CHAPTER IV
GIS MODELLING

4.1 GENERAL

In the third stage, that is, subsequent to the thematic modelling and numerical modelling, the Geographic Information Systems (GIS) modelling was carried out using the same set of numerical data bases and for the same, the GRAM (Geo-Referenced Area Management) GIS package, developed by Centre of Studies in Resources Engineering (CSRE), Indian Institute of Technology (IIT), Bombay (Venkatachalam, 1993) was made use off.

4.2 GRAM-GIS PACKAGE AND ITS CAPABILITIES

The GRAM stands for Geo-Referenced Area Management and it is a low cost PC based GIS, developed to manage spatial data using digital technology, initiated under Natural Resources Data Management system (NRDMS) of the Department of Science and Technology, Government of India, New Delhi. The CSRE (Centre of Studies in Resources Engineering), IIT (Indian Institute of Technology), Bombay has developed this software. This software package provides tools for developing information systems to cater to the needs of planners and decision makers in decision making. The package is capable to handle both vector and raster inputs and can also integrate data gathered from both ground surveys and remote sensing data bases.

4.2.1 Hardware Components

GRAM Package needs a computer which should at least be an
- Intel 80286 base PC/AT with co processor and
- 640 KB memory
- 40 MB hard disk
- 1 X 1.2 MB floppy drive
- high resolution colour monitor with EGA and to display 16 colours in 350 x 640 resolution
- a digitiser and
- a dot matrix printer with colour ribbon or Tectronix/IBM ink jet printer or compatible.

Additional facilities such as higher cache memory, 80386, 80486, processors, etc. help in faster processing of data. The software can also be used with high resolution colour monitor with VGA card.

4.2.2 Software Components

GRAM Package consists of software tools to manage, analyse and display data. The following six modules constitute the GRAM-GIS package (FIG. 4.1).

4.2.2.1 Input Module
It is used to digitise and edit maps, to create vector data bases, to build topological relations, to generate polygons and to rasterise vector data (TABLE 4-1).

4.2.2.2 Attribute Link Module
It has the capability to link map data with non-spatial data and to prepare thematic maps on the attribute data (TABLE 4-2).

4.2.2.3 Analysis Module
This module is used to carry out various operations on the data already available in the system. ANALYSIS module supports a series of arithmetic and relational operations that can be performed either on single or multiple data planes. Suitable combination of the mathematical, relational and logical operators available in this module facilitates application/modelling studies such as land capability analysis, soil erosion modelling, watershed and wasteland management, etc. (TABLE 4-3).
FIG. 4.1
### TABLE 4-1

**GRAM - INPUT MODULE**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DIGSETUP</td>
</tr>
<tr>
<td>2</td>
<td>DIGITIZE</td>
</tr>
<tr>
<td>3</td>
<td>CLEAN</td>
</tr>
<tr>
<td>4</td>
<td>CLEANDUP</td>
</tr>
<tr>
<td>5</td>
<td>SLIVER</td>
</tr>
<tr>
<td>6</td>
<td>POLFORM</td>
</tr>
<tr>
<td>7</td>
<td>POLFILL</td>
</tr>
<tr>
<td>8</td>
<td>POLRAS</td>
</tr>
<tr>
<td>9</td>
<td>SEGRAS</td>
</tr>
<tr>
<td>10</td>
<td>QUIT</td>
</tr>
</tbody>
</table>

### TABLE 4-2

**GRAM - ATTRIBUTE LINK MODULE**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LN_DBF</td>
</tr>
<tr>
<td>2</td>
<td>DBF_MAP</td>
</tr>
<tr>
<td>3</td>
<td>DBASE</td>
</tr>
<tr>
<td>4</td>
<td>QUIT</td>
</tr>
</tbody>
</table>

### TABLE 4-3

**GRAM - ANALYSIS MODULE**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ADD</td>
</tr>
<tr>
<td>2</td>
<td>SUBTRACT</td>
</tr>
<tr>
<td>3</td>
<td>MULTIPLY</td>
</tr>
<tr>
<td>4</td>
<td>DIVIDE</td>
</tr>
<tr>
<td>5</td>
<td>LOG</td>
</tr>
<tr>
<td>6</td>
<td>EXPO</td>
</tr>
<tr>
<td>7</td>
<td>SQUARE</td>
</tr>
<tr>
<td>8</td>
<td>SQUAREROOT</td>
</tr>
<tr>
<td>9</td>
<td>AVERAGE</td>
</tr>
<tr>
<td>10</td>
<td>MAXIMISE</td>
</tr>
<tr>
<td>11</td>
<td>MINIMISE</td>
</tr>
<tr>
<td>12</td>
<td>CONVERT</td>
</tr>
<tr>
<td>13</td>
<td>PROTECT</td>
</tr>
<tr>
<td>14</td>
<td>DCONVERT</td>
</tr>
<tr>
<td>15</td>
<td>RENAME</td>
</tr>
<tr>
<td>16</td>
<td>MAPCOMP</td>
</tr>
<tr>
<td>17</td>
<td>EXPOSE</td>
</tr>
<tr>
<td>18</td>
<td>DISPLAY</td>
</tr>
<tr>
<td>19</td>
<td>VIEW</td>
</tr>
<tr>
<td>20</td>
<td>EXPLAIN</td>
</tr>
<tr>
<td>21</td>
<td>LEGEND</td>
</tr>
<tr>
<td>22</td>
<td>MASK</td>
</tr>
<tr>
<td>23</td>
<td>OVERLAY</td>
</tr>
<tr>
<td>24</td>
<td>REGROUP</td>
</tr>
<tr>
<td>25</td>
<td>ERASE</td>
</tr>
<tr>
<td>26</td>
<td>XCOPY</td>
</tr>
<tr>
<td>27</td>
<td>ZOOMING</td>
</tr>
<tr>
<td>28</td>
<td>SEGDRAW</td>
</tr>
<tr>
<td>29</td>
<td>VECTDRAW</td>
</tr>
<tr>
<td>30</td>
<td>GEOTRANS</td>
</tr>
<tr>
<td>31</td>
<td>SHADE</td>
</tr>
<tr>
<td>32</td>
<td>SHADRAW</td>
</tr>
<tr>
<td>33</td>
<td>PASTE</td>
</tr>
<tr>
<td>34</td>
<td>SHOWPIX</td>
</tr>
<tr>
<td>35</td>
<td>DISTANCE</td>
</tr>
<tr>
<td>36</td>
<td>SPREAD</td>
</tr>
<tr>
<td>37</td>
<td>CLIP</td>
</tr>
<tr>
<td>38</td>
<td>SPLDISPLAY</td>
</tr>
<tr>
<td>39</td>
<td>DOCGEN</td>
</tr>
<tr>
<td>40</td>
<td>EVALUATE</td>
</tr>
<tr>
<td>41</td>
<td>CROSTABLE</td>
</tr>
<tr>
<td>42</td>
<td>REAL</td>
</tr>
<tr>
<td>43</td>
<td>IMAGESTAT</td>
</tr>
<tr>
<td>44</td>
<td>RANGCLAS</td>
</tr>
<tr>
<td>45</td>
<td>QUIT</td>
</tr>
</tbody>
</table>
4.2.2.4 DTM Module

