RELMA
REGIONAL LAND MANAGEMENT UNIT

GIS Exercise
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Thomas Gumbricht
T.Gumbricht@cgiar.org

Introduction to Modeling and Decision Support in GIS – Lake Nakuru, Kenya

Requirements
This exercise requires a PC with Windows 95/98/2000, Windows NT, or later and the freeware DIVA GIS 2.5. To download and install DIVA GIS see appendix 1. The necessary data are available on the RELMA_GIS1.0 CD. Sources of internet available data are given in appendix 2, and in the document Spatial Data and Applications for Environmental Studies in Africa.

Recommended prerequisites
It is recommended that you do the exercise GIS and satellite image data analysis – Lake Nakuru, Kenya before doing this exercise.

Objectives
This exercise will give an introduction to vector and data raster models, map algebra and modeling in GIS, and GIS as a tool for decision support. The objective of the exercise is that the students should gain insight into GIS as a more advanced tool for natural resource management, and for solving spatial allocation problems. After completing the exercise students should understand the concepts of vector and raster data, and the applicability of GIS for modelling, and for decision support.

Task
To pass the exercise a map showing suitability for commercial agriculture in the Nakuru region, Kenya, should be handed in.

Move the Nakuru database to your harddrive

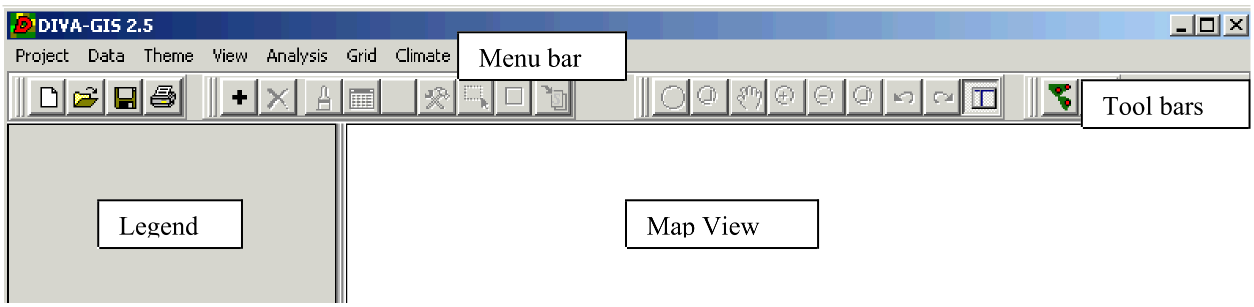
In this exercise you will create several new map layers. Hence the database must be in a directory where you can not only read the data, but also write data. The database is on the RELMA_GIS1.0 CD in the directory **…data/spatial/nakuru**. To have access to the whole database it is recommended that you copy the whole database on the RELMA_GIS1.0 (**…data/**) to your harddrive. By doing so you will also preserve the directory tree structure as it is given throughout this exercise.

Start the GIS freeware DIVA and add data

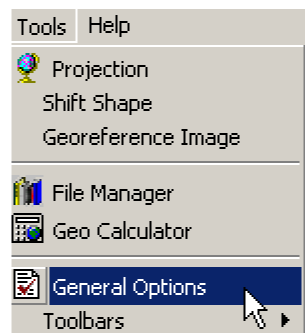
In this exercise we will use DIVA, - a GIS freeware from The International Potato Center (CIP) – see appendix 1 for instructions on how to retrieve DIVA from the internet and set it up. If the DIVA icon is not on your desktop you can find it on the Desktop via **Start - Programs - DIVA-GIS - DIVA.** The source program is under **C:\Program Files \DIVA-GIS\DIVA.** Start **DIVA**.

