Possible contribution of River Saraswati in groundwater aquifer system in western Rajasthan, India*

*D. S. Mitra*** *and Balram Bhadu*

River Saraswati is believed to have flown through the Thar Desert, as reconstructed by several experts based on critical data gathered by them. A careful observation of the channel shows that in most of the places these are fault-controlled. Studies of palaeochannels in many parts of the world proved successful in identifying high-yielding freshwater zones. Presence of fault system accelerates the recharge process and down-flow of water gets maximized through fault planes during the wet period. The present work is an attempt to emphasize the contribution of palaeo Saraswati River to groundwater exploration in drought-prone areas of western Rajasthan.

Keywords: Aquifers, lineaments, neotectonics, Palaeochannel, subsurface ridge.

WESTERN Rajasthan, which is part of the Great Thar Desert, has no perennial and dependable source of water, and accounts for about 60% area of the state. The Thar Desert is bound in the northwest by the Sutlej River, in the east by the Aravalli range, in the south by the salt marsh known as the Rann of Kachchh and in the western side by the Indus valley. The terrain consists mainly of rolling sandy hills, which shows scattered growth of shrub and rock outcrops.

During the Pleistocene period the Himalayan mountains were under glacial cover and climate was fluctuating between glacial and interglacial phases. Around 40,000 yrs BP, the present Thar Desert enjoyed wet climate and greenery. Mythological River Saraswati/Vedic Saraswati (also known as Saraswati Nadi, Saraswati Nala, Sarsuti and Chautang in certain places, variously spelt as Sarasvati) is believed to have flowed during 6000–3000 BC from the melting glaciers of Garhwal Himalaya to Arabian Sea through the Thar Desert[1,2]. Several researchers agree about the existence of palaeochannels[2]. According to the Ground Water Cell of Haryana, a large number of water wells fall on these palaeochannels and their lithology is coarse sand/gravel of riverine nature. Now palaeochannels exhibit discontinuous drainage. Geomorphological and tectonic study of drainage of northern Haryana was discussed by Thussu[3] and Virdi *et al.*[4]. A good compilation of researches covering various aspects of Saraswati is available in Valdiya[5] and also posted by him at http://www.omilosmeleton.gr/pdf/en/indology/The_Saras-wati_was_a_Major_River.pdf.

The present work is an attempt to emphasize the contribution of palaeo Saraswati River to relatively deeper groundwater exploration in drought-prone areas of western Rajasthan.

Course of Saraswati

Palaeo-drainage network formed by several palaeochannels has been worked out by different researchers in western Rajasthan and neighbouring states, which is mainly buried under sand cover of the Thar Desert and parallel to the Aravalli Hills[6–8]. In the last couple of years with the advancement in satellite and remote sensing technology, palaeochannels have been mapped systematically. Different workers have different opinions about the number of courses of Saraswati River. Ghosh *et al.*[6,9] reported five, Yashpal *et al.*[10] reported one, Bakliwal and Grover[11] reported seven.

On the basis of aerial photographs and Landsat imagery, faults/lineaments and palaeo-drainage system in NW India have been delineated[6,7,9,12–15]. Several authors[16–18] have opined that upliftment of the Aravallis led to the westward migration of Saraswati River system due to fault-controlled movements. The faults have been and continue to be active, registering various sideways and up–down movements in the geological past. As a consequence, there was uplift and sinking or horizontal (lateral) displacement of the ground. Under such tectono-physiographic upheavals, the rivers and streams were frequently forced to change their courses, sometimes gradually, sometimes abruptly, as seen on satellite images.

*The views expressed here are not those of the organization which the authors belong to, but solely the opinion of the authors based on their own research and review of previous work.

