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Remote Sensing and GIS Based 3d Visualization of Groundwater Level Modification and Their Signatures: Pudukkottai District, Tamil Nadu

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ABSTRACT

The developmental index and the developmental planning of a Country/Nation mostly depend on its natural resources potential including water resources. The emerging of Remote Sensing and GIS has substantially reduced the problems of groundwater targeting in various aquifer systems. The groundwater aquifer system in Pudukkottai district is distinctly controlled by western crystalline, central Tertiary sandstone and eastern Quaternary sediments. While the groundwater behavior in crystalline is dominantly controlled by secondary porosity, in Tertiary formation and Quaternary sediments, it is controlled by the primary porosity. The analysis of groundwater levels of 1975, 1985 and 1995 under the 3D GIS environment and their integrations show that the groundwater system in Pudukkottai district is also controlled by the major tectonic features deduced from tectonic and fluvial geomorphological anomalies. The groundwater domes and basins are alternatively aligned in NW-SE direction in western crystalline segment and the groundwater ridge and valley is found in tertiary formation shows the N-S alignment. The groundwater ridge aligned along Gandavarvakkottai-Alangudi indicates that the groundwater movements obstructed by the upliftment of Mio-Pliocene sandstone in between the two N-S faults. The alternatively arranged groundwater ridge and valley in western crystalline are dominantly controlled by the NW-SE major lineaments/faults. The present study revealed that groundwater aquifer system in this region is also controlled by the tectonic grains.

Key words: GIS visualization of water levels, active tectonics, groundwater management

INTRODUCTION

The surface and groundwater systems is very enigmatic in crystalline, sedimentary and coastal aquifer systems owing to polyphase metamorphism, multiple deformations and the resultant frequent variations in composition, compaction, primary porosity and morphology of lineaments/fractures. Understanding of aquifer behavior and targeting of groundwater therefrom, have ever remained a complex task since decades in such hard rock crystalline aquifers area. The recent remote sensing technology has emerged as a credible tool in locating potential groundwater target due to varying spectral response of the rock types in different bands of satellite multispectral data (Bannerman, 1973; Lillesand, 1989; Kimblin, 1995) and vivid display of fracture/lineaments due to synoptic view provided by satellite imagers (Ramasamy, 1995; Kimblin, 1995; Kumar *et al.*, 1999; Kumanan and Ramasamy, 2001). At the same time, GIS technology has proved itself to be a powerful tool in groundwater targeting and management due to its credentials in storing, integrating and modeling huge volume of multi-thematic data related to various geological variables of the crystalline aquifer systems (Khan and Asif, 1997; Palanivel, 2000; Nagappan, 2003). These technologies have got many advanced credentials and proper utilization of them can lead in better understanding of the groundwater systems and there from variable strategies can be eveolved for groundwater targeting and management. with this idea, a study was carried out in Pudukkottai district, Tamil Nadu, India using a new techniques of visulating groundwater levels accomplishing "Spatial Analyst Module" of Arc GIS, from which the geosystem, hydrosystem and strategies for groundwater management were brought out.

Study area: The study area, Pudukkottai district, is located in the southeastern tip of Tamil Nadu state, India (Fig. 1). The study area is bounded in the North and Northwest by Tiruchirappalli

