

GIS Based Semi Automated Extraction of Sites for Artificial Recharge

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Abstract: The artificial recharge has emerged as the only alternative to restore the alarmingly falling water table. Hence, various nations including India have embarked into major programs on artificial recharge. But maximum benefits can be achieved if only the sites are selected on geological and other terrain conditions. But many a times, as these structures are to be constructed on emergency basis, the scientific protocols could not be followed. To get over this, a computer model was developed on GIS based semi-automated extraction of artificial recharge sites. In this model, a set of seven geosystem variables/maps which control the overall infiltration were prepared and converted into spatial GIS databases showing the favorable (pervious) and unfavorable (impervious) zones for artificial recharge, imported to a specially written software in VB.NET called RECHARGE. The program has been written in such a way that the user can retrieve these geosystem maps from the computer showing only the favorable areas, integrate them and on the basis of number of variables coincided, suitable sites on various priorities for recharge can be displayed in the computer by following the tutored protocol provided in the software. This will be an useful tool, and further detailed studies would bring out generic software to benefit the larger cross section of the countries.

Keywords: Artificial, Automated, Extraction, GIS, Recharge, Semi.

I. Introduction

The unprecedented population explosion has led to the condition that the available surface water resources have become too inadequate to cope up to the demands of the human beings. This has further led to the massive mining of the groundwater reservoirs which started causing faster depletion of the water table in many parts of the world. While such population explosion has also triggered the contamination of the surface water resources adding further scarcity of the surface water resources, the massive exploitation of the coastal aquifers have led to the intrusion of the sea water into the potable coastal aquifers. Hence the planners, scientists and technocrats from all over the world have unanimously converged their philosophies towards restoring the fast falling groundwater table through artificial recharge schemes. The Indian sub-continent too is not an exception to this phenomenon and both Government of India and the federal Governments have embarked into artificial recharge schemes and plans.

But the artificial recharge itself is very complex, because the sites should be suitably selected so that the water being impounded for recharge must be quickly transmitted into the sub soil and the deeper part of the aquifer systems. The recent studies carried out around the world ([1], [2], [3]) and in India ([4], [5], [6]) show that varied geological parameters are to be considered for selecting suitable sites. The study carried out by [7] has brought out detailed information on how the suitable geological parameters can be identified and optimally amalgamated using GIS techniques to select not only the suitable sites for recharge but also in detecting site specific techniques of artificial recharge viz; percolation ponds, check dams, pitting, induced recharging, etc. However, the Government systems are constrained to select the sites for recharge in a shortest span of time and get it implemented in war footing when the heavy rainfall are forecast or drought situations are to be managed. So the need has come to develop techniques to select suitable sites for recharge and how the executors can select optimum techniques according to the site conditions. The coming in of Remote Sensing and GIS technologies are vested with adequate virtues to achieve this.

Keeping these constraints and needs of selecting suitable sites in quick span of time in mind, a GIS based semi-automated technique was developed to extract the suitable sites for artificial recharge by taking Pudukkottai district, India as the study area (Fig.1)