The authors are working with the K.D.M. Institute of Petroleum Exploration, ONGC, 9, Kaulagarh Road, Dehradun 248 195, India.
**For correspondence. (e-mail: dsmitra@gmail.com)

Figure 1 shows palaeochannels traced on multi-sensor data identified by Gupta *et al.*[19] superimposed on a satellite image (Source: Regional Remote Sensing Service Centre (RRSSC), Jodhpur). A careful observation of the channel shows interesting results. In its upper reaches, in Haryana, a zone of linear, NE–SW trending palaeochannels can be seen. In the adjacent Himalayan foothills, a number of thrusts, running parallel/subparallel to the Himalaya with conjugate NE–SW faults are mapped in the field and on the satellite image. Reactivation of these thrusts during subsequent phases is recorded in many places. In the Punjab–Ganga Plains, a number of subsurface ridges have been identified in the geophysical data. This region is bound by two such ridges, the Delhi–Kalka Ridge (A, Figure 1) in the east and Delhi–Sargodha Ridge (B, Figure 1) in the south. This indicates that because of the unstable condition within this zone, the river abandoned its course frequently as it gradually migrated westward.

Beyond this zone the river flows linearly till it enters Pakistan, beyond which the style of mapped palaeochannels suggests rapid, large-scale meandering along with its westward shift. However, the meandering nature of the river abruptly terminates near Shahgarh and the river follows a linear course with change in direction (Figure 2). Such transformation occurs when river flowing on a gentle slope reaches a moderately steeper slope. Incidentally, the NW–SE trending Jaisalmer–Mari Arch (C, Figure 1) passes through this point separating a shallower sub-basin (Kishangarh) in the north and the deeper Shahgarh sub-basin in the south. The enhanced daytime thermal IR (Landsat TM Band 6) image of the area SW of the Jaisalmer–Mari Arch shows a series of linear, parallel, cool signatures, possibly moist river beds of palaeochannels (t1, t2, t3, Figure 3) corresponding to the single channel shown by various authors (arrow in Figure 4). This series of NW–SE trending parallel channels resulted due to the shifting of the river because of tilting of the block due to reactivation of the arch, as depicted schematically in Figure 3.

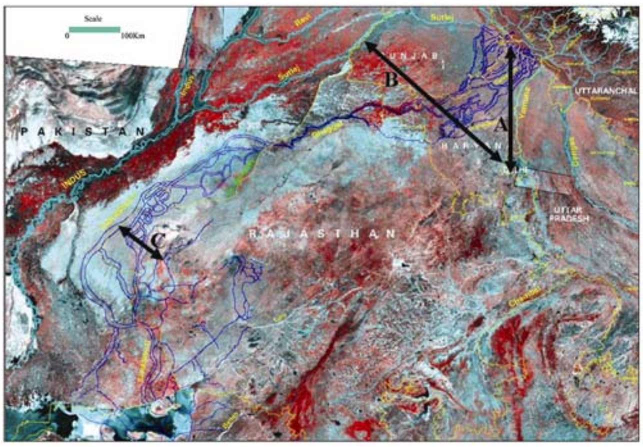

Figure 1. Satellite image showing the course of palaeo Saraswati River (Source: RRSSC, Jodhpur). A, Delhi–Kalka Ridge; B, Delhi–Sargodha Ridge; C, Jaisalmer Mari Arch.

Fault-controlled stream and groundwater augmentation

The studies of palaeochannels in many parts of the world proved successful for identifying high-yielding freshwater zones. Rajawat *et al.*[20] studied lineaments in the Luni River by superimposing the drainage, tectonic, hydrogeological map, groundwater potential and gravity contour maps and prepared the Rose diagrams. Lineaments trending NE–SW have controlled the basin configuration of the Luni River Basin. Mitra *et al.*[21] identified major lineament trends in Jaisalmer Basin based on satellite images, integrated with the subsurface faults identified on seismic data and observed that the general trend of palaeochannels of Saraswati River system is controlled by NE–SW to ENE–WSW major lineaments in the Jaisalmer Basin. However, these trends are not seen on the seismic data probably due to low resolution. The tectonic trend analysis of Jaisalmer Basin, as depicted by the Rose diagram (Figure 4), indicates continuous reactivation of older trends in the geological past. Many major and minor palaeochannels are aligned along these trends. The linearity of the river suggests that it was mainly following the major deep-seated week zones in the region.