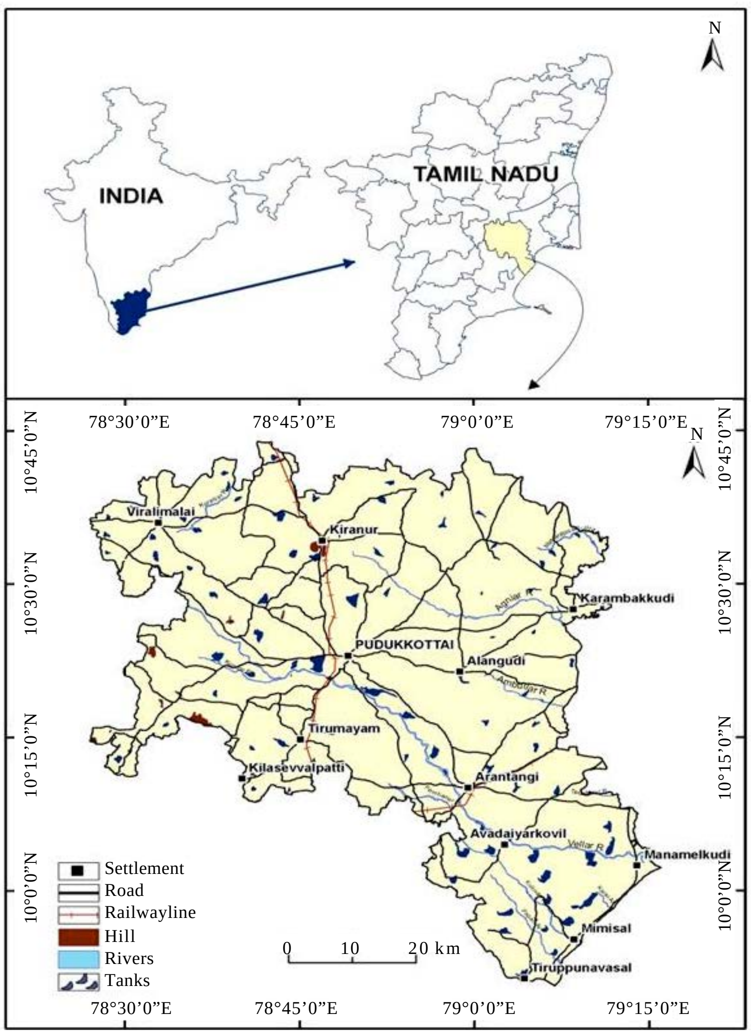

Fig. 1: Study area-Pudukkottai district

district, in the West, Southwest and South by Sivaganga district, in the Southeast by Bay of Bengal and in the east and northeast by Thanjavur district. The study area (Pudukkottai district) is located in between North latitudes 9°50' 00" and 10°40' 00" and East longitudes 78°25' 00" and 79°15' 00". The study area covers an area of 4663 km^2 with a coastline of 39 km and lies 600 feet above M.S.L. in the western part and gradually reaches the sea level in the eastern part. The Vellar, Agniar and Ambullar (Ambuliyar) are the main rivers draining the study area. Besides a number of streams and around 5400 water bodies are found to spread over the district.

In Pudukkottai district, there are three divergent aquifer systems, hard rock aquifer system in the western, sedimentary aquifer system constituted by the Tertiary Sandstone (Cuddalore Sandstone) in the central and quaternary aquifer system constituted by fluvial, fluvio-marine and marine systems in the eastern parts of the district (Fig. 2).