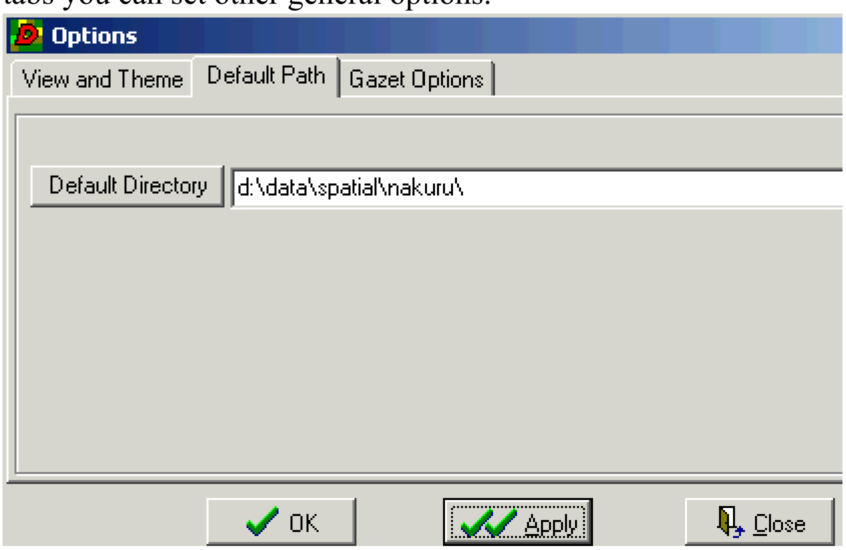
The main parts of the DIVA interface are shown in the figure below. You will be presented with an empty project. The user manual for DIVA (**DIVA-GIS2b.pdf**) is available on the RELMA_GIS1.0 CD and also in the same folder as the program file. This manual can be read by using Adobe Acrobat reader (see appendix 1 for download of Adobe Acrobat).

In the interface you will notice that some menu and tool items are gray (fuzzy) that means that they are not available at the moment. Many items require that you have some themes in the view, (a *theme* is a *maplayer* in GIS jargong) and some that you have at least one theme active (this will soon be clear to you).



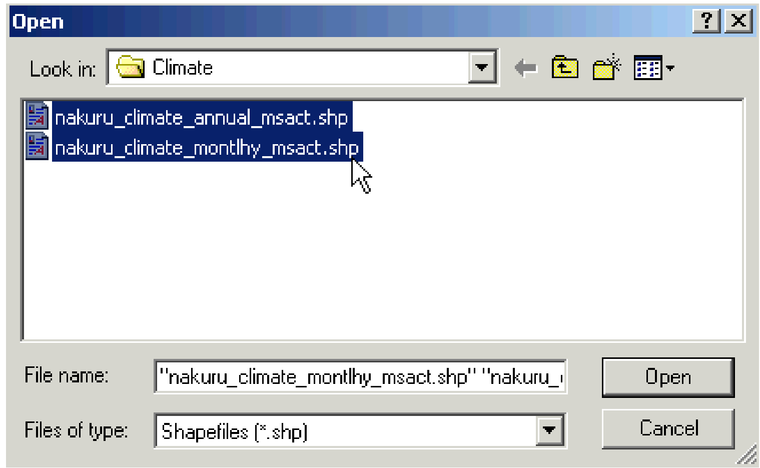
Before adding map layers you should set the default directory of the project. The data you will use is under **…data/spatial/nakuru** on the RELMA_GISCD1.0. Click Tools in the Menu bar and then General Options in the Pop-up menu, as shown to the right. In the Options dialogue you can set the Default Directory as shown below. Under the tabs you can set other general options.



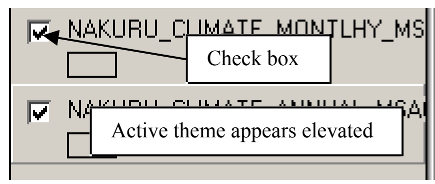


Save the DIVA project, give it a logical name. Remember to save the project frequently in case you should cause the program to crash or loose power supply.