This is to handle terrain data for digital terrain modelling, slope and aspect mapping. It helps in analysing spatial data using digital terrain models (DTM). Interpolation utilities, available in this module are capable of generating a surface from contours as well as random spot (elevation) data. The module can be used for digital elevation modelling, geochemical mapping, viewing 3D projections, generating slope, aspect and relief maps (TABLE 4-4).

4.2.2.5 Image Processing Module

The image processing module of the GRAM-GIS package consists of utilities for image pre-processing, enhancement, classification and geometric transformation. Image pre-processing covers band separation, window extraction, histograms generation, scatter plot creation, data compression and data enlargement. Image enhancement covers density slicing, lookup table manipulation, linear / non-linear stretching, filtering edge operators, etc. Both supervised and unsupervised procedures are included under classification (TABLE 4-5).

4.2.2.6 Print Module

It helps to provide hard copy output with the help of an output device (TABLE 4-6).

4.3 DATA INPUT

To start with the GIS modelling, data input was given. The main input was the digitisation of base map, digitisation of well locations and entry of non-spatial attribute data, that is, all the structural, geomorphological, subsurface geological and aquifer characteristic data for 200 sampling points.
### TABLE 4-4

**GRAM - DTM MODULE**

1. KRIGG
2. GRIDS
3. CRESS
4. TRENDS
5. CONTOUR
6. 3D VIEW
7. SAR
8. QUIT

### TABLE 4-5

**GRAM - IMAGE PROCESSING MODULE**

1. BANDSEP
2. WINDOW
3. HISTOGRAM
4. COMPRESS
5. ENLARGE
6. ENHANCEMENTS
7. CLASSIFICATION
8. IMAGE DISPLAY
9. QUIT

### TABLE 4-6

**GRAM - OUTPUT MODULE**

1. OVR PRINT
2. GRAYP
3. QUIT
4.3.1 Digitisation of Base Map

The Vellar basin base map (FIG. 1.1) contains many important features such as basin boundary, hills, major rivers, crystalline-sedimentary contact, etc. This map was fixed over the A0 digitiser and by accessing the INPUT module of the GRAM package, the digitisation was done. The digitisation of map has some formalities. That is, the base map should be first registered with all the basic informations such as scale of the map, coordinates of all the four corners of the map, etc. The coordinates were given in ground distance in meters. As a practice, the coordinates of the south western corner was entered as (0,0) and other three corners were given as per their ground distances. To do such registration, the curser of the A0 digitiser was used and all four corners were digitised.

After registering the base map, other features like basin boundary, boundary of the hills and crystalline-sedimentary contact were digitised by using the sub menu of digitise programme such as 1. LINEAR, 2. POINT and 3. EXIT. While digitising, the different curser buttons were selected in the tablet, digitising for different nodes like start node (new), end node (new), start node (old), end node (old), etc. Thus the entire linear informations were digitised.

After digitising the base map, using the "error detection" and "removal" sub menu of DIGITIZE programme of INPUT module, the errors that were creeped in during the digitisation of base map were removed. There were six functional keys (F1 to F6) provided to achieve this task. These functional keys are having the capability to, make a window, zoom a window, make a point, insert a point, delete a point, make a segment, break a segment, delete a segment, screen attribute, etc. In addition, while digitisation, hanging, overshooting and undershooting of segments will also be common. This was also removed by using appropriate functional keys. Such error detecting provision is also having the sub menu to

- error display on
- error display off
- locate error point and
- error auto.
All these things were used to remove the errors in the base map. In addition, the 'error auto' menu was capable of removing some errors within the search radius of 25 (in terms of digitiser counter). This was also used.

Subsequently, the broken segments or dangling errors or overshootings or undershootings were removed. Finally, POLFORM sub menu available in INPUT module of GRAM package, was used to complete the formation of polygon. The POLFORM menu checks up whether all polygons such as basin boundary, crystalline boundary are correct. In the final stage, POLFILL sub routine and POLRAS sub routine of ANALYSIS module were used to complete the base map digitisation and rasterisation.

4.3.2 Digitisation of Well Locations

As the next step, all the point features were digitised. In our case, the main point features were 200 well locations / sampling points of the study area. This was digitised by using DIGITIZE sub routine of INPUT module of GRAM package (TABLE 4-1). To digitise the same, the tablets of the digitiser were used and curser was placed over each of the 200 sampling points and the appropriate button was pressed which has initialised the particular location in the base map and also records the (X Y) coordinates of the particular point. Simultaneously, the cursor will give a beep sound and the monitor asks for labeling the particular point digitised. At that time, number of the sampling point which was digitised at the point of time was typed in the monitor. Then the digitiser tablet was moved to next point and entered by alternatively pressing the curser buttons of digitiser and typing the number of the sampling point in the computer. And thus the whole digitisation and labeling of all 200 points were completed.