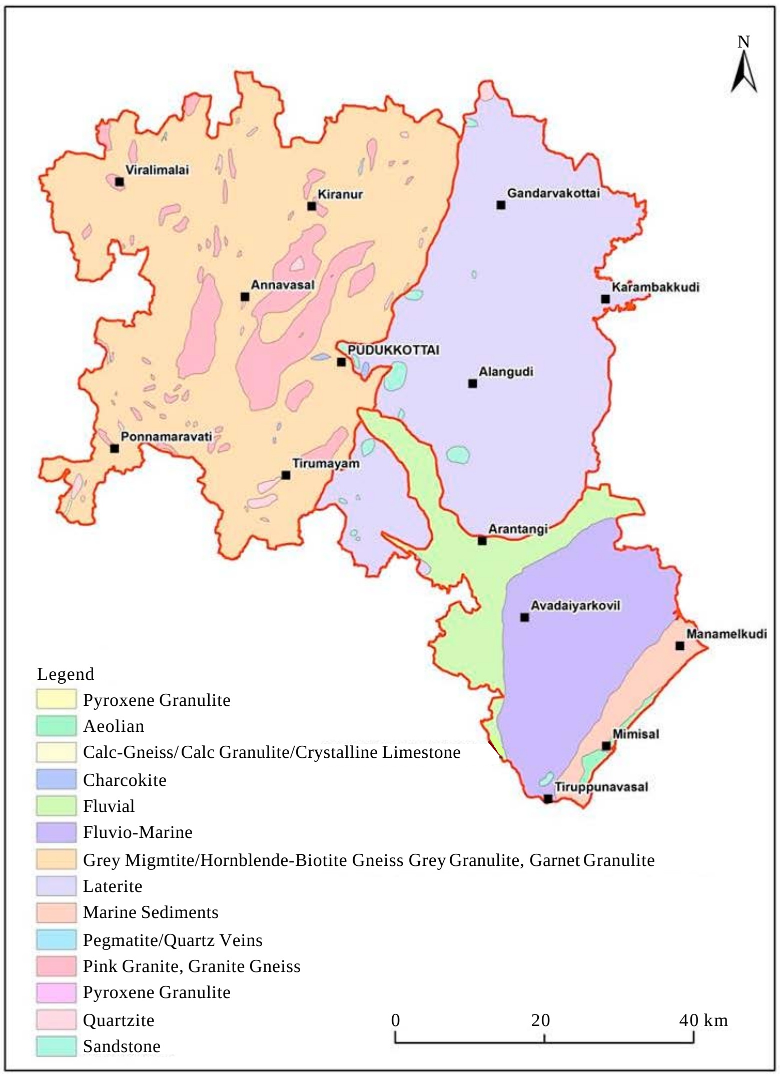

Fig. 2: Lithology map-Pudukkottai district

METHODOLOGY

Groundwater level-1975

Water level DEM-1975: From the monthly water level data collected from 58 observation wells (Fig. 4) for the year 1975, the mean annual water level was studied out for each well by averaging such 12 months data. Then geographical locations (X, Y) of the 58 wells and the corresponding mean annual water levels for 1975 (Z) were entered in ArcGIS and using 3D analyst module of ArcGIS, DEM was created for the 1975 water level data (Fig. 4a).

Water level features-1975: From the DEM, various water level features such as Domes, Basins, Ridges and Valleys were interpreted for the year 1975. For example, the zones of deeper water levels in the core encircled by the successive shallower water levels in the peripheries will appear as a peak in DEM, as DEM always represents higher values as peaks and lower values as deeps. But in the case of groundwater levels, as such 3D representation is just opposite to the ground reality, the above DEM was inverted using the provision available in ArcGIS 3D Analyst module and thus the actual water levels were represented with shallow water levels as peaks and deeper water levels as deeps/valleys (Fig. 4b). From, such GIS based 3D visualized groundwater levels, groundwater domes (wherever shallow water levels are encircled by successive deeper water levels), basins (vice-versa to the above), groundwater ridges (the long, linear and elliptical water level peaks enveloped by the deeper water levels) and groundwater valleys (vice-versa to the above). Such water level domes, basins, ridges and valleys interpreted for 1975 is shown in Fig. 3. Such an interpretation revealed three water level domes (1-3, Fig. 4b) in the drainage catchments of Agniar, Koraiyar and Vellar rivers and three basins (4-6, Fig. 4b) aligned in general N-S direction, east of Alangudi. Again, 1975 water level data showed a major groundwater ridge (7) with NW-SE orientation along Vellar river and two valleys (8 and 9), one along Kiranur and the other east of Alangudi (Fig. 4b).