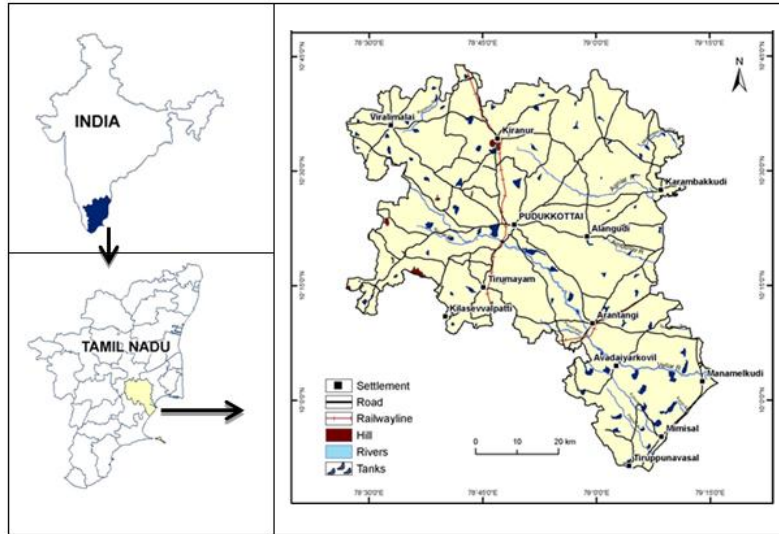


Figure 1 Study area – Pudukkottai district

II. Methodology In Brief

To achieve this objective a methodology was developed (Fig. 2) and for the same various thematic maps were generated on the geosystems viz; lithology, lineament density, depth to bed rock, geomorphology, slope, drainage density and water level as basic units. As this is an experimental cum demonstrative study, minimum, but all important geosystem parameters were taken as input data. These data sets were generated by collecting data from government and research institutions and also by updating some of the data using Indian Remote Sensing satellite data. Then these 7 thematic maps were converted into spatial GIS databases using ArcGIS. Further, depending upon the credentials of the sub variables of each of these seven geo system databases these were classified into two groups as favorable and unfavorable polygons in GIS as far as the artificial recharge is concerned. Then a special software was designed in VB .NET with Arcobjects to select the favorable zones in six geosystem parameters (except water level), integrate them using GIS overlay function menu of ArcGIS, prioritize the favorable zones into 3 categories, integrate such priority areas with water level data and finally identify the suitable zones for recharge. This can be accomplished by the user by clicking the Recharge main menu, and the software will display all the six geosystem layers, and on clicking them one after the other it will filter out the favorable zones in each individually. Then on clicking the menu “Data integration” the software will integrate such six favorable zones. Then on clicking Priority area-I the software will identify the polygons where more than four geosystem parameters have coincided in such an integrated layer. Then on further clicking the menu “Suitable area” it will integrate the Priority area I with GIS data water level and wherever the water level is deep within such Priority area-I, it will identify and mark as suitable area for recharge.

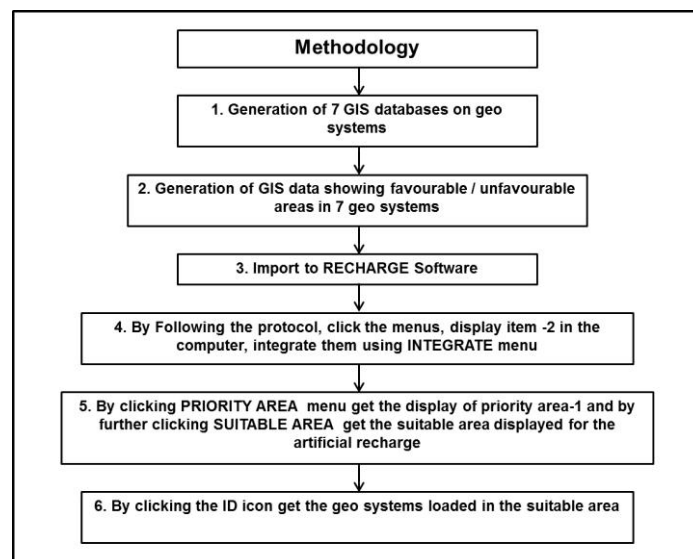


Figure 2 Methodology

III. Generation Of Spatial GIS Databases On Geosystems

Various databases have been generated for selecting the suitable sites for artificial recharge, as briefed below

1.1 Lithology

The rock types are of the important parameters controlling the porosity and imperviousness of the terrain. So a detailed lithological map was prepared from the map published by the Geological Survey of India [8] and spatial GIS database was generated on the same. The area exposes the hard crystalline rock viz; gneisses, pink granite, charnockite, calcgranulites belonging to the Precambrian period; sandstone of the Mio-Pliocene period; and the fluvial and marine sediments of the Quaternary period. Depending upon their porosity, the weathered gneisses, sandstones, laterites, fluvial and fluvio marine landforms were buffered out as favorable areas {1} for artificial recharge leaving remaining rock types (sub variables of the main variable lithology) as unfavorable areas {2} and the vector based GIS database was generated showing these two polygon classes (Fig. 3A).