4.3.3 Entry of Non-Spatial Attribute

In our case, all other point informations of data bases are the non-spatial attribute. That is, the 200 values of interval between laminations (TABLE 2.2), interval between joints (TABLE 2.3), lineament density (TABLE 2.4), geomorphic grade (TABLE 2.5),
drainage density (TABLE 2.6), slope (TABLE 2.7), infiltration rate (TABLE 2.8), thickness of top soil (TABLE 2.9), thickness of weathered zone (TABLE 2.10), thickness of fractured zone (TABLE 2.11), depth to bed rock (TABLE 2.12), water level mean (TABLE 2.13), aquifer depletion (TABLE 2.14), storage coefficient (TABLE 2.15), specific capacity (TABLE 2.16), transmissivity (TABLE 2.17), permeability (TABLE 2.18), optimum yield (TABLE 2.19) and recovery rate (TABLE 2.20) are the non-spatial attributes. So subsequent to the digitisation and labeling of 200 sampling points, the corresponding 200 numerical values of the 19 variables were entered into the GRAM package. Such entry was done by dBASE, which automatically links 200 sets of data of all the 19 variables along with respective 200 sampling points. However, to link these particular data file namely *.PNT code was given. Now this process was completed by entry of all non-spatial attributes.

4.4 GENERATION OF RASTER IMAGES / DATA BASES

Subsequent to the entry of all the numerical data of all the 19 variables, the raster images were generated for all the above 19 variables one after the other using CRESSMAN algorithm available in the DTM (Digital Terrain Modelling) sub menu of GRAM package. For example, the method followed to generate a raster image for interval between laminations data is discussed below.

To generate a raster image on interval between laminations, the DTM (TABLE 4-4) sub menu was accessed and the appropriate PNT file along with appropriate column, say column 1 which was referable to X coordinate of 200 points, column 2 which was referable to Y coordinate of 200 points and column 3 which was referable to Z coordinate or interval between laminations data of the 200 sampling points were given as input in the DTM sub menu. Then the DTM programme (CRESSMAN algorithm) has spread the Z data according to X and Y and the Digital Terrain Modelling (DTM) was generated.
Subsequent to the execution of DTM programme, the DOCGEN (Document Generation) sub menu of the ANALYSIS module of the GRAM package (TABLE 4-3) was accessed and such DTM generated for interval between laminations was documented. At the time of DOCGEN sub routine, important details like total number of columns, total number of rows, measuring unit, data format, etc. were given.

Subsequent to the generation of DTM, the RANGCLAS sub menu was accessed which is also available in the ANALYSIS module (TABLE 4-3) of the GRAM package. To generate raster image for such interval between laminations, the required informations such as number of classes and their ranges by keeping minimum and maximum values of the interval between laminations in mind were given by preparing a specific file (*.TAB) in the Nortan Editor. Then the RANGCLAS programme has classified the interval between laminations DTM data into number of classes prescribed by the user and classified the raster image and displayed the same. Similarly, raster images were generated for the other 18 variables belonging to structural, geomorphological, subsurface geological and aquifer parameters.

4.5 GENERATION OF BINARY CLASSIFIED RASTER IMAGES

Subsequent to the generation of raster images, the binary classified raster images were generated for all the 19 variables. To generate such binary classified raster images, the minimum and maximum values amongst 200 values of particular variable were analysed for each variable independently and the mean value was worked out. And whatever values are falling in more than mean and less than mean were grouped out separately. For example, in one particular variable, if the values are ranging from 50 to 150, 100 was kept as the mean value. The points falling in between 50 and 100 were grouped separately and 101 to 150 were grouped separately. To do the same, once again the RANGCLAS sub menu was used and such values were given as input and the programme has automatically classified the concerned raster image into two classes. This was done for each of the 19 variables independently for the purpose of modelling and this
images are called as BINARY CLASSIFIED RASTER IMAGES. But in the GIS outputs, these have been annotated as CLASSIFIED RASTER IMAGES (e.g. FIG. 4.2).

Subsequent to the generation of binary classified raster images, all the concerned binary classified raster images were grouped into number of parameters namely structural parameters, geomorphological parameters and subsurface geological parameters and they were called as "hybrid images" or "composite raster images" of structural, geomorphological and subsurface geological parameters respectively. On the contrary, all the 9 aquifer characteristic variables including overall aquifer condition data were kept as separate binary classified raster images for the purpose of present modelling as these are the dependent variables.