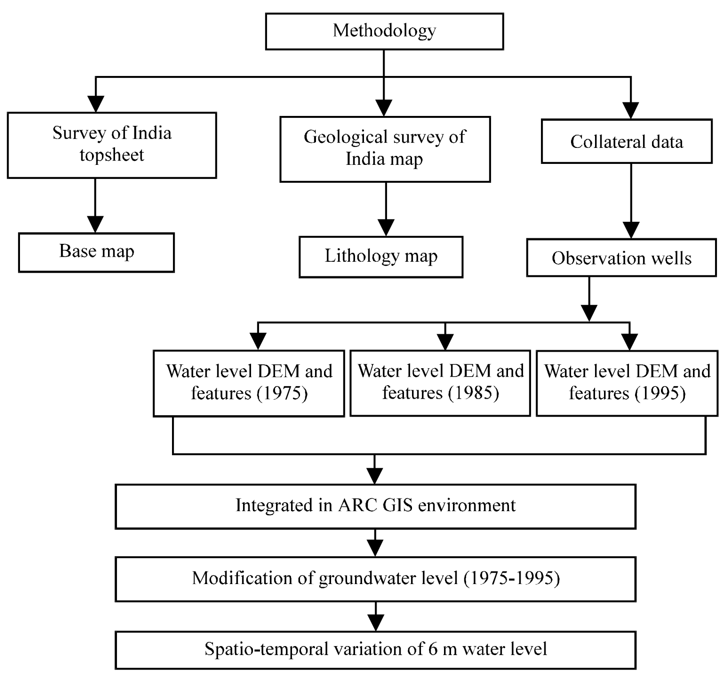

Fig. 3: Methodology

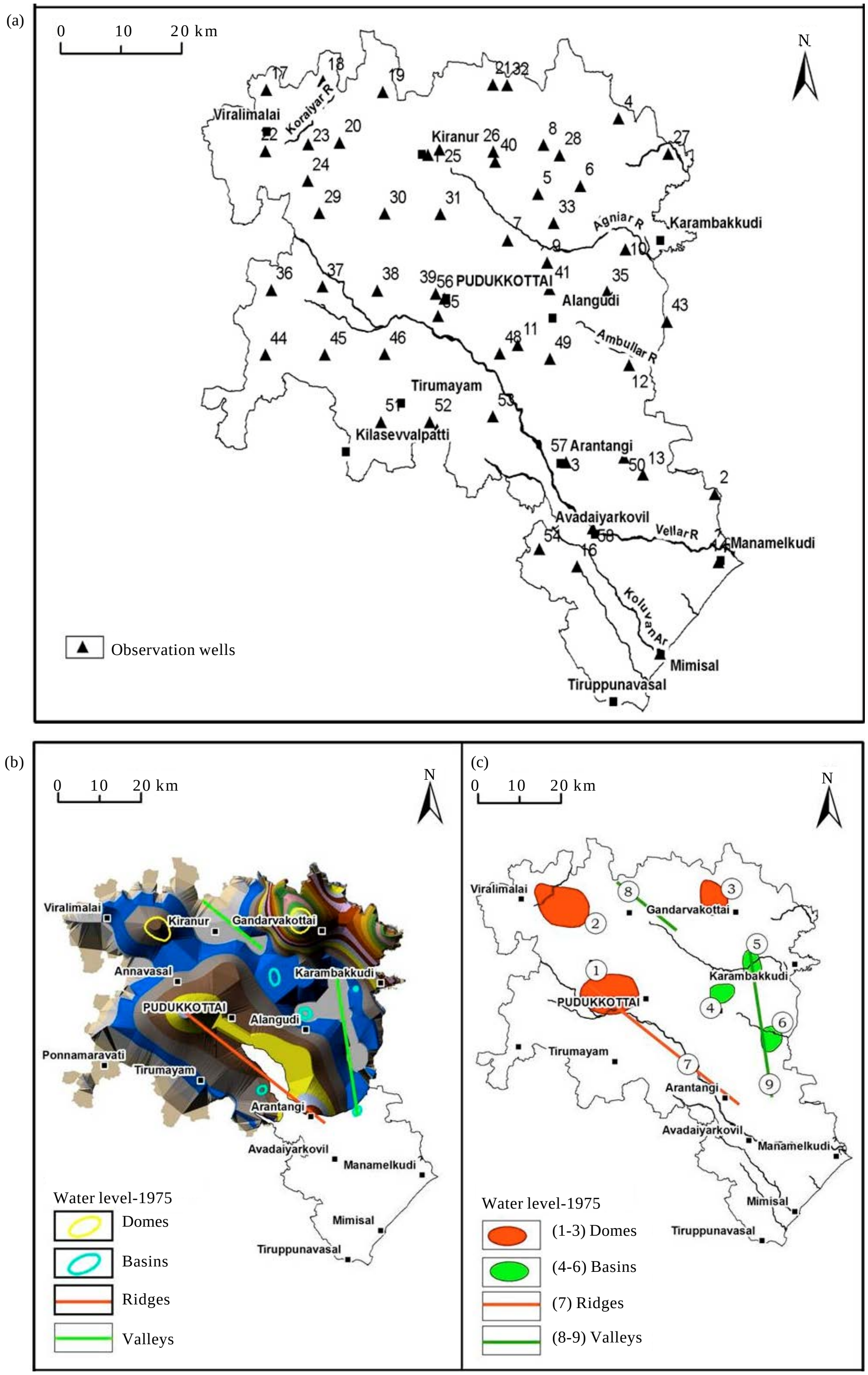

Fig. 4(a-c): (a) Observation wells-Pudukkottai district (b) Water level DEM 1975 and (c) Water level features 1975

Groundwater level-1985

Water level DEM-1985: In the same way, water level DEM was generated using by the mean annual water level of the year 1985 (Fig. 5a).

Water level features-1985: Such water level DEM of 1985 showed two water level domes, one east of Viralimalai (1) and the other east of Kiranur (2) and four small basins (3-6) in between Alangudi-Tirumayam (Fig. 5b). A major groundwater ridge (7) was seen with NW-SE orientation along Viralimalai-Pudukkottai-Arantangi coinciding with Vellar river. A small E-W ridge (8) and two N-S to NNW-SSE water level valleys (9 and 10) were also seen in the eastern part of the area (Fig. 5b).

Groundwater level-1995

Water level DEM-1995: Water level DEM was similarly generated for the mean annual water level data of 1995 (Fig. 6a).