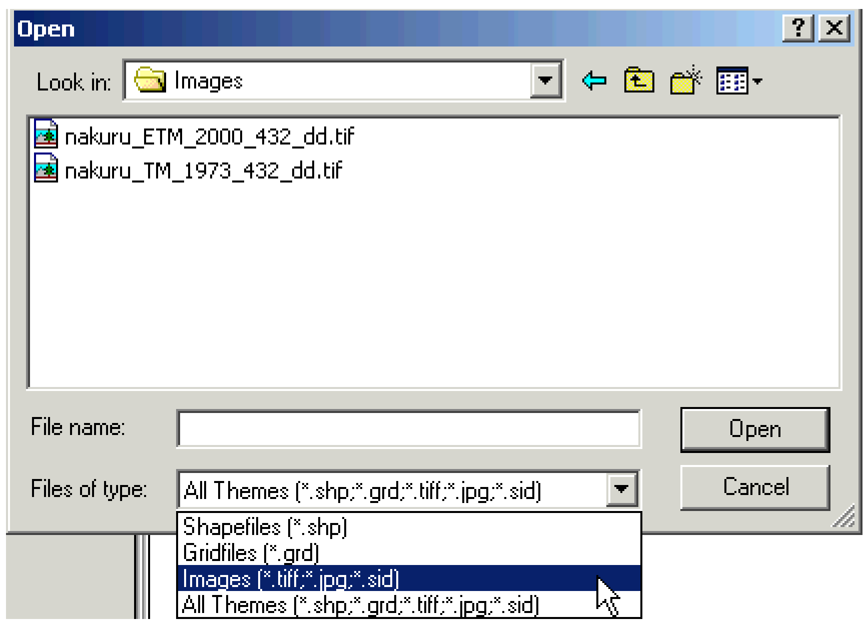
Now we are ready to add some maps from the RELMA_GIS1.0 CD. Press the Add theme button, . You will automatically come to the Default directory (**…data/spatial/nakuru**). Go to the **Climate** directory and add the two shape files with climate data. You can select both by holding down Ctrl+Shift on the keyboard and clicking the files. Click Open.

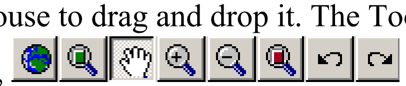


The two climate shape files both consist of rectangular polygon records with associated databases containing climate statistics. By default the added themes are turned on (i.e. the Check Box is marked), but this can be changed in the Options dialogue where you set the Default Directory.



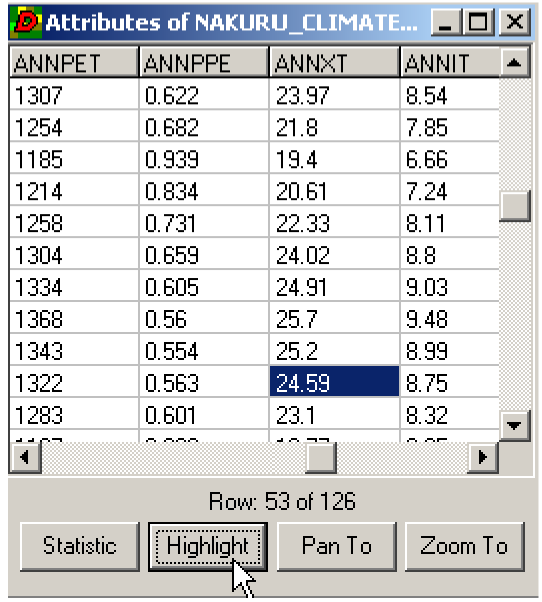
To get a reference to the area you are working with you must add a backdrop image. Use the Add theme button,  and navigate to the directory **Images**. The Open (or Add Theme) dialogue will be empty. DIVA (like most other GIS) needs to recognize what kind of theme that is added. In the bottom center of the dialogue box you must hence select Images from the drop-down menu.



There are two Landsat satellite images available. Add the one from 2000. Move the image theme to the bottom of the legend by using the mouse to drag and drop it. The Tools for zoom and pan in DIVA looks different from ArcExplorer,  and also include more advanced options. Zoom in,  to the satellite images and try out the Zoom and Pan tools.

Attribute data

Make sure that the annual climate theme is active (i.e. appears elevated).



Use the Identify tool, and click on any polygon in the active theme to see the records for that field. If you click around a little you will see that precipitation (the record **ANNPRE**) varies a lot over Nakuru and its surroundings. To look at the whole database (or attribute table in GIS jargon) click the Table tool, . You can now click any cell in the table and use the Highlight, Pan To and Zoom To buttons for seeing the corresponding shape in the View.