4.5.1 Structural Parameters
4.5.1.1 Interval Between Laminations

The interval between laminations varies from 0.35 to 4.60 centimeters in the study area (TABLE 4-7). Amongst the 200 values, there were very few anomalous values. These anomalous values were removed and the mean value was worked out as 2.48. So the sampling points falling in between 0.35 and 2.48 were kept as less than mean class and the sampling points falling in between 2.49 and 4.60 were grouped in to more than mean class. These values were entered into the RANGCLAS sub menu and the same sub menu has accessed the original raster image of the interval between laminations and classified the same into two groups as less than mean and more than mean. The same is presented in FIGURE 4.2. To generate such binary classified raster image, the RANGCLAS sub menu has accessed the DTM data of the concerned raster image available in the system. Such binary classified raster image or classified raster image of interval between laminations is shown in FIGURE 4.2.
FIG. 4.2
<table>
<thead>
<tr>
<th>SL. NO.</th>
<th>VARIABLE</th>
<th>UNIT</th>
<th>MINIMUM VALUE</th>
<th>MAXIMUM VALUE</th>
<th>MEAN VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Interval Between Laminations</td>
<td>CM</td>
<td>0.35</td>
<td>4.60</td>
<td>2.48</td>
</tr>
<tr>
<td>2.</td>
<td>Interval Between Joints</td>
<td>CM</td>
<td>15.00</td>
<td>98.00</td>
<td>51.00</td>
</tr>
<tr>
<td>3.</td>
<td>Lineament Density</td>
<td>KM/1.56 SQ.KM.</td>
<td>0.25</td>
<td>2.25</td>
<td>1.00</td>
</tr>
<tr>
<td>4.</td>
<td>Geomorphic Grade</td>
<td>---</td>
<td>80.00</td>
<td>100.00</td>
<td>90.00</td>
</tr>
<tr>
<td>5.</td>
<td>Drainage Density</td>
<td>M/SQ.KM.</td>
<td>300.00</td>
<td>2400.00</td>
<td>1160.00</td>
</tr>
<tr>
<td>6.</td>
<td>Slope</td>
<td>PERCENT</td>
<td>0.50</td>
<td>18.00</td>
<td>3.00</td>
</tr>
<tr>
<td>7.</td>
<td>Infiltration Rate</td>
<td>M/DAY</td>
<td>0.30</td>
<td>13.00</td>
<td>3.10</td>
</tr>
<tr>
<td>8.</td>
<td>Thickness of Soil</td>
<td>METER</td>
<td>0.30</td>
<td>2.80</td>
<td>1.00</td>
</tr>
<tr>
<td>9.</td>
<td>Thickness of Weathered Zone</td>
<td>METER</td>
<td>3.50</td>
<td>25.00</td>
<td>9.30</td>
</tr>
<tr>
<td>10.</td>
<td>Thickness of Fractured Zone</td>
<td>METER</td>
<td>3.00</td>
<td>55.00</td>
<td>21.00</td>
</tr>
<tr>
<td>11.</td>
<td>Depth to Bed Rock</td>
<td>METER</td>
<td>8.30</td>
<td>63.00</td>
<td>29.00</td>
</tr>
<tr>
<td>12.</td>
<td>Depth to Water Level</td>
<td>METER</td>
<td>4.00</td>
<td>20.00</td>
<td>9.10</td>
</tr>
<tr>
<td>13.</td>
<td>Width of Aquifer Depletion</td>
<td>METER</td>
<td>1.10</td>
<td>20.00</td>
<td>7.60</td>
</tr>
<tr>
<td>14.</td>
<td>Storage Coefficient</td>
<td>---</td>
<td>0.01</td>
<td>0.94</td>
<td>0.18</td>
</tr>
<tr>
<td>15.</td>
<td>Specific Capacity</td>
<td>LPM/M DD/M</td>
<td>6.00</td>
<td>640.00</td>
<td>63.00</td>
</tr>
<tr>
<td>16.</td>
<td>Transmissivity</td>
<td>SQ.MT./DAY</td>
<td>4.00</td>
<td>130.00</td>
<td>31.00</td>
</tr>
<tr>
<td>17.</td>
<td>Permeability</td>
<td>MT./DAY</td>
<td>1.50</td>
<td>70.00</td>
<td>15.80</td>
</tr>
<tr>
<td>18.</td>
<td>Optimum Yield</td>
<td>CUB.MT/DAY</td>
<td>3.00</td>
<td>210.00</td>
<td>30.00</td>
</tr>
<tr>
<td>19.</td>
<td>Recovery Rate</td>
<td>CUB.MT/DAY</td>
<td>14.00</td>
<td>640.00</td>
<td>101.00</td>
</tr>
</tbody>
</table>
4.5.1.2 Interval Between Joints

The binary classified raster image for interval between joints was generated by using the same RANGCLAS sub menu. The interval between joints data varies from 15 to 98 centimeters (TABLE 4-7) and hence the mean was 51. So the interval between joints raster image was classified into two classes showing the more than mean zone and less than mean zone separately and the same is shown in FIGURE 4.3.

4.5.1.3 Lineament Density

The lineament density values varied from 0.25 to 2.25 kilometer per one square kilometer in the basin area and hence, the mean was worked out as 1.00 (TABLE 4-7). So the lineament density raster image was classified into two zones, grouping the sampling points falling in less than mean range and more than mean range, using the RANGCLAS sub menu. The same is shown in FIGURE 4.4.

4.5.1.4 Hybrid / Regrouped Image on Structural Parameters

Subsequent to the generation of binary classified raster images (classified raster images) of interval between laminations (FIG. 4.2), interval between joints (FIG. 4.3) and lineament density (FIG. 4.4), the buffered images were generated for all the three, buffering out less than mean zones in interval between laminations (FIG. 4.5), less than mean zones in interval between joints (FIG. 4.6) and more than mean zones in lineament density (FIG. 4.7). In all such three buffered images, the unwanted or unfavourable areas (That is, more than mean laminations, more than mean joints and less than mean lineament density zones) were given black colour. Finally all these three buffered images were added together using CROSSTABLE function sub menu. When such addition was done, the following 9 classes have resulted.

CLASS-1 Interval Between Laminations Minima
CLASS-2 Interval Between Joints Minima
CLASS-3 Lineament Density Maxima
CLASS-4 Combined Zone of CLASSES 1 and 2
FIG. 4.5
LESS THAN MEAN ZONE IN MAGENTA

FIG. 4.6
LESS THAN MEAN ZONE IN MAGENTA
FIG. 4.7 MÓRE THAN MEAN ZONE IN MAGENTA
These 9 classes have been given 9 different colours (FIG. 4.8). But out of these 9 classes, excluding the hills and the unfavourable areas, all the other 7 classes from 1 to 7 are referable to structural maxima zone. So they have all been combined and a regrouped image has been generated showing only structural maxima zone in one colour and minima zone in black colour (FIG. 4.9). Such REGROUPED IMAGE is equivalent to the map showing the structural parameter composite anomaly axes (FIG. 2.21) and digital data base on structural parameters (TABLE 2-44).

4.5.2 Geomorphological Parameters

4.5.2.1 Geomorphic Grade

The geomorphic grade values for the 200 sampling points vary from 80 to 100 (TABLE 4-7). So value 90 was kept as the mean and the geomorphic grade raster image was classified into two zones such as more than mean zone and less than mean zone, once again by using the same RANGCLAS sub menu. From such binary classified image, the zones of more than mean was buffered out and buffered image was generated (FIG. 4.10) so as to correlate such zones of geomorphological maxima with aquifer parameters.