Water level features-1995: Such GIS based 3D visualization of the water levels of 1995 has indicated one major dome (1) near Pudukkottai and a small dome (2) near Alangudi and three small

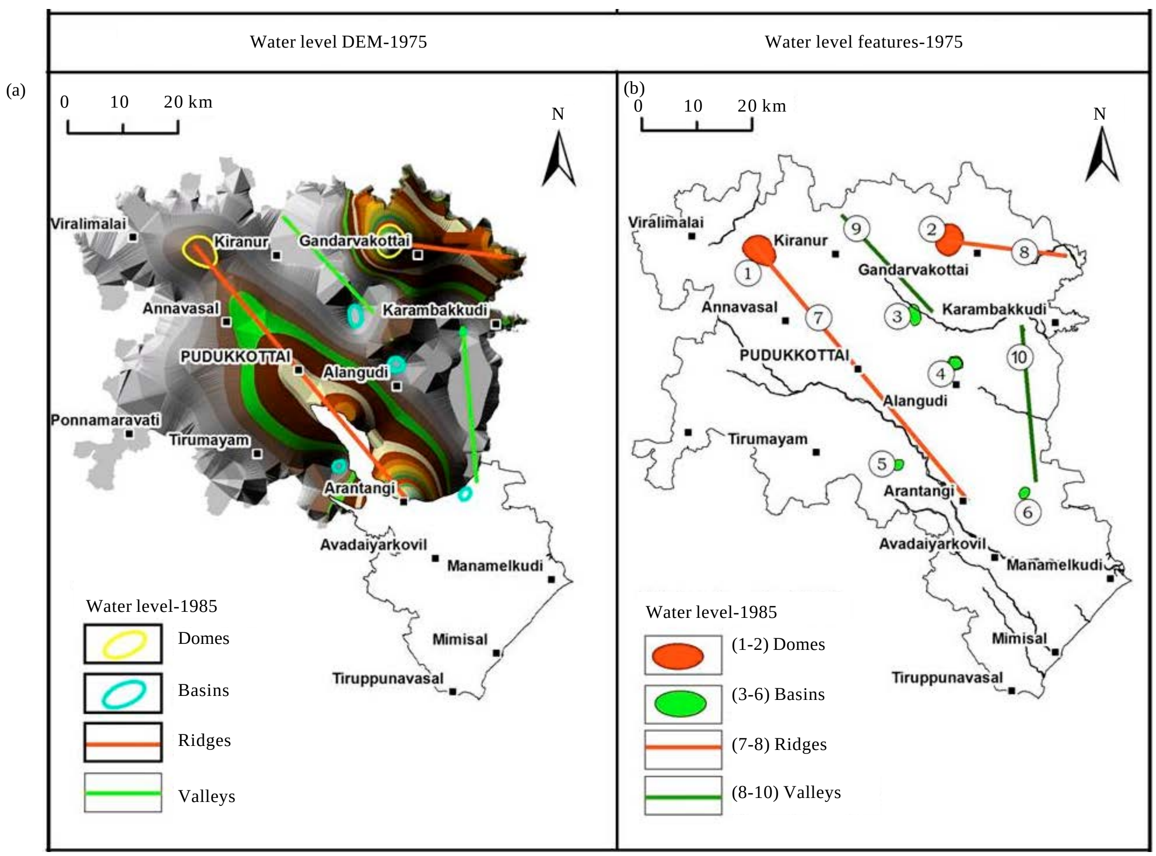

Fig. 5(a-b): Water level (a) DEM 1985 and (b) Features 1985

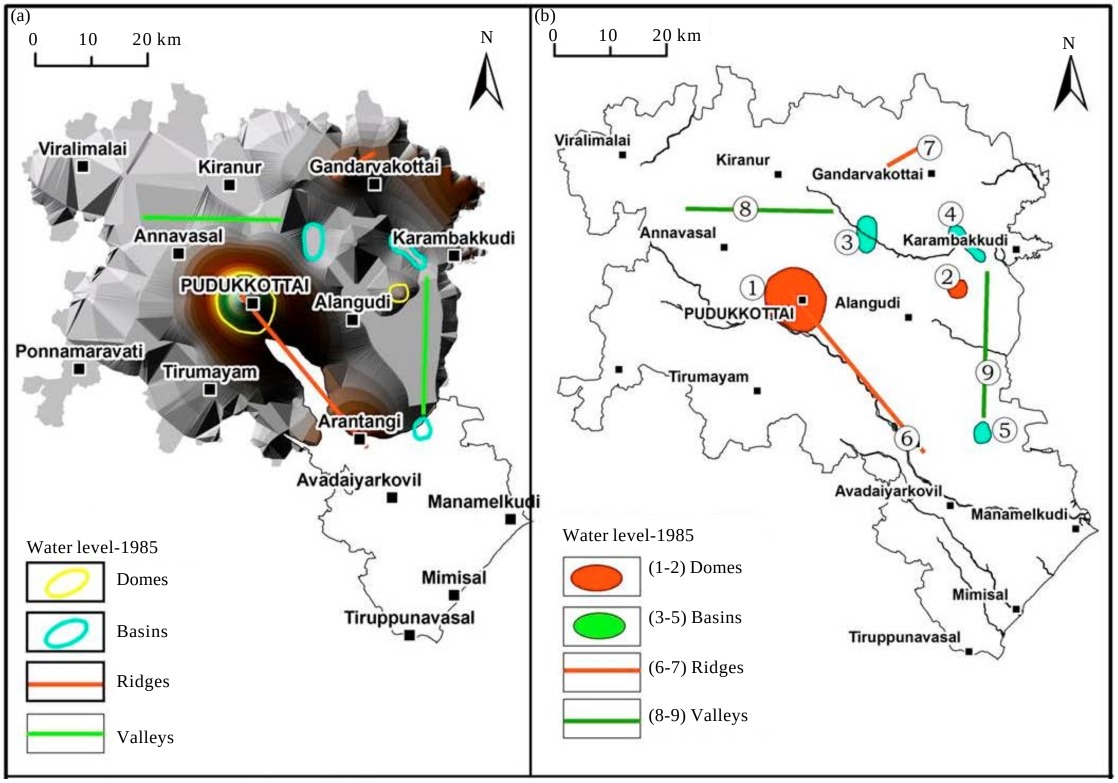

Fig. 6(a-b): Water level (a) DEM 1995 and (b) Features 1995

basins (3-5) as shown in Fig. 6b. The major NW-SE trending groundwater ridge (6) seen in the earlier year (1985) along Viralimalai-Pudukkottai-Arantangi (Fig. 5b) seems to have reduced its length and seen only in between Pudukkottai and Arantangi (6, Fig. 6b) in 1995 indicating the over exploitation of groundwater in Viralimalai area. In addition, a few scattered basins, one E-W groundwater valley (8) and another N-S valley (9) were also seen in 1995 data (Fig. 6b).

Modifications in groundwater levels (1975-1995): Subsequent to the detection of various water level features for the years 1975 (Fig. 4b), 1985 (Fig. 5b) and 1995 (Fig. 6b), these features of the three years were integrated using the overlay function of ArcGIS (Fig. 7). The same conditions revealed that the groundwater domes seen near Pudukkottai (1) and east of Kiranur (2) along the Crystalline-Tertiary contact have shrunk during these 10-15 years indicating the massive groundwater exploitation. The groundwater ridge seen in between Viralimalai and Arantangi in NW-SE direction (3) during 1975 has also reduced its length and seen only in between Pudukkottai and Arantangi during 1995 (4) confirming the above massive groundwater exploitation (Fig. 7). The oscillatory nature of the basins and the N-S aligned groundwater valley (5) seen in Alangudi area indicate the probable differential groundwater extraction in the Mio-Pliocene Sandstone which is a potential aquifer in Tamil Nadu.

The groundwater ridge along Viralimalai-Arantangi (3-4) and the complementary valley (6) along Kiranur are oriented in NW-SE direction (Fig. 7). Ramasamy *et al.* (2007) has observed similar alternatively arranged NW-SE groundwater ridges and valleys in the area west of the