Many authors have suggested that the Saraswati was a mighty river for a considerable period causing flood, depositing enormous volume of sediments and forming a delta. The spell of warm, wet climate caused plentiful availability of water in the Saraswati and its tributaries. Depending upon the bedrock/soil, groundwater recharge is normally through the rock matrix. Presence of a fault system accelerates the recharge process and down-flow of water gets maximized through fault planes during wet period. A groundwater well gives high yield if situated in a fractured reservoir than those situated in an unfractured zone in an otherwise similar condition due to facilitation by high porosity and permeability. The entire Saraswati River Basin is riddled with a multiplicity of long, reactivated and deep faults (as evidenced from straight segments of rivers/streams and supported by subsurface information), accelerating the downward percolation of water. In the present study, the regional lineaments as inferred from straight segments of river channels, supported by geophysical data for a selected area are shown in Figure 5.

To assess the occurrence of freshwater at greater depths, the electrolog data of different wells drilled in connection with hydrocarbon exploration in Jaisalmer and Barmer districts, Rajasthan have been evaluated[22]. Salinity of formation water (in terms of NaCl concentration) at formation temperature was carried out by determining resistivity using spontaneous potential (SP) electrolog and

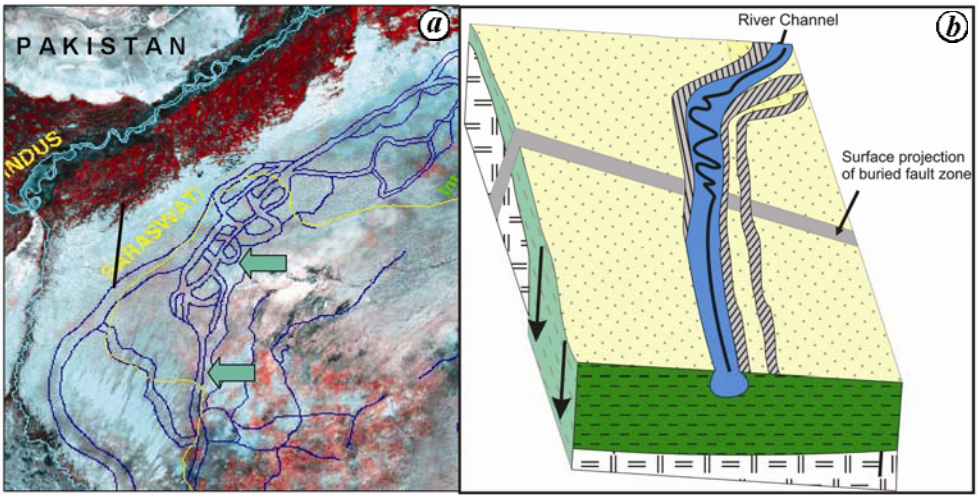

Figure 2. ***a***, Sudden change in the course of the portion of the river morphology (shown by arrow) due to presence of a buried structure. ***b***, Schematic representation of the process.