4.5.2.2 Drainage Density

Drainage density data for the 200 sampling points ranges from 300 to 2400 meters per one square kilometer area (TABLE 4-7). So the 1160 value was kept as mean and the whole data has been grouped into two classes, one is less than mean and the other one is more than mean. In order to again spatially show the sampling points, falling in more than mean and less than mean zone, the original drainage density raster image was
FIG. 4.10  MORE THAN MEAN ZONE IN MAGENTA
converted to binary classified raster image again by following the same RANGCLAS sub menu of ANALYSIS module of the GRAM package. From such classified image, the buffered image bringing out the areas of less than mean drainage density was generated (FIG. 4.11).

4.5.2.3 Slope

The binary classified raster image for the slope data was also generated by using the RANGCLAS sub menu and grouping the whole range of values which ranges from 0.5 to 18.0 percent into two classes keeping 3.0 as threshold. In this case, area falling in less than 3 percent slope only taken as the possible zone, contributing infiltration as slope more than that will promote only run-off. From such binary classified image, the buffered image was generated buffering out zones of less than 3 percent slope and darkening the zones of more than 3 percent slope (FIG. 4.12).

4.5.2.4 Infiltration Rate

The infiltration data for the 200 sampling points vary from 0.3 to 13.0 meter per day. But while removing the anomalous values, the mean fell in 3.0. So accordingly, the raster image of infiltration rate was converted to binary classified raster image, classifying the area into two groups such as less than mean and more than mean zones. From the same buffered image was generated buffering more than mean zones (FIG. 4.13).

4.5.2.5 Regrouped Raster Image on Geomorphological Parameters

Subsequent to the generation of buffered raster images of above all four geomorphological variables, all the four images were superposed using the same CROSSTABLE function of ANALYSIS module of GRAM package. Such superposition has resulted in 17 classes as follows:

CLASS-1 Zones of Geomorphic Maxima
CLASS-2 Zones of Drainage Density Minima
CLASS-3 Zones of Slope Minima
FIG. 4.11  LESS THAN MEAN ZONE IN MAGENTA

FIG. 4.12  LESS THAN MEAN ZONE IN MAGENTA
FIG. 4.13  MORE THAN MEAN ZONE IN MAGENTA
CLASS-4 Zones of Infiltration maxima
CLASS-5 Zones of CLASSES 1 and 2
CLASS-6 Zones of CLASSES 1 and 3
CLASS-7 Zones of CLASSES 1 and 4
CLASS-8 Zones of CLASSES 2 and 3
CLASS-9 Zones of CLASSES 2 and 4
CLASS-10 Zones of CLASSES 3 and 4
CLASS-11 Zones of CLASSES 1, 2 and 3
CLASS-12 Zones of CLASSES 1, 2 and 4
CLASS-13 Zones of CLASSES 1, 3 and 4
CLASS-14 Zones of CLASSES 2, 3 and 4
CLASS-15 Zones of CLASSES 1, 2, 3 and 4
CLASS-16 Zones of Hill Domain
CLASS-17 Unfavourable Zones (Geomorphic minima, drainage density maxima, slope maxima and infiltration minima).

Amongst which, as the above fifteen classes, namely the CLASS-1 to CLASS-15 are possible geomorphological maxima which control aquifer condition, all of them have been welded together as a single zone. Using the CROSSTABLE function. Thus the "REGROUPED IMAGE" was generated (FIG. 4.14) showing geomorphologic maxima zones in one domain, unfavourable zone in another domain and hills in yet another domain.

4.5.3 Subsurface Geological Parameters

In the case of subsurface geological parameters, such raster images were generated first for thickness of soil, thickness of weathered zone, thickness of fractured zone and depth to bed rock values. In all four cases, the maxima zones could act as favourable groundwater reservoirs. So in all the cases, the minimum and maximum values of each data bases were analysed and mean values were fixed up independently for each variable.
(TABLE 4-7) and each and every data base was grouped into two classes, one in less than mean zone and the other more than mean zone and such values were given to GRAM-GIS package. The RANGCLAS sub menu which has used such values and pictorially grouped the thickness of soil, thickness of weathered zone, thickness of fractured zone and depth to bed rock raster images into classified raster images. From such binary classified raster images of thickness of top soil, thickness of weathered zone, thickness of fractured zone and depth to bed rock buffered images were generated buffering out the zones falling in more than mean zones in all cases (FIG. 4.15 to FIG. 4.18). Then all such four images were added using CROSSTABLE function of ANALYSIS module of GRAM. The same has resulted again seventeen classes. That is, fifteen classes of subsurface geologic maxima, one class indicating hill domain and another class suggesting subsurface geologic minima domain. All such fifteen classes were combined as a single domain using ADD function menu. Thus the final "REGROUPED" subsurface geological image has shown ultimately three zones (FIG. 4.19).

4.5.4 Aquifer Characteristics Data

In the case of aquifer characteristic data, again 200 sampling points of depth to water level mean (TABLE 2-13), width of aquifer depletion (TABLE 2-14), storage coefficient (TABLE 2-15), specific capacity, (TABLE 2-16), transmissivity (TABLE 2-17), permeability (TABLE 2-18), optimum yield (TABLE 2-19) and recovery rate (TABLE 2-20) were analysed. Minimum and maximum values were worked out and mean values were fixed (TABLE 4-7) and grouped into two classes namely sampling points falling in more than mean zone and sampling points falling in less than mean zone. Such minimum and maximum values were given one after other in the RANGCLAS sub menu and binary classified raster images were generated.