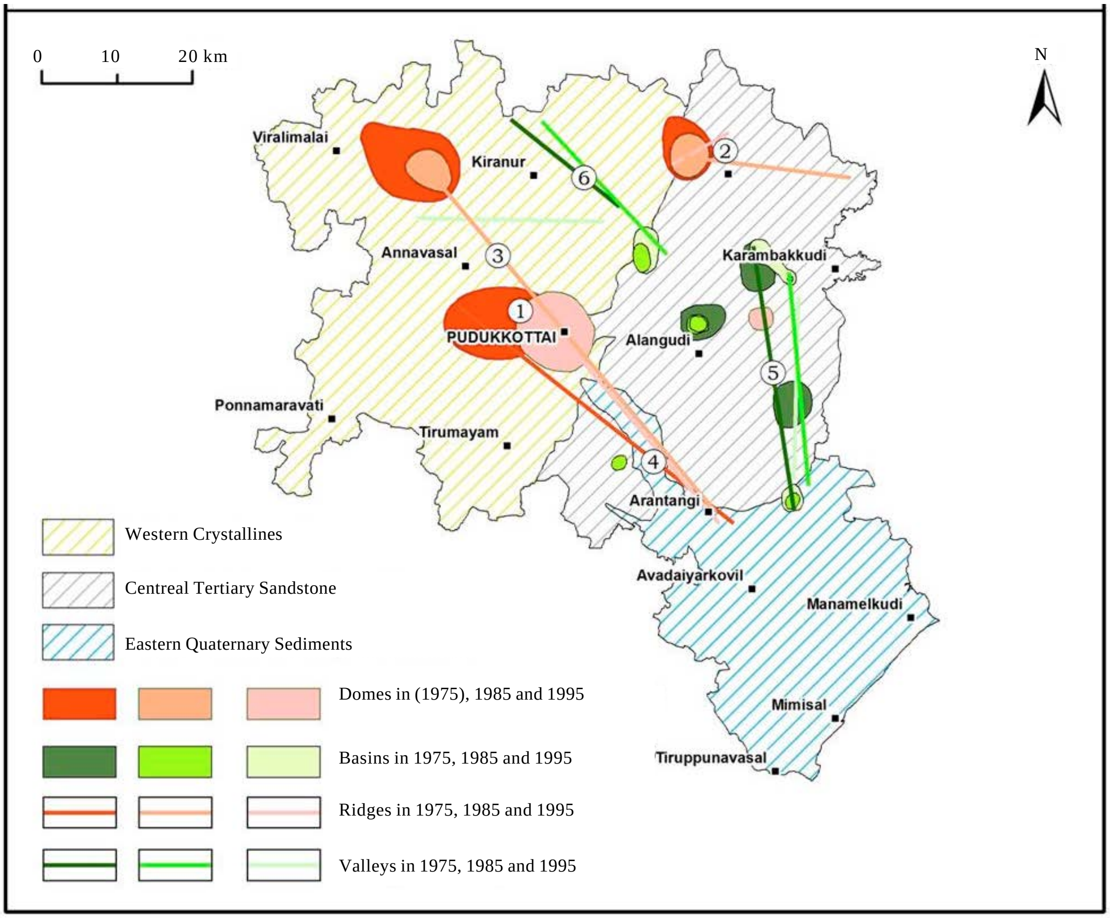

Fig. 7: Modification in groundwater levels (1975-1995)

present study area in parts of Madurai and Dindigul districts and attributed the same to NNE-SSW aligned compressive forces related Post Collision tectonics. So, the similar occurrences of NW-SE trending groundwater ridge and the valley in Pudukkottai district may also be related to Post Collision tectonics. Further, such groundwater ridge of Pudukkottai (3-4) and the complimentary valley of Kiranur (6) seem to have shifted towards north easterly in between 1975 and 1995 (Fig. 7) which confirms the still prevailing north northeasterly compressive force and its reflection in the water levels, as also observed by Ramasamy *et al.* (2007) in Madurai and Dindigul districts. While the above groundwater ridge (3-4) and the valley (6) were oriented in NW-SE direction, the groundwater valley (5) found east of Alangudi fell in N-S direction (Fig. 7). This leads to the surmise that such NW-SE groundwater ridge and valley, when obstructed by the NNE-SSW Crystalline-Tertiary fault and the Tertiary Sandstone, might have got deflected to N-S direction. This phenomenon has opened up some new ideas which of course warrants detailed studies.

Modifications of 6M water level: However, in order to confirm the above analysis, the 6 m water level was sliced individually for 1975, 1985 and 1995. This was done by representing the 6 m water level as a ribbon in GIS independently for each year and finally all the three layers were integrated