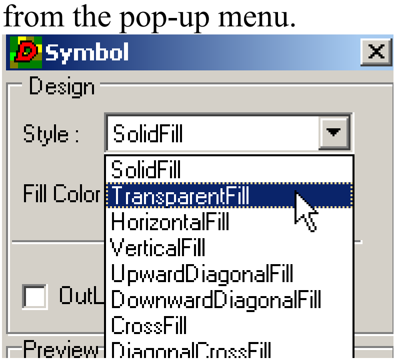
Use the Statistics button to calculate average precipitation over the study area. In the Statistic dialogue box scroll down to **ANNPRE** and select it. The annual precipitation for the area is 844 mm.

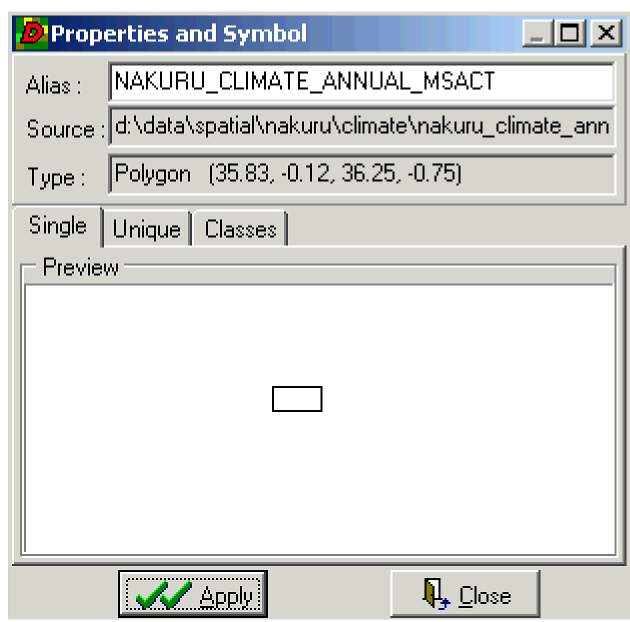
Each record (or shape in this case) in the vector file (whether point, line or polygon – see below) is associated with a record ('rows') in the attribute table. For each record there is a number of fields ('columns') with different attributes. This is a simple but often sufficient form of database connection used in all vector data GIS models.

Symbolizing data

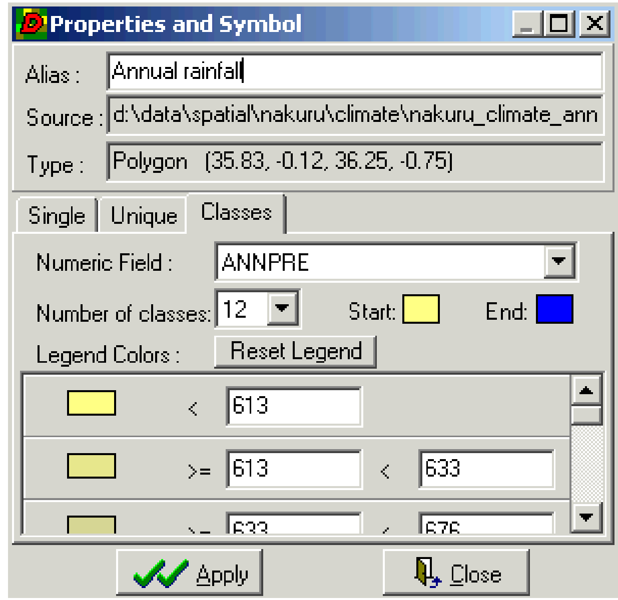
By default DIVA displays polygons with transparent fill and black outlines. You shall now create a color ramp for symbolizing the rainfall pattern of Nakuru. This is done from the Properties and Symbol dialogue that you open either via the Symbol tool, , by double clicking the theme in the Legend, or from the pop-up menu under Theme in menu bar.

There are three tabs in the Properties and Symbol dialogue. First you must change the Fill and Outline from the Single Tab. Double click the rectangle in the Preview window to access the Symbol dialogue, deselect the Check box for Outline and choose Solid Fill from the pop-up menu.