From the binary classified images, the buffered images were generated buffering out the less than mean zone in mean water level (FIG. 4.20), less than mean zone in aquifer depletion (FIG. 4.21), more than mean zone in storage coefficient (FIG. 4.22),
FIG. 4.15  MORE THAN MEAN ZONE IN MAGENTA

FIG. 4.16  MORE THAN MEAN ZONE IN MAGENTA
FIG. 4.17     MORE THAN MEAN ZONE IN MAGENTA

FIG. 4.18     MORE THAN MEAN ZONE IN MAGENTA
FIG. 4.21 LESS THAN MEAN ZONE IN MAGENTA

FIG. 4.22 MORE THAN MEAN ZONE IN MAGENTA
specific capacity (FIG. 4.23), transmissivity (FIG. 4.24), permeability (FIG. 4.25), optimum yield (FIG. 4.26) and recovery rate (FIG. 4.27). They have been kept as independent overlays as these are the independent variables. In such buffered images unwanted or unfavourable areas were given black colour.

4.6 GIS MODELLING

4.6.1 Methodology of Map Overlaying

The main purpose of this study is to evaluate the functions of the aquifer variables such as the functions of water level, aquifer depletion, storage coefficient, specific capacity, transmissivity, permeability, optimum yield, recovery rate and overall aquifer conditions by interrelating them with structural, geomorphological and subsurface geological parameters. In the case of thematic modelling (CHAPTER II), it has been achieved by superimposing the anomaly / maxima axes of each and every aquifer parameters data over the anomaly maxima axes of structural, geomorphological and subsurface geological parameters. In the case of numerical modelling (CHAPTER III), the 200 values of each of the aquifer parameters variables were kept as dependent variables, correlated with corresponding 200 values of structural, geomorphological and subsurface geological parameters data. But in the present case, such aquifer functions were evaluated by overlaying the buffered images of each of the dependent variable, namely aquifer characteristic data with regrouped image of the structural, geomorphological and subsurface geological parameters data. For example, the buffered (raster) image of storage coefficient data (FIG. 4.22) was superimposed over the regrouped or hybrid image of structural parameters data (That is, Laminations + Joints + Lineaments; FIG. 4.8) by using CROSSTABLE sub menu of the ANALYSIS module of the GRAM package. When these two maps were integrated, three classes were resulted.

CLASS-1 Zones of storage coefficient maxima
CLASS-2 Zones of structural parameters maxima and
CLASS-3 Combined zones of storage coefficient maxima and structural parameters maxima.
FIG. 4.23 MORE THAN MEAN ZONE IN MAGENTA

FIG. 4.24 MORE THAN MEAN ZONE IN MAGENTA
FIG. 4.27  MORE THAN MEAN ZONE IN MAGENTA
The CLASS-1, namely the zones of storage coefficient maxima suggests that the storage coefficient is high, but it is not related to the structural parameters and hence in CLASS-1, storage coefficient is not controlled by structures. The zones of structural parameters maxima, namely CLASS-2, suggests that it is showing the area of maximum structural deformations, but it does not control the storage coefficient in CLASS-2 zone. But the CLASS-3 are zones where the storage coefficient maxima and structural parameters maxima coincide with each other. So this must be the zone where storage coefficient is controlled by the structural parameters like laminations, joints and lineaments. Now we are interested in CLASS-3. So in order to bufferout CLASS-3 and nullify CLASS-1 and CLASS-2, the REGROUP sub menu was accessed. The REGROUP sub menu has displayed these three classes in three different colours as CLASS-1 in blue, CLASS-2 in red and CLASS-3 in green. Now CLASS-1 and CLASS-2 were assigned black colours and CLASS-3 was kept in green colour and final image has totally displayed only in green colour.

Similarly, the storage coefficient buffered image was superimposed over regrouped image of the geomorphic parameters and similar CLASS-3 was buffered out. In the same way, the buffered out image of storage coefficient was superimposed over regrouped image of subsurface geological parameters and the CLASS-3 was buffered out.

Finally, all the CLASS 3 zones of all the three images were overlaid together by once again using the CROSSTABLE function and the final model for storage coefficient was developed. This has pictorially shown

1. Zones where storage coefficient is controlled by structures
2. Zones where storage coefficient is controlled by geomorphology
3. Zones where storage coefficient is controlled by subsurface geology
4. Zones where storage coefficient is controlled both by structures and geomorphology
5. Zones where storage coefficient is controlled both by structures and subsurface geology
6. Zones where storage coefficient is controlled both by geomorphology and subsurface geology and
7. Zones where storage coefficient is controlled by all the three parameters namely structures, geomorphology and subsurface geology.

This is how aquifer function models were developed for each and every aquifer parameters.

4.6.2 Functions of Water Level

For evaluating the functions of water level, the buffered out image of depth to water level mean (FIG. 4.20) was superimposed over the regrouped image of the structural parameters (FIG. 4.9) using CROSSTABLE function. Such superposition has resulted in the following classes in such superimposed raster image.

CLASS-1 Zones of water level minima
CLASS-2 Zones of structural parameters maxima
CLASS-3 Combined zones of water level minima and structural parameters maxima.

Again the CLASS 3 was buffered out by nullifying the CLASS 1 and CLASS 2 by accessing the REGROUP menu and assigning black colour to CLASS 1 and CLASS 2. So automatically the areas where water level is controlled by structural parameters have come out separately in the final raster image (FIG. 4.28). In this case, such zones were given green colour coding darkening CLASS 1 and 2. This analysis has shown that such domains where water level is shallow due to structural parameters are observed in the eastern half of the basin.

Similarly, the buffered out raster image of water level mean (FIG. 4.20) was overlaid with regrouped raster image of geomorphological parameters (FIG. 4.14) which again resulted in three classes as follows:
FIG. 4.28
CLASS 1  Zones of water level minima
CLASS 2  Zones of geomorphological parameters maxima and
CLASS 3  Zones of both water level minima and geomorphological parameters maxima.

In that, again the CLASS 3 which indicates the zones of coincidence of water level minima and geomorphological parameters maxima were buffered out using the REGROUP sub menu and final water level function image was generated (FIG. 4.29) showing CLASS 3 in one colour and CLASS 1 and 2 in dark colour. Such depth to water level mean function image shows that the zones where water level is controlled by geomorphological parameters. Again the zones of water level controlled by geomorphology too is found only in eastern half of the area.