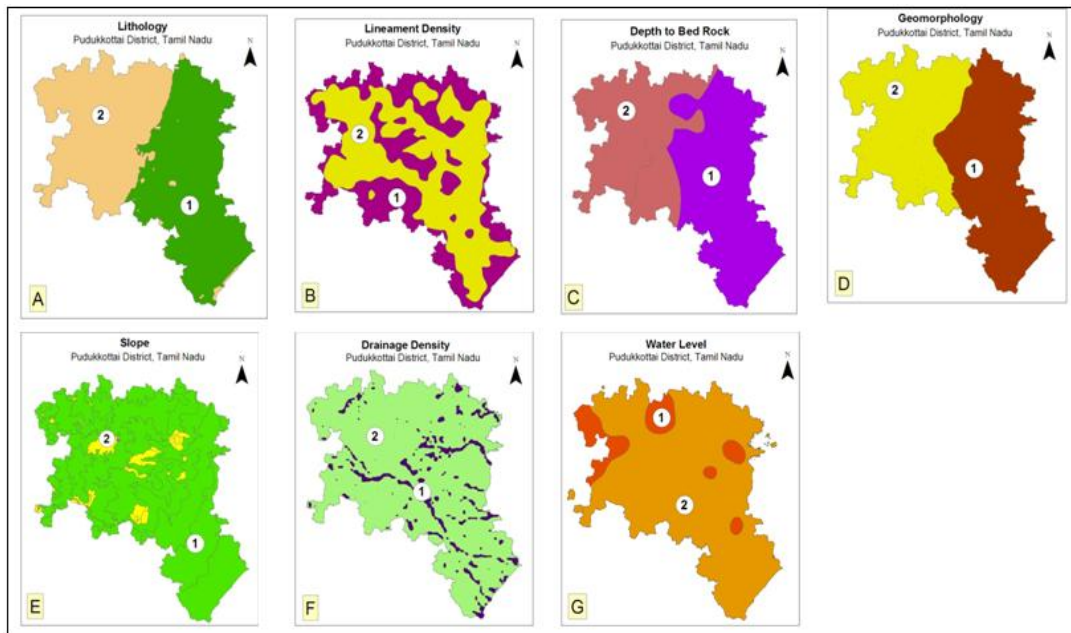


Figure 3 Spatial GIS databases on geological / terrain / hydrological systems showing favorable {1} and unfavorable {2} zones for recharge. (A) Lithology (B) Lineament Density (C) Depth to Bed Rock (D) Geomorphology (E) Slope (F) Drainage Density (G) Water Level

1.2 Lineaments

The area has undergone extensive deformation both during the Precambrian period [9], [10] and during the Quaternary period, the later related to the phenomenon of post collision tectonics [11], [12]. These tectonism have developed fractures, that are expressed as lineaments in satellite data with polymodal orientation and amongst these the lineaments with open geometry were interpreted using IRS satellite data and lineament map was prepared. From the lineament map, lineament density diagram was prepared by counting the total length of the lineaments per 1 sq.km area, plotting them in the respective grid centers and contouring them [13]. Such lineament density varied roughly from 100 m to more than 1500 m / sq.km. Based on the dynamic range these values, the study area was grouped into two grades as low (<750 m) and high (>750 m) and spatial GIS databases was generated showing the zones of high density as favorable areas {1} and the low density zones as unfavorable areas {2} as the areas of high lineament density can act as path ways for the quick infiltration of surface water into the sub soil system. The spatial GIS data showing such favourable and unfavorable zones in lineament density is shown in Fig. 3B.

1.3 Depth To Bed Rock

The State Groundwater Directorate, Public Works Department, Government of India has conducted grid pattern geophysical resistivity survey and archived the data with them. From their archives, the resistivity data were collected for the study area, analyzed and the depth to bed rock contours were drawn for the study area. From the dynamic range of the depth to bed rock values, the study area has been divided into two classes i.e. less than 9 m and more than 9 m of depth to bed rock. In these the former was marked as unfavorable zone {2} and the later zone as favourable {1}, because the storage capacity of the aquifer depends upon this. The same is shown in the Fig. 3C.