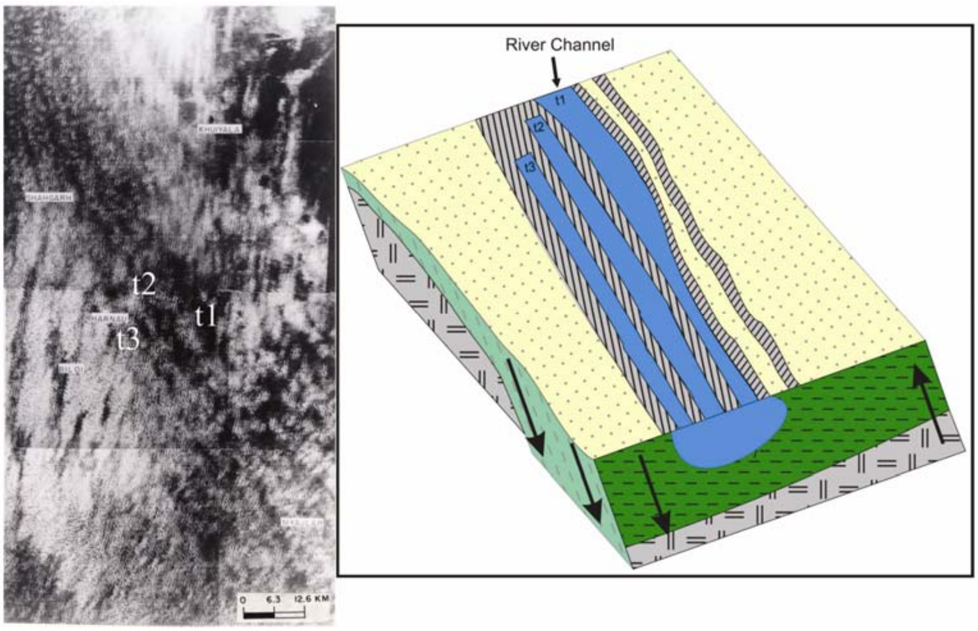

Figure 3. Shifting of river channel (t1 to t3), as seen on the satellite thermal IR image, due to tilting of the tectonic block as shown in the adjacent block diagram.

Rwa (apparent formation water resistivity) method in 11 wells drilled in Barmer District and 19 wells drilled in Jaisalmer District.

Wells drilled in the Barmer Basin show well-developed reservoir facies within various formations over the basement rock. The electrolog data of one of the wells under study show a high porosity and permeability aquifer containing freshwater just below the water table, but the salinity of formation water rapidly increases to 5 gpl with depth up to 300 m. No freshwater aquifer was observed in other formations containing sands on logs of any one of the wells drilled in Barmer District. Kumar and Sinha[23], based on similar studies in Barmer Basin, identified an 800 m thick aquifer zone located 350 m bgl consisting of well-sorted, medium-to-fine grained sand and having salinity ranging with depth from 5500 mg/l at the top of the aquifer to ~ 10,000 mg/l at the bottom. Interestingly, no major Saraswati River channel has been identified in the area. A number of linear river channels indicate the presence of faults in the area.

The study of groundwater occurrences in the western part of Jaisalmer District, western Rajasthan based on the electrologs of the wells drilled for hydrocarbon exploration reveals that the formation water has less salinity (up to 5 gpl) in shallow intervals (surface to 500 m) and 10 gpl up to 1000 m in and around the location A (Figure 6).