Finally, such buffered water level mean image was superimposed over the regrouped raster image of subsurface geology (FIG. 4.19) and the zones where depth to water level minima coinciding with subsurface geology maxima zones were buffered out using REGROUP menu and final raster image was developed which shows the zones where water level is controlled by subsurface geology (FIG. 4.30). In this case such subsurface geology controls water level mainly in two zones. One in central part along NNE-SSW axis and another in the eastern fringe. (Given in megenda colour in FIG. 4.30). Such water level minima may be due to the stagnation caused by the obstruction by NNE-SSW trending major mylonite dyke trending along Gangavalli and Attur (FIG. 1.2).

Finally, such three raster images which were showing the areas where water level controlled by structural parameters (FIG. 4.28), water level controlled by geomorphological parameters (FIG. 4.29) and water level controlled by subsurface geological parameters (FIG. 4.30) were superimposed together using CROSSTABLE function available in the ANALYSIS module of the GRAM package and such final image has resulted in seven classes as follows (FIG. 4.31):

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Water Level controlled by:

- \(C_1\) : Structural parameters (Orange colour)
- \(C_2\) : Geomorphological parameters (Blue colour)
- \(C_1+C_2\) : Both structural and geomorphological parameters (Deep brown)
- \(C_1+C_3\) : Both structural and subsurface geological parameters (Light brown)
- \(C_2+C_3\) : Both geomorphological and subsurface geological parameters (Dark blue)
- \(C_1+C_2+C_3\) : Both structural, geomorphological and subsurface geological parameters (Green) and UNFAVOUR: Areas where water level is not showing any relation with any of the above parameters (Black).

This is the ultimate model explaining the functions of water level minima. That is, in different parts of the area different types of terrain characteristics namely structural parameters, geomorphological parameters and subsurface geological parameters control the water level minima. But in general, in western part of the basin, water level is deep and more over no relation exists with terrain parameters. In the central part, just west of Gangavalli - Attur mylonite ridge, water level is shallow due to all three parameters. This indicates that this dyke acts as a major barrier in obstructing the groundwater flow and hence raised the water level to shallow condition.

### 4.6.3 Functions of Aquifer Depletion

In the same way, the model showing the functions of width of aquifer depletion was developed. For the same, the buffered raster image of the width of aquifer depletion (FIG. 4.21) was superimposed over the regrouped image of structural parameters (FIG. 4.9) first and the zones of concidence were buffered out as zones where aquifer depletion is controlled by structures (FIG. 4.32). This was followed by the integration of buffered raster image of width of aquifer depletion and regrouped image of geomorphological parameters (FIG. 4.14) and subsurface geological parameters (FIG. 4.19). Finally the zones...
of coincidence between width of aquifer depletion minima and geomorphologic maxima were buffered out as zones where aquifer depletion is controlled by geomorphology (FIG. 4.33). Similarly, the zones where aquifer depletion is controlled by subsurface geology was also buffered (FIG. 4.34).

Again such three buffered out zones were superposed together by using CROSSTABLE function and final model showing the functions of aquifer depletion was generated (FIG. 4.35). Such image has shown six classes as follows:

- **C1**: Zones where aquifer depletion is controlled by structures
- **C2**: Zones where aquifer depletion is controlled by geomorphology
- **C1+C2**: Zones where aquifer depletion is controlled both by structures and geomorphology
- **C1+C3**: Zones where aquifer depletion is controlled both by structures and subsurface geology
- **C2+C3**: Zones where aquifer depletion is controlled both by geomorphology and subsurface geology and
- **C1+C2+C3**: Zones where aquifer depletion is controlled by all the three parameters namely structures, geomorphology and subsurface geology.

And unfavourable area which means aquifer depletion is not showing any direct relation with any of the above three parameters which warrents detailed study.

Once again in this case also in the western half of the basin, aquifer depletion is not controlled by any terrain parameters. In the central NNE-SSW trending zone all put together (Structures, Geomorphology and Subsurface Geology) control the aquifer depletion. Whereas, in the eastern half, the structure either in combination with geomorphology or subsurface geology control width of aquifer depletion. However, low rate of aquifer depletion in central zone is due to mylonite dyke which obstruct and cause quick recovery.
FIG. 4.35
4.6.4 Functions of Storage Coefficient

The model showing the functions of storage coefficient was similarly developed by integrating the buffered out raster image of storage coefficient (FIG. 4.22) with regrouped image of structural parameters (FIG. 4.9), geomorphological parameters (FIG. 4.14) and subsurface geological parameters (FIG. 4.19) one after the other. Wherever there were coincidence, those domains were buffered out as zones where storage coefficient is controlled by structures (FIG. 4.36), geomorphology (FIG. 4.37) and subsurface geology (FIG. 4.38). Finally all the three were superposed as done in the above case for mean water level and the storage coefficient function pictorial model was developed (FIG. 4.39). The same has shown six classes as below:

- C1 : Zones where storage coefficient is controlled by structures
- C2 : Zones where storage coefficient is controlled by geomorphology
- C1+C2 : Zones where storage coefficient is controlled both by structures and geomorphology
- C1+C3 : Zones where storage coefficient is controlled both by structures and subsurface geology
- C2+C3 : Zones where storage coefficient is controlled both by geomorphology and subsurface geology and
- C1+C2+C3 : Zones where storage coefficient is controlled by all the three parameters namely structures, geomorphology and subsurface geology.

In the said analysis, it is interesting to observe that the storage coefficient is nowhere controlled by subsurface geology alone in any part of the area. The storage coefficient is controlled by the structural parameters in Perambalur area.

Another interesting observation is the area falling east of Attur the storage coefficient does not show any relation with any of the parameters. This may be due to the same NNE-SSW trending mylonite dyke which runs along Gangavalli - Attur.
FIG. 4.36

FIG. 4.37
alignment which is orthogonal to the regional groundwater flow and regional drainage flow. So the same would have acted as major feature of obstruction which resulted in accumulation of groundwater through the structures, geomorphic landforms and subsurface geology in the west of mylonite dyke. Whereas the eastern part of the basin is a water shadow tract so it is a zone of poor storage coefficient in the basin.