1.4 Geomorphology

Geomorphology is yet another geosystem parameter controlling the porosity of the terrain systems. In the study area, the crystalline and the sedimentary formations have undergone physio-chemical disintegration during the Quaternary period and developed a hierarchy of land forms. In the area while the Precambrian rocks have resulted into linear ridges and pediments, the sedimentary rocks like Mio-Pliocene sandstone has been geomorphologically evolved into pediplains and lateritic plains. The flood plains, deltaic plains and beach ridges have formed the flat landforms with adequate porosity. These were interpreted by taking the basic geomorphology map [12] and updating it. From the same the pediments and laterite plains of the Mio-Pliocene sandstone, flood plains, deltaic plain and beach ridges were buffered as favorable areas {1} and remaining western crystalline as unfavorable areas {2} for recharge and spatial GIS database was generated showing these two classes as far as geomorphology is concerned (Fig. 3D)

1.5 Slope

The slope of the terrain is again an important parameter as it only either slows down the flow of water and facilitating recharge in case of less slope and accelerates the flow and reduces the recharge in case of high slope. So the slope map was prepared by using the distance between the two adjacent 20 meters contours on 1:50,000 scale toposheet and accordingly the area was classified into 7 zones of slopes such as, 1-3%, 3-5%, 5-10%, 10-15%, 15-35%, and >35% and amongst these 7 zones of slopes, the areas falling in < 3% slope were buffered as favorable areas {1} for recharge and remaining areas as unfavorable zones {2} and GIS database was generated (Fig. 3E).

1.6 Drainage Density

Similar to slope, the drainage density is also a vital parameter for artificial recharge. This is because wherever the drainage density is high it indicates the clayey soils or the impervious geological formations like shale, mudstone etc. In contrast the areas of low drainage density suggest high porous rocks / terrain conditions. So to include this vital parameter also in the site selection process, all the drainages were drawn from the topographic sheets of Survey of India, total length of drainages in meters per 1 sq.km grid were counted, plotted in the respective grid centers and drainage density contour map was prepared. Then from the dynamic range of drainage density values of the zones of <500 m/1 sq. km were identified as favorable areas and more than 500 meters as unfavorable areas respectively due to drainage density minima in the former case and drainage density maxima in the latter case. Such classified GIS database on drainage density showing favorable zones {1} and unfavorable zones {2} are shown in Fig. 3F.

1.7 Water Level

Water level is a mandatory parameter in selecting suitable sites for artificial recharge. The State Groundwater Directorate, Public Works Department of Government of India is collecting monthly water level data from the already identified observation wells and maintains the same in their archives. The same was collected for all the observation wells numbering over 58 from Pudukkottai district for the period from 1970 to 2001 and are averaged such 360 monthly values for each well independently, plotted in the respective well locations and contoured. It shows that the groundwater level has varied from 1 meter to 10 meters. From the contours the zones where groundwater level was deeper than 6 m were identified as favorable areas for recharge because in the zones of comparatively deeper water levels only water can get stored. So spatial GIS database was accordingly generated showing the zones of deeper levels as favorable {1} and shallow water levels as unfavorable zones {2} and shown Fig. 3G.

IV. Semi Automated Extraction Of Sites For Recharge

After generating the above data bases on various geosystems, a special software program was written in VB .NET with Arc Objects called "RECHARGE". In that, a domain area was created as "Input data" in which all the 7 spatial databases (Figure 3A – 3G) were imported.

1.8 Selection of Input Data

Now for selecting the suitable area for artificial recharge, the user has to click the icon "Recharge" in the Computer in which the above GIS databases and the software is loaded. Then the main frame will appear showing **Input data, Data integration, Recharge sites, Print, Help and Exit** in the top main menu bar (Fig. 4). Then on clicking the 'Input data' option in the main menu (1, Fig. 4), a pull down menu will appear showing the 6 geosystem maps such as Lithology maxima, Lineament density maxima, Depth to bed rock maxima, Geomorphology maxima, Slope Minima, and Drainage density minima. On clicking the Lithology maxima (2, Fig. 4), the software will browse the input data from the domain identified as the lithological layer and display it in the central display frame (A, Fig. 4) showing the favorable (colored zones) and unfavorable zones (uncloured)

and simultaneously, the favorable areas filtered out for artificial recharge will be displayed in the small box shown in the right side (B, Fig.4). Similarly, on clicking the other geo system maps like Lineament density maxima, depth to bed rock maxima, geomorphology maxima, slope minima and drainage density minima, these will be displayed in display area (A, Fig. 4) and their respective favorable areas in box (B, Fig.4).