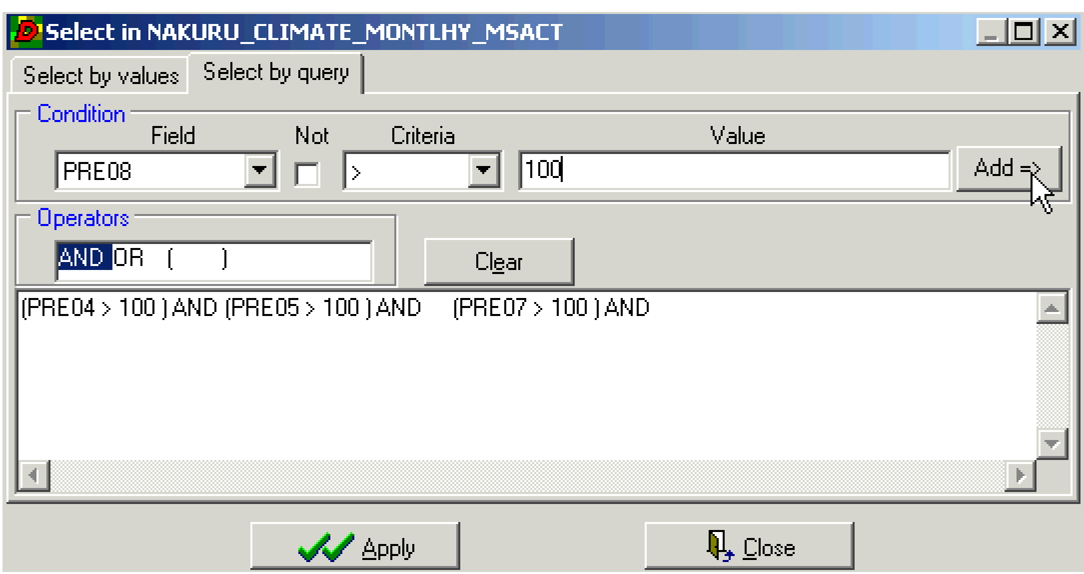


Click Apply in the Symbol dialogue and then Apply in the Properties and Symbol dialogue. (If you still see the polygon outlines it is probably because you did not deselect the check box for the monthly climate theme in the Legend). To create a color ramp for annual precipitation click the Classes tab in the Properties and Symbol dialogue. Change the Alias to Annual rainfall. Select **ANNPRE** as Numeric Field, and set the number of classes to 12. Double click on the rectangle for Start color. Select a yellow color in the Color dialogue that pops up and click OK. Select a blue color for End. Then click Reset Legend in the Properties and Symbol dialogue. Finally click Apply. You should now have a map and legend with a ramp of colors symbolizing precipitation.

