (>250 ppm) besides enrichment of toxic elements such as Ni and Pb have been observed in the Industrialized Coastal Zone (ICZ) of Jamnagar–Jambuda area. Lead (Pb) values grater than 0.50 ppm have been observed at Gulabnagar (0.080 ppm), Jambuda (0.074 ppm), Nwagaon (0.75 ppm) in the eastern part and also in the western part (0.060 ppm). High nickel (Ni) values ranging from 0.052 to 0.075 ppm have been observed in ICZ. Cobalt (Co) 0.081 ppm has been detected from the well water of Salaya town where shipping and fishing industries are located.

Chemical hazard in mega petroleum based industrial complex.

Ground water at Northeastern part of the mega petroleum based industrial complex, near Moti Khavdi is containing

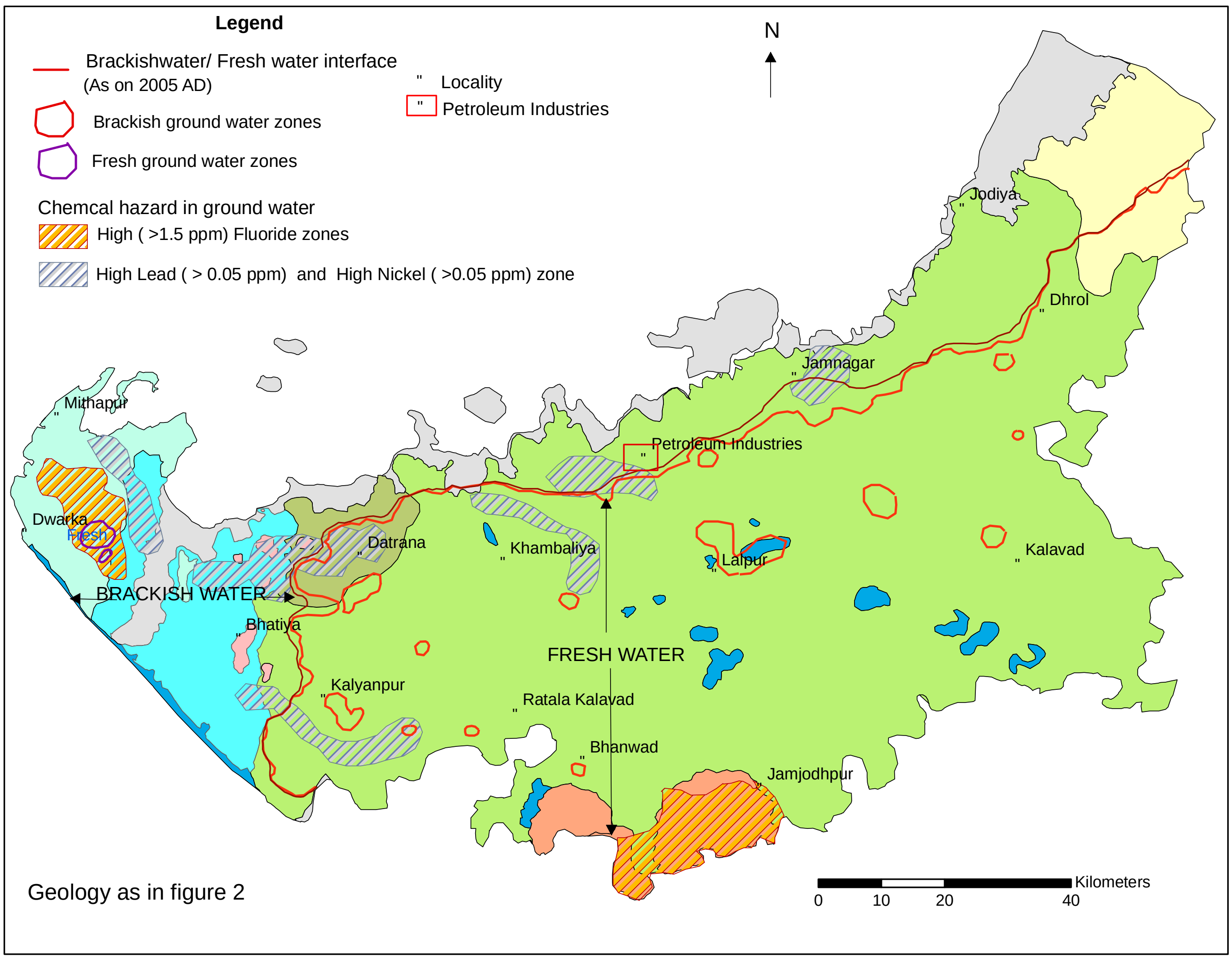

Fig.9. Chemical hazard map of ground water showing high fluoride, lead and nickel zones.

0.060-0.074 ppm Pb whereas in the northern fringe around Nani Khavdi it is 0.080 ppm. High Pb concentration is also observed in the well water in and around Jamnagar City. These values of Pb are more than the toxic limit (> 0.050 ppm).

Chemical hazard in west part of Jamnagar.

In the western part of the district, around Limbdi and Datrana where picrite basalt is exposed, higher values of Pb (0.068 - 0.127ppm) and Ni (0.125 0.250ppm) are detected from dug well water. This may be ascribed to fact that picrite basalt contains much higher values of Ni, Cr, Cu and Pb. This is also evident from the soil chemistry, as in-situ soil over Picrite basalt contains 5 to 10 times more Pb, Cu and Ni than normal tholeiitic basalt. Therefore, it appears that Pb and Ni have been subsequently dispersed from rock to soil and then into groundwater. Higher values of Pb and Ni in ground water around petrochemical industrial area of Jamnagar are also observed as a result of industrial waste. Higher concentration of sulphate and nitrate has been observed along the boundary of brackish-fresh water (Fig. 8).

CONCLUSIONS

Ground water hazards in this area are mainly related with the inherent salinity of rocks, sea water ingress and chemical pollution. Major part of the western district and coastal areas are facing problem of the potable water as well as water for agriculture use despite the construction of a number of check/ storage dams. Disposal of chemical wastes from industries without proper treatment has aggravated the problem. Overexploitation of the ground water in recent time due to rapid urbanization and industrialization without adequate recharge is the main cause of ground water problem. Increase in sea water ingress has been observed up to 7.5 km distance landward within last 20years. At present brackish ground water zone is extending up to 24 km inland in the coastal area. High values of Pb, Ni, NO_3 and SO_4 have been observed in and around industrial area. Higher values of Pb and Ni are also observed in the area occupied by picrite basalt. Higher concentration of sulphate and nitrate along the boundary of brackish-fresh water probably indicate that it is acting as barrier for migration of these elements. Integrated GIS study has helped in the identification of various ground water hazard zones and in understanding their relationship with the geology and anthropogenic activities in the area.

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