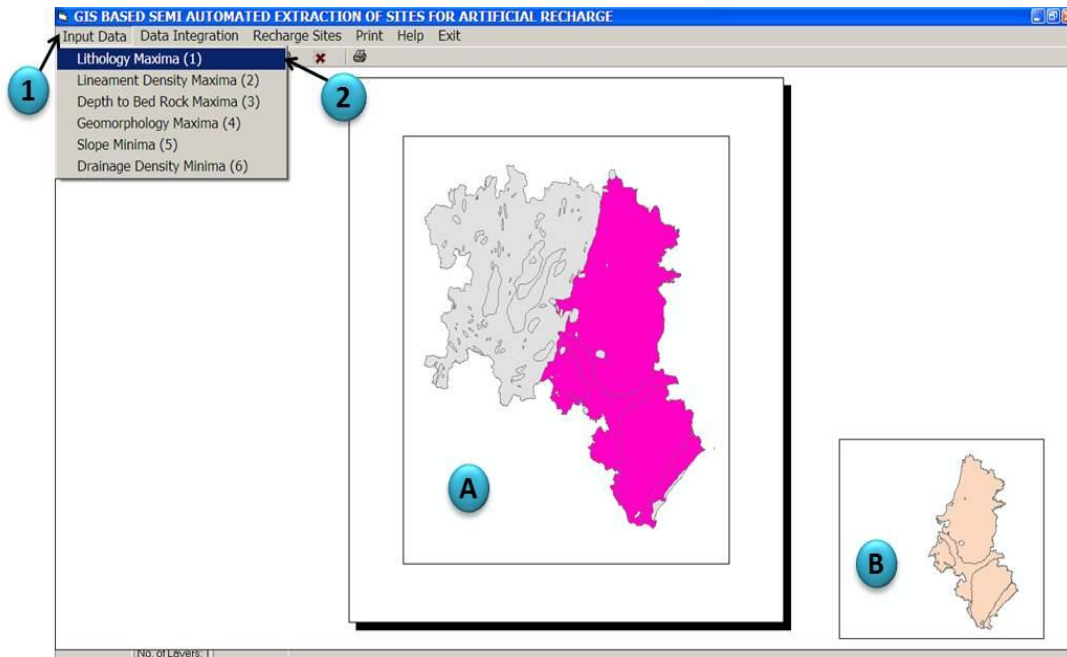


Figure 4 Semi automated extraction of areas favorable or recharge for lithology data

1.9 Data Integration

Nextly, on clicking the ‘Data integration’ option in the main menu bar (1, Fig.5), the software will analyze all the favorable zones mapped in the above 6 GIS databases on geosystems and superpose these layers one over the other using add function menu of ArcGIS (A, Fig. 5). Such an integrated layer will have multiples of polygons loaded with 6, 5, 4, 3, 2 and 1 geosystem variables from which prioritization can be done. Such prioritization will be based on the number of variables loaded in them viz; more than 4 geosystem variables loaded zones as Priority-I, 2 to 3 as Priority-II and one variable loaded zone as Priority – III (B, Fig.5)