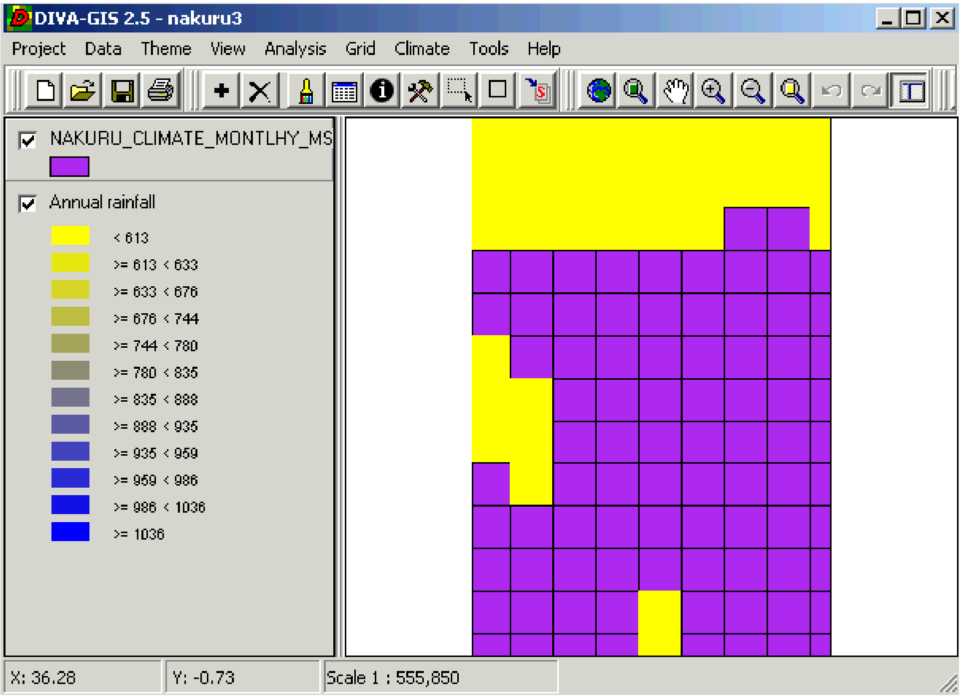


Query the database

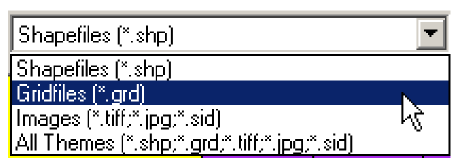
For agriculture it is not only the total annual precipitation that is of interest, also the distribution over the year is important. In Nakuru there are two rainy seasons per year, April to May, and July to August. For successful rainfed crop growth it is necessary that precipitation during these four months of rain exceed 100 mm per month. To find out which areas in the map that have sufficient rainfall you must use a query. Make sure that the monthly climate theme is active and click the Select Record tool, . In the Selection dialogue click the Select by Query tab. Select Field to be **PRE04**, set criteria to > and enter 100 for Value. Click the Add button. Then click the AND operator and enter the same conditions but for month 5, 7 and 8. Click Apply.



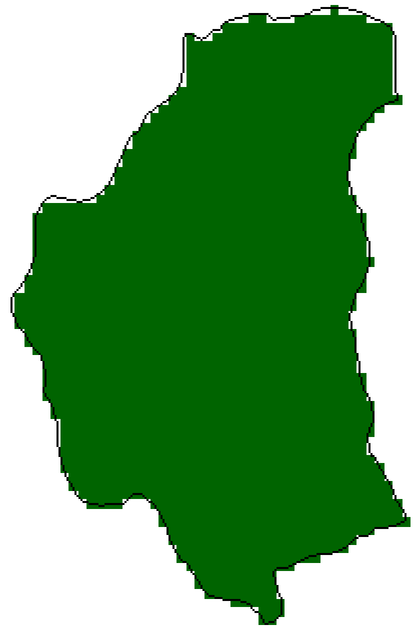
Your map should now look like the example below, where the yellow areas denote those with sufficient precipitation for rainfed agriculture.



Vector vs Raster data



DIVA can handle both vector and raster data. Use the Add Theme button,  to add a raster layers showing annual precipitation and areas suitable for rainfed agriculture. Navigate to the climate directory and change the File type to be grid. Add both grids.The grid themes cover (almost) the same area as the shape files; the grid files however do not have any attribute table.



To have a look at the difference between shape and grid files you must add some more map themes. Use the Add Theme button,  to add the basin (or catchment) of Lake Nakuru both as polygon and as a grid – both themes are under the directory **Hydro**.

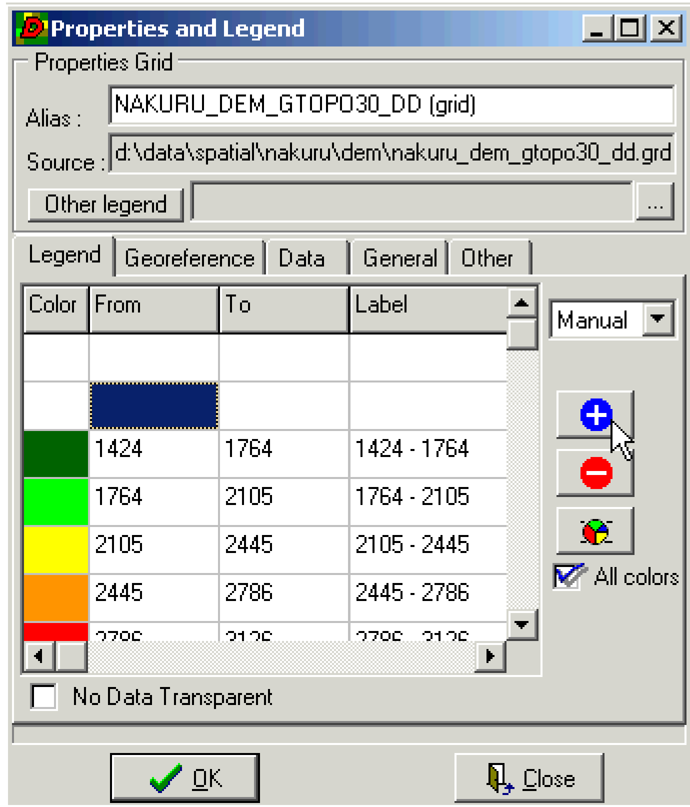
Vector data can be of three types:
Points (i.e. a city on a small scale map, or a well on a large scale map),
Lines (i.e. roads or rivers), or
Polygons (i.e. watersheds or political units)
Vectors are associated with attribute data (tables or databases in GIS jargon).
The precision of vector data is better, but for map algebra, map calculations and GIS modeling, raster data is easier to use. Remember that satellite data is also in a raster format, and more and more used for mapping and map updating.