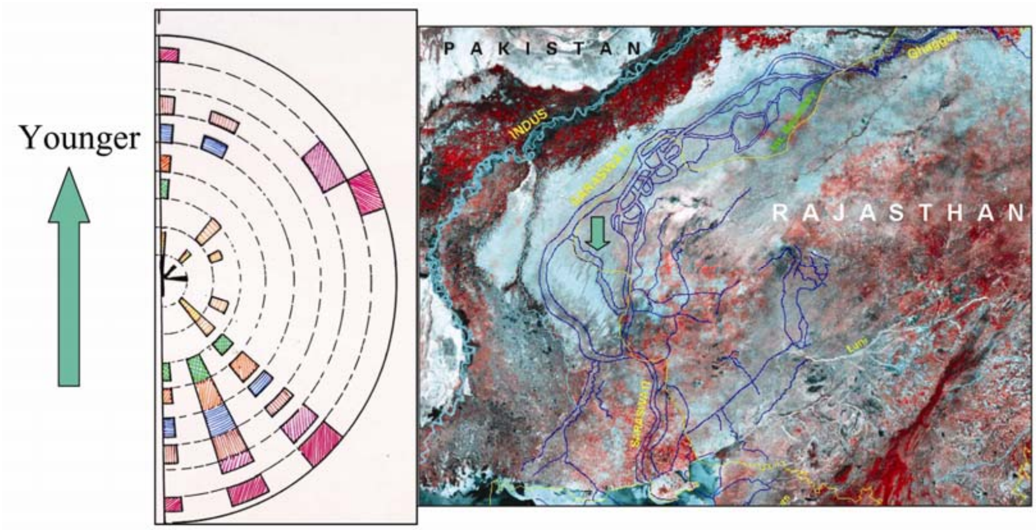

Figure 4. Rose diagram showing reactivation of older trends, as observed in successive magnetic, gravity and seismic maps. The younger trends are mapped on satellite images. The river and palaeochannels, as shown in the adjacent satellite image, are aligned along some of these trends.

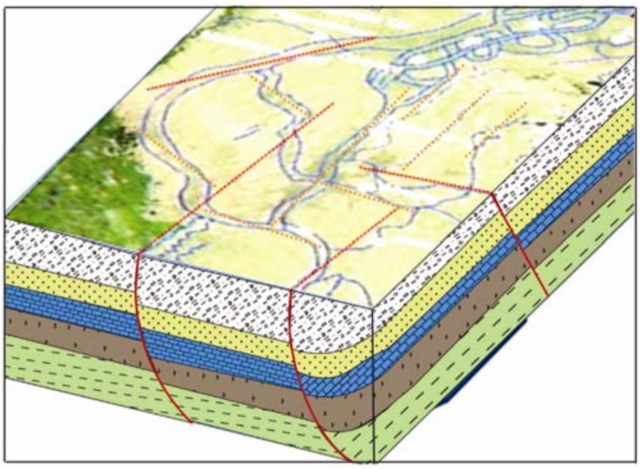

Figure 5. Block diagram showing fault-induced groundwater recharge to form deeper aquifers.

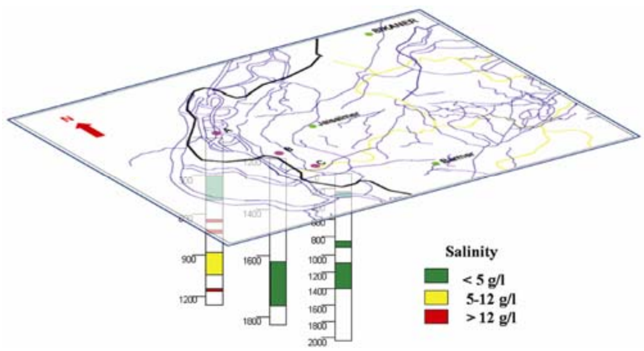

Figure 6. Log-derived salinity of deeper water (depth in m) as observed in various wells.

Beyond 1000 m, the salinity increases sharply with depth from 12 to 140 gpl and even more. However, in some wells, a thin layer of deeper freshwater aquifer has been identified between 700 and 1200 m. Well A is one such example located within the Saraswati River channel and the subsurface data show presence of faults parallel/subparallel to the Saraswati River channel trend in the area. This shows that the faults might be extending up to the surface and acting as conduits for groundwater percolation. Tripathy *et al.*[24] made an attempt to decipher regional disposition of low-salinity water-bearing layers observed on well logs in the study area using 2D seismic data. However, due to non-suitable acquisition parameters and lack of specific signatures, the desired result could not be achieved.

In the southwestern part of Jaisalmer District, Ghosh *et al.*[22] identified a deeper freshwater aquifer between 1600 and 1750 m bgl in well B. SP log response reversal confirms the presence of relatively fresher water. Detailed formation analysis reveals that four thick sands totalling 50 m of thickness contain freshwater having salinity of 4 gpl. In another well (well C), a number of sand layers containing freshwater (salinity ranging between 1.9 and 5 gpl) within 250–1450 m bgl were identified. Both these wells are near a major N–S trending Saraswati channel and in the subsurface faults with similar trends have been observed.