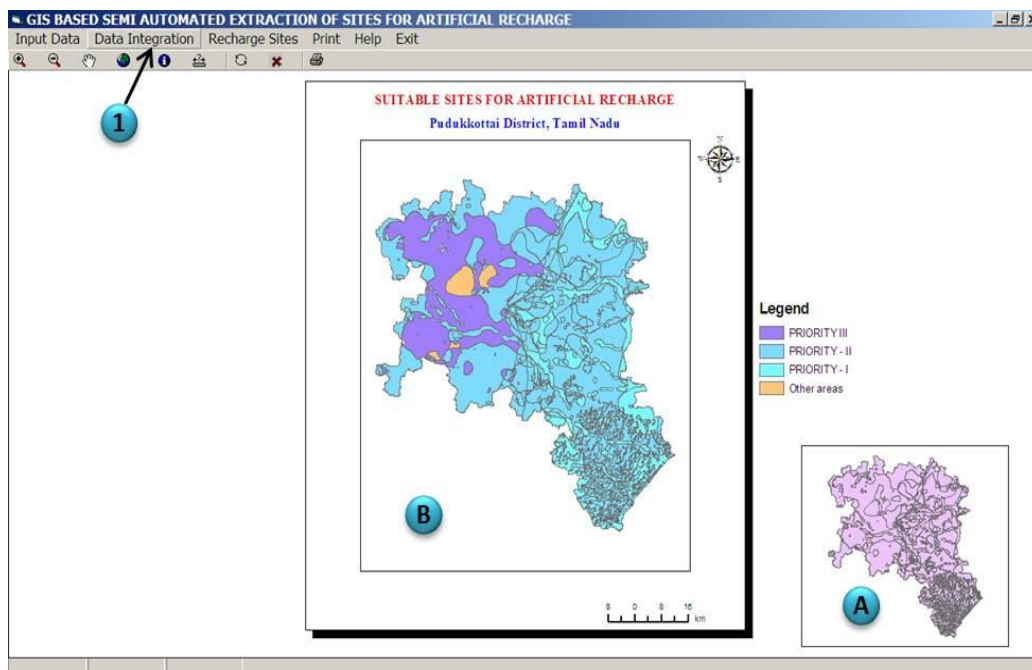


Figure 5 GIS layer showing all the six geosystem layers overlaid on over the other (A); Prioritized area I - III (B)

1.10 Prioritization of Recharge Sites

To extract such priority areas, from the integrated data, the user has to click the ‘Recharge sites’ option in the main menu bar (1, Fig.6). Then a pull down menu will appear showing Priority I, II and III. Then on clicking the Priority-I (2, Fig.6) the areas where more than 4 geosystem variables are loaded will be filtered out from Figure 5 and displayed in the display area (A, Fig.6). Within the priority area, the suitable site should be selected and this will depend on the Water Level data which is the mandatory variable in site selection process. To do so, on clicking suitable area (3, Fig.6) the GIS data showing the deeper water level zones (B, Fig.6) will be superposed over the priority-I area and wherever the deeper zones of water levels are there, those areas will be buffered out as suitable areas for recharge and displayed (C, Fig.6). In fact, this will be the best area for artificial recharge in priority area I whereas since water level will be shallow in the remaining areas of Priority I, recharge will not be that encouraging though other conditions favorable.

Similarly, by following the same protocol, the suitable sites can be identified for Priority-II and Priority-III also by clicking the appropriate options in the menu.

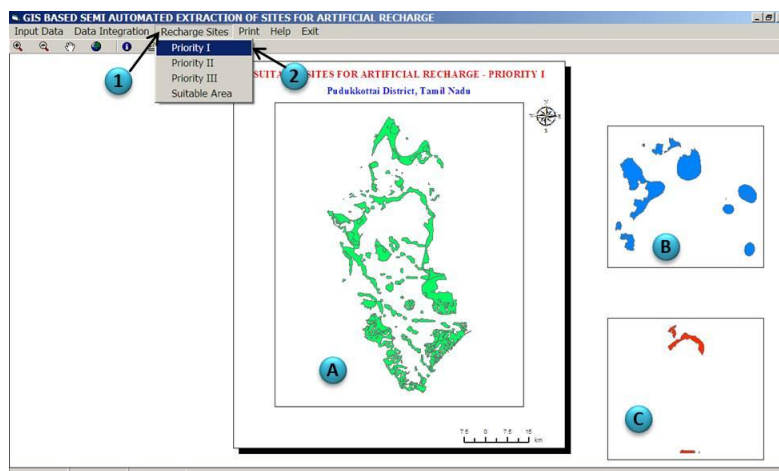


Figure 6 Recharge module showing the Priority area I (A), Zones of deeper water level (B) and the suitable area (C)

The suitable area selected for priority area II by following the similar protocol is shown in Fig. 7