Digital Elevation Models (DEM)

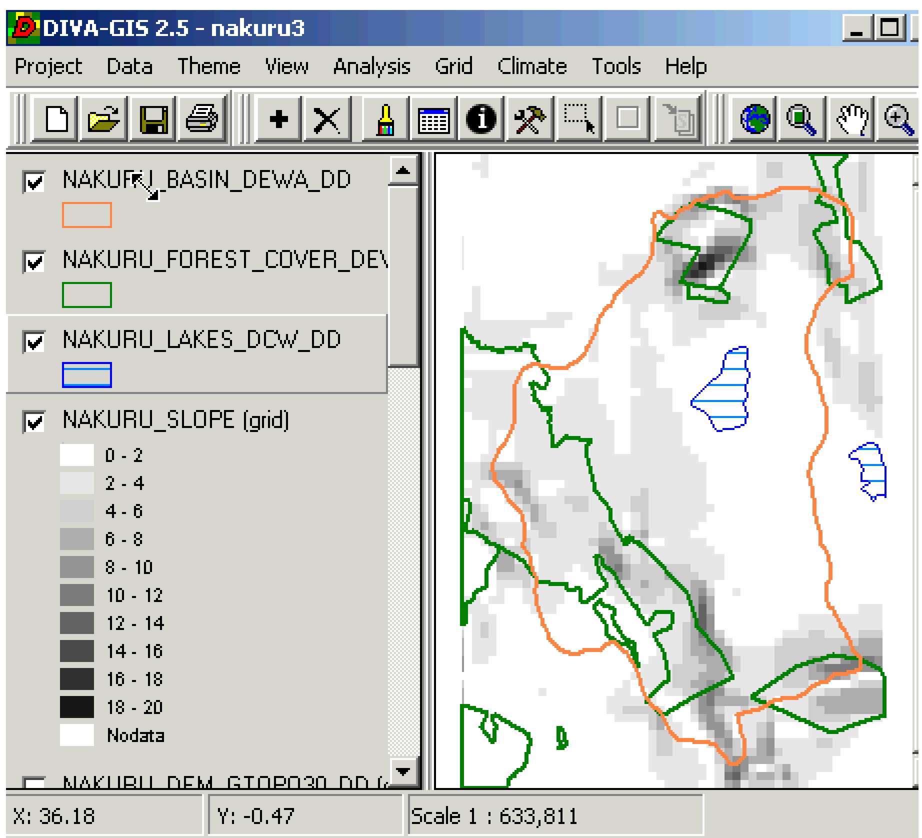
Digital elevation models are widely used for modeling e.g. hydrology and erosion in GIS (and other software). Elevation data in GIS can be in three different formats, as contour lines and spot heights, as triangular irregular networks (TIN) or as raster data. Contour lines are how elevation is usually presented on topographic maps (sometimes with additional hillshading). TIN is the format elevation data is collected from trigonometric surveys. Raster is the preferred data model for doing mathematical analyses and map algebra.