Figure 5 depicts a generalized model to explain the possible presence of deeper aquifers in Jaisalmer Basin. Water moves primarily through fault-induced fractures in younger unconsolidated sediments. In the northwestern part, the younger continental formation exhibits less salinity values than the older marine formations having limestone units. However, in some cases the water entrapped in the sandstone units occurring as lenses or thin/thick beds, within them, is relatively fresher. In the southwestern part, the presence of freshwater has been mainly reported from the continental Lathi Formation of the Jurassic period.

The present study is an attempt to explain the presence of relatively freshwater at greater depths, with inferences based on oil well data. The spatial distribution of the aquifer could not be mapped because of the limitations of the available seismic data and non-availability of water samples for age and source determination.

Conclusion

The Thar desert, once wet and lush with greenery, is now dry and under water stress due to frequent droughts and erratic rainfall. Most of the water has evaporated from the surface water bodies due to subsequent dry and hot climate. Another possible reason for water scarcity is that it has percolated down through the faults/lineaments which are prevalent, as revealed in neo-tectonic studies. Further, this water has contributed to the recharge of the existing aquifers, either shallow or deeper.

It is well known that the groundwater table in the area, at present, has gone down drastically and the quality of groundwater has also deteriorated. Using this perspective, the contribution of Saraswati River to relatively deep groundwater resources needs to be studied scientifically. Though exploration and exploitation of deep groundwater resources is costly and time-consuming, to mitigate water scarcity these so-far unexplored resources need attention. This kind of resource is of utmost importance to mankind for healthy growth of the population in water-scarce areas.