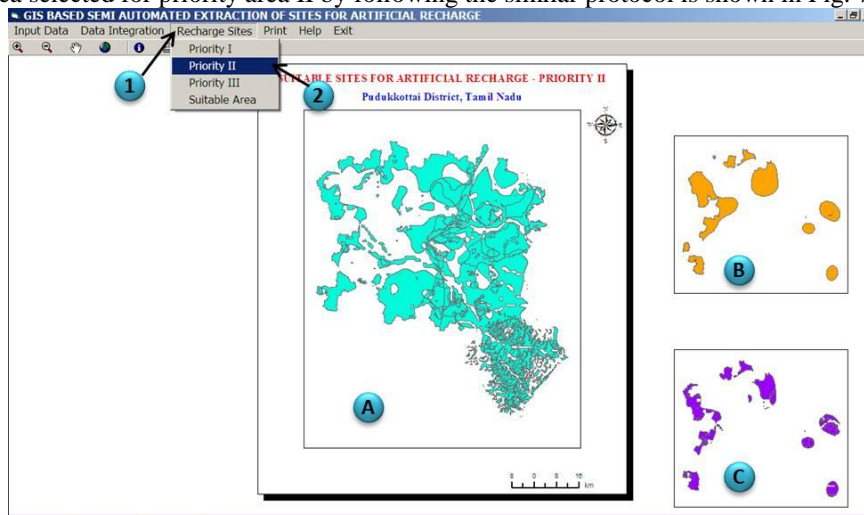


Figure 7 Recharge module showing the Priority area II (A), Zones of deeper water level (B) and the suitable area (C)

1.11 Identification of geosystem data loaded into prioritized areas

In addition, the user can also see the geosystem variables loaded in the suitable areas selected in the priority areas so identified. Because, for example, in the selected areas of the Priority-I any of the four or five or all the six geosystem variables might have been loaded. In order to broadly identify the type of artificial recharge mechanisms like percolation ponding, check damming, pitting, furrowing etc., the user may like to see the type of geosystem variables loaded in Priority area I selected. To do so, the user has to click the identity icon

in the tool bar (1, Fig.8) which is just below the main menu and take the cursor to the particular polygon and click it, then the geosystem variables loaded will be displayed in a separate identify results window(2, Fig. 8).

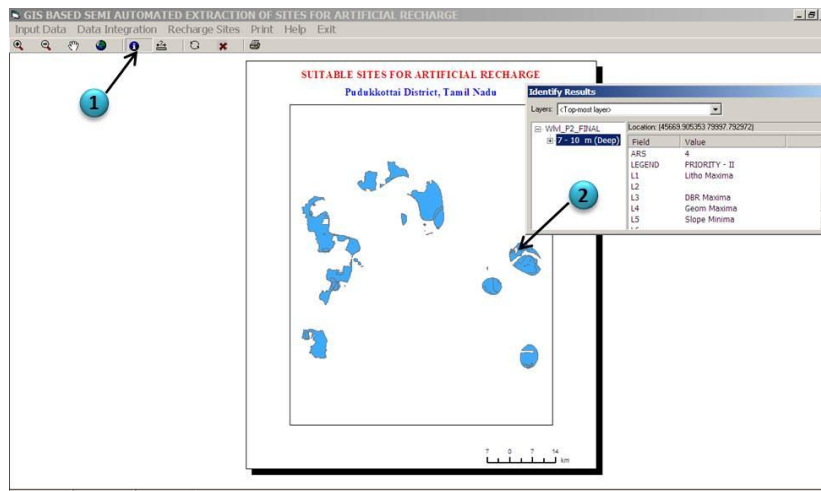


Figure 8 Recharge module showing the combinations of geosystem variables loaded in suitable areas selected for recharge.

V. Discussion And Conclusion

As discussed above, the artificial recharge has been unanimously accepted as the only option to restore the depleting water table. Many a times, as such recharge schemes are executed on emergency basis, selection of suitable sites on scientific criterion emerges as a major issue. Under this scenario, the site selection by using GIS based automated extraction technology will definitely be a boon. In this method, the user can to quickly vectorize the favorable zones in different geosystem related parameters, import them in the computer and keep on clicking it following the protocol. Then it will automatically lead to the suitable sites. As this study has been done for demonstrative purposes and highlight the possibility of such tools, the involvement of minimum variables may appear to be a limitation. But the study with more number of user specific geosystem variables will yield tangible results and can be conveniently applied in all areas.

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