One important landscape character that can be computed from a DEM is slope (steepness) which influences both runoff and erosion. Use the Add Theme button,  to add the raster Dem and the derived slope map, both available in the DEM directory. By default DIVA displays continuous raster themes with five colors.

Change the color ramp for symbolizing the DEM and slope by using the Properties and Legend for grids dialogue that you open either via the Symbol tool, , by double clicking the grid theme in the Legend, or from the pop-up menu under Theme in menu bar. To change the color ramp for grid themes is more complex than for polygon themes. Change from Auto to Manual on the right side of the Properties and Legend dialogue, and add some more rows, . You must do a manual reclassification in the From and To fields and also manually enter new colors (double click the color rectangles). Click OK when you are finished.

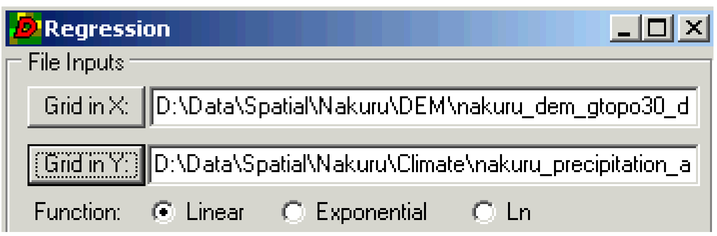


Add the shape themes for Lake Nakuru and its basin (in the **Hydro** directory) and for forest areas (in the **Landcover** directory). Put them on top of the grid theme for slope, and turn on these three themes. Symbolize them; in the example to the right the Lake theme has a Horizontal Fill in order for the underlying slope theme to be visible also 'under' the lakes. The other polygons have a Transparent Fill. The lake is in a flat area, whereas the forests are found in the steeper parts of the catchment.



Regression analysis

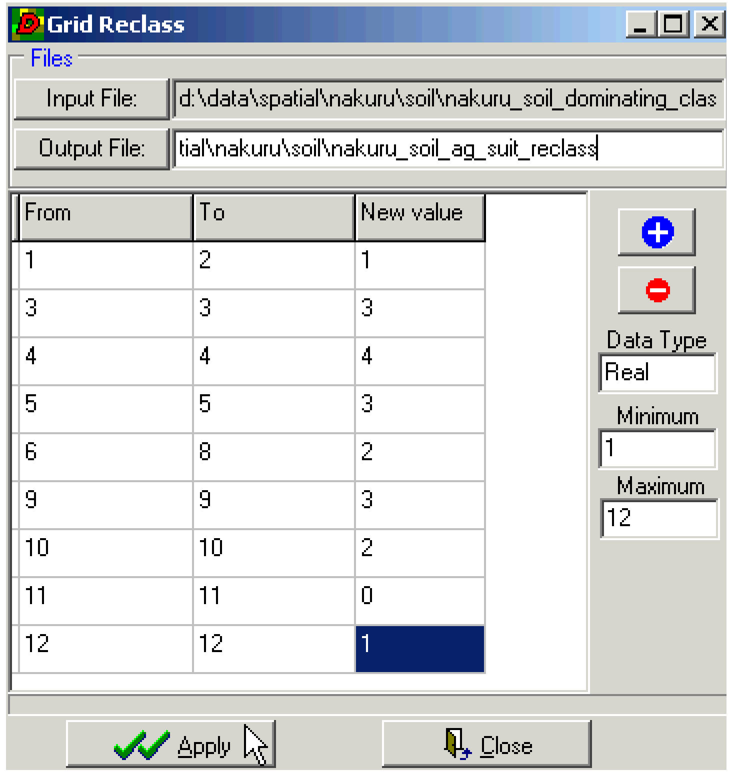
Both the rainfall and the topography in the basin vary quite a lot over a rather small area. To see whether there is any correlation between the two themes (possibly caused by orographic precipitation over the mountains) we will use regression analysis. Click on the DEM grid theme to make it active, then click Analysis in the menu bar and select Regression from the drop-down menu. DEM should now be the Grid in X, click the Grid in Y button and select the grid with annual precipitation data as Y variable. Do the regression by clicking Apply. Have a look at the chart and the result. What is the coefficient of determination? Charting data is a standard procedure for displaying the properties of spatial data in a more comprehensive form.