4.6.5 Functions of Specific Capacity

The areas where specific capacity is controlled by structures (FIG. 4.40), by geomorphology (FIG. 4.41) and by subsurface geology (FIG. 4.42) were again brought out by similar integration of specific capacity image (FIG. 4.23) with regrouped image of structures (FIG. 4.9), geomorpholgy (FIG. 4.14) and sub surface geology (FIG. 4.19). Finally, all the three above images (FIG. 4.40; 4.41 and 4.42) were superimposed and final model was developed (FIG. 4.43) which has shown seven classes where specific capacity is controlled by by structures, geomorphology, various combination of structures, geomorphology and subsurface geology and the areas where no correlation exists between any of the three terrain parameters which was shown as unfavourable area in the same figure in black colour (FIG. 4.43).

In this case also, the specific capacity shows correlation with various terrain parameters only in peripheral part of the basin. In the case of numerical modelling too specific capacity did not show any mathematical relation with any of the structural parameters, geomorphological parameters and subsurface geological parameters (CHAPTER III). This is again the confirmation. But in this case, some relation could be established in peripheral part of the basin. This may be because of the reason that all more than mean zones were buffered out in all cases. Where as in numerical modelling, discrete digital values were taken.
4.6.6 Functions of Transmissivity

In the same way, the relation between transmissivity and the various terrain parameters data such as structural, geomorphological and subsurface geological parameters were established by the above map overlaying techniques (FIG. 4.44; 4.45 and 4.46) and the final raster image showing various functions of transmissivity was developed integrating above three images (FIG. 4.47). In this case also, the transmissivity is not controlled by any of the parameters in the entire basin (Black in FIG. 4.47) and the same is controlled by structures, geomorphology and subsurface geology only in the peripheral part of the basin.

4.6.7 Functions of Permeability

Such aquifer function model developed for the permeability through the above GIS techniques (FIG. 4.48; 4.49 and 4.50) and their integration has again shown six varying classes as shown below (FIG. 4.51).

- C1 : Zones where permeability is controlled by structures
- C2 : Zones where permeability is controlled by geomorphology
- C1+C2 : Zones where permeability is controlled both by structures and geomorphology
- C1+C3 : Zones where permeability is controlled both by structures and subsurface geology
- C2+C3 : Zones where permeability is controlled both by geomorphology and subsurface geology and
- C1+C2+C3 : Zones where permeability is controlled by all three parameters namely structures, geomorphology and subsurface geology.

Again almost in the entire part of the basin, permeability does not show any relation with terrain parameters (Black in FIG. 4.51).
FIG. 4.46

FIG. 4.47
4.6.8 Functions of Optimum Yield

The aquifer function model developed for optimum yield in similar way are shown in FIGURE 4.52; 4.53 and 4.54 and the final model in FIGURE 4.55. The image 4.52 shows that optimum yield is controlled by structures all along the peripheral part of the basin only and in central part (Black in FIG. 4.52), it is not controlled by structures. Almost same is the result while correlating optimum yield with geomorphology (FIG. 4.53) and subsurface geology (FIG. 4.54). The final model (FIG. 4.55) also shows that only in peripheral part, structures, geomorphology and subsurface geology control optimum yield in various combinations.

4.6.9 Functions of Recovery Rate

The functions of recovery rate images (FIG. 4.56; 4.57 and 4.58) and the final model (FIG. 4.59) again show the better correlation between structures, geomorphology and subsurface geology only in the peripheral part of the basin. In zones where recovery rate is controlled by structures (Green in FIG. 4.56), there are definite set of wide open lineaments with N-S and ENE-WSW orientations. There are circular green islands in NNE-SSW orientation showing parallelism to NNE-SSW trending mylonite ridge. This again indicates that the same mylonite ridge has acted as barrier and caused high recovery rate because of obstruction of easterly flowing streams. Same is observed in FIGURE 4.57 and 4.58.

4.6.10 Overall Aquifer Function Model

The overall aquifer function model was developed by similar overlaying of buffered raster image of overall aquifer system data with regrouped image of structures (FIG. 4.9), geomorphology (FIG. 4.14) and subsurface geology (FIG. 4.19) by using CROSSTABLE function and again REGROUP function of GRAM package was used and models were developed (FIG. 4.60; 4.61 and 4.62). While the images 4.60 and 4.61 show that the overall aquifer health (water level, width of aquifer depletion, storage coefficient, specific capacity, transmissivity, permeability, optimum yield and recovery rate) is
controlled by structures and geomorphology the FIGURE 4.62 shows that the subsurface geology controls the same only in the area west of mylonite dyke. This shows that the mylonite ridge acts as barrier and facilitates accumulation of groundwater in all possible porosities west of it. That is why there is a relation between all the three variables and the aquifer condition in the area west of mylonite dyke. Finally, the combined image was developed (FIG. 4.63) as done in the earlier cases.

4.7 SYNTHESIS

Using the numerical data of all the structural, geomorphological and subsurface geological parameters and also the various aquifer characteristics digital data, raster images and classified raster images were generated. From them, the zones of structural minima in the case of interval between laminations and joints and maxima in lineaments, minima in slope and drainage density and maxima in geomorphic grade, infiltration, thickness of top soil, weathered zone, fractured zone and depth to bed rock were buffered out and such buffered images were generated. And from these, regrouped raster images on structural, geomorphological and subsurface geological parameters were developed. Similarly, from various aquifer characteristic images, water level minima, width of aquifer depletion minima and maxima of storage coefficient, specific capacity, transmissivity, permeability, optimum yield and recovery rate were buffered out and such buffered raster images were generated.

All these buffered raster images of aquifer characteristic data were kept as dependent variables and correlated with structural, geomorphological and subsurface geological images by map overlaying techniques and the functions of each aquifer variable was thus established.