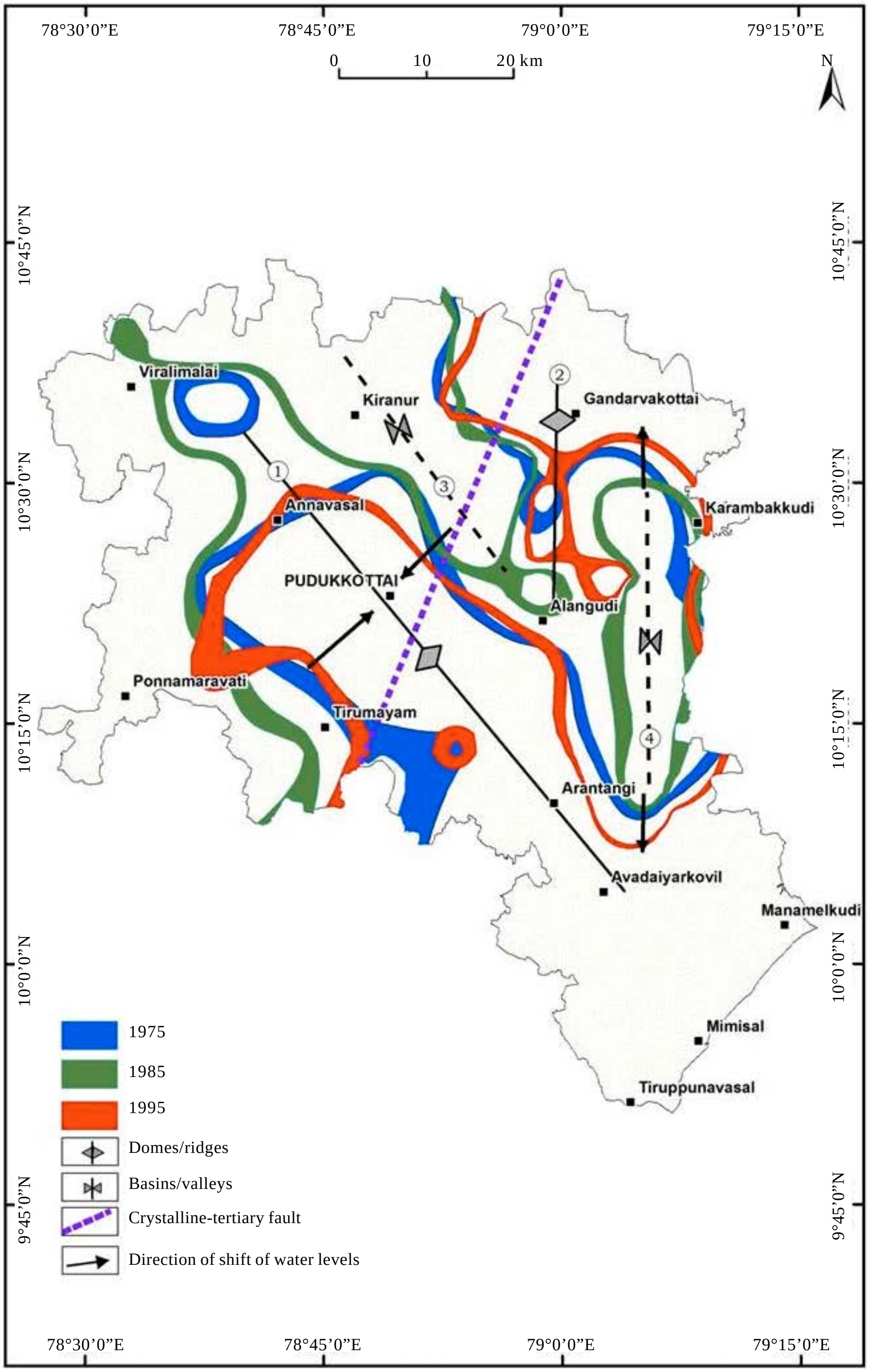

Fig. 8: Spatio-Temporal of 6 m water levels during 1975-1995

using ArcGIS (Fig. 8). The same has also indicated a NW-SE trending groundwater ridge along Viralimalai-Avadaiyarkovil (1), another N-S ridge (2) north of Alangudi area and two valleys

(3 and 4), one with NW-SE orientation along Kiranur and the other in N-S direction in the area west of Karambakkudi. Such alternate arrangement of ridges and valleys of 6 m water level also confirms the above reflection related to Post Collision tectonics.

In addition, while the groundwater ridges seen near Pudukkottai (1) and north of Alangudi have shrunk, the groundwater valleys seen along Kiranur and west of Karambakkudi (4) have widened both indicating the massive groundwater exploration (Fig. 8).

RESULTS AND CONCLUSION

The present 3D visualization of groundwater levels in GIS environment of 1975, 1985 and 1995 have shown the following:

- The GIS based 3D visualization of groundwater levels for the years 1975, 1985 and 1995 showed the shrinking of the groundwater domes/ridges and widening of groundwater valleys (Fig. 6) in the study area
- Again, the visualization of such groundwater ridges and valleys showed their alternate arrangement in NW-SE direction and their gradual shift towards northeasterly indicating the movement of the groundwater in a wavy pattern due to the northeasterly aligned Post Collision compressive force (Fig. 7)
- Turning of such NW-SE aligned groundwater ridges and valleys to N-S orientation in Tertiary Sandstone near Gandharvakkottai and Karambagudi region may indicate the obstruction of such northeasterly moving groundwater by the NNE-SSW aligned Crystalline-Tertiary fault and the resultant deflection (Fig. 8)

Thus, the present DEM based visulation of groundwater levels has brought out newer information on the interface dynamics between the geosystems and the hydro systems which can be effectively used for the management of groundwater resources. Various GIS based modeling indicate that aquifer in general is fracture controlled. Regionally the NNE-SSW Crystalline-Tertiary boundary fault zone and the NW-SE faults are the potential groundwater reservoirs. Further, such 3D visualization of groundwater levels can be effectively utilized in monitoring the recharges/discharges pattern and also for rapidly identifying suitable sites/basins for artificial recharge.

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