1. Bhardwaj, O. P., Vedic Saraswati. *J. Indol. Stud.*, 1987, **2**, 38–58.
2. Bhadra, B. K., Gupta, A. K. and Sharma, J. R., Saraswati Nadi in Haryana and its linkage with the Vedic Saraswati River – Integrated study based on satellite images and ground based information. *J. Geol. Soc. India*, 2009, **73**, 273–288.
3. Thussu, J. L., Role of tectonics in drainage migration in Punjab–Haryana plains in recent times. In *Vedic Saraswati: Evolutionary History of a Lost River in Northwest India* (eds Radhakrishna, B. P. and Merh, S. S.), Geological Society of India, Bangalore, 1999, vol. 42, pp. 205–217.
4. Virdi, N. S., Philip, G. and Bhattacharya, S., Neotectonic activity in the Markanda and Bata River basins, Himachal Pradesh, NW Himalaya: A morphotectonic approach. *Int. J. Remote Sensing*, 2006, **27**(10), 2093–2099.
5. Valdiya, K. S., *Saraswati: The River that Disappeared*, Universities Press (India) Ltd, Hyderabad, 2002, p. 116.
6. Ghosh, B., Kar, A. and Hussain, Z., The lost courses of the Saraswati River in the Great Indian Desert: New evidence from LANDSAT imagery. *Geogr. J. London*, 1979, **145**(3), 446–451.
7. Kar, A. and Ghosh, B., The Drishadvati river system of India – An assessment and new findings. *Geogr. J.*, 1984, **150**(2), 221–229.
8. Sharma, J. R., Srinivasan, R. and Dhabriya, S., Studies on palaeo/buried channels of Kantli river (western Rajasthan) using IRS-1A Satellite data. In Abstract Volume, International Symposium on Evolution of Deserts, Physical Research Laboratory, Ahmedabad, 1992, pp. 187–189.
9. Ghosh, B., Kar, A. and Hussain, Z., Comparative role of Aravalli and Himalayan river systems in the fluvial sedimentation of Rajasthan desert. *Man Environ.*, 1980, **4**, 8–12.
10. Yashpal, Sahai, B., Sood, R. K. and Agarwal, D. P., Remote sensing of the 'lost' Saraswati River. *Proc. Indian Acad. Sci., Earth Planet. Sci.*, 1980, **69**, 317–331.
11. Bakliwal, P. C. and Grover, A. K., Signature and migration of Sarasvati river in Thar desert, western India. *Rec. Geol. Surv. India*, 1988, **116**(3–8), 77–86.
12. Kar, A., A hitherto unknown palaeodrainage system from the radar imagery of southeastern Thar Desert and its significance. In *Vedic Saraswati: Evolutionary History of a Lost River in Northwest India* (eds Radhakrishna, B. P. and Merh, S. S.), Geological Society of India, Bangalore, 1999, vol. 42, pp. 229–235.
13. Sahai, B., Unraveling the 'lost' Vedic Sarasvati. In *Vedic Saraswati: Evolutionary History of a Lost River in Northwest India* (eds Radhakrishna, B. P. and Merh, S. S.), Geological Society of India, Bangalore, 1999, vol. 42, pp. 121–142.
14. Nair, A. S., Navada, S. V. and Rao, S. M., Isotope study to investigate the origin and the age of ground water along the palaeo channels in Jaisalmer and Ganganagar districts of Rajasthan. In *Vedic Saraswati: Evolutionary History of a Lost River in Northwest India* (eds Radhakrishna, B. P. and Merh, S. S.), Geological Society of India, Bangalore, 1999, vol. 42, pp. 315–321.
15. Gupta, A. K., Sharma, J. R., Sreenivasan, G. and Srivastava, K. S., New findings on the course of River Sarasvati. *J. Indian Soc. Remote Sensing*, 2004, **32**(1), 1024.
16. Bakliwal, P. C. and Ramasamy, S. M., Lineament fabric of Rajasthan and Gujarat. *Rec. Geol. Surv. India*, 1987, **113**(7), 54–65.
17. Sinha Roy, S., Malhotra, G. and Mohanty, M., *Geology of Rajasthan*, Geological Society of India, Bangalore, 1998, p. 278.
18. Valdiya, K. S., *Dynamic Himalaya*, University Press, Hyderabad, 1998, p. 178.
19. Gupta, A. K., Bhadra, B. K. and Sharma, J. R., Saraswati drainage system of Haryana – satellite based study. In *Vedic Saraswati and Hindu Civilization* (ed. Kalyanaraman, S.), Aryan, Books International, New Delhi, 2008, pp. 46–64.
20. Rajawat, A. S., Sastry, C. V. S. and Narain, A., Application of pyramidal processing on high resolution IRS I-C data for tracing migration of the Saraswati River in parts of Thar Desert. In *Vedic Saraswati: Evolutionary History of a Lost River in Northwest India* (eds Radhakrishna, B. P. and Merh, S. S.), Geological Society of India, Bangalore, 1999, vol. 42, pp. 259–272.
21. Mitra, D. S., Bhoj, R. and Agarwal, R. P., Hydrocarbon exploration in Shahgarh and Myajlar Sub-basins of Jaisalmer Basin, Rajasthan, India using remote sensing techniques. *Indian J. Petrol. Geol.*, 1993, **2**, 31–42.
22. Ghosh, D. K., Chattopadhyay, T. and Mitra, D. S., Identification of deeper fresh water aquifer from well log data in Rajasthan, India – a case study. In Proceedings PETROTECH, 2007.
23. Kumar, A. and Sinha, R., Well field design for abstraction of high volume saline groundwater from Thumbli Aquifer, Barmer Basin, Rajasthan, India. In Proceedings 38th International Association of Hydrogeologists' Congress, 2010.
24. Tripathy, B. M., Mitra, D. S., Ghosh, D. K., Pal, S., Rana, S., Kaprosang, J. and Rao, M. R., Exploration for deeper unconventional aquifers – a feasibility study in Western Rajasthan based on information from drilled wells of ONGC. In Proceedings of Society of Petroleum Geophysicists, India, Kolkata, 2006.

Received 21 July 2011; revised accepted 4 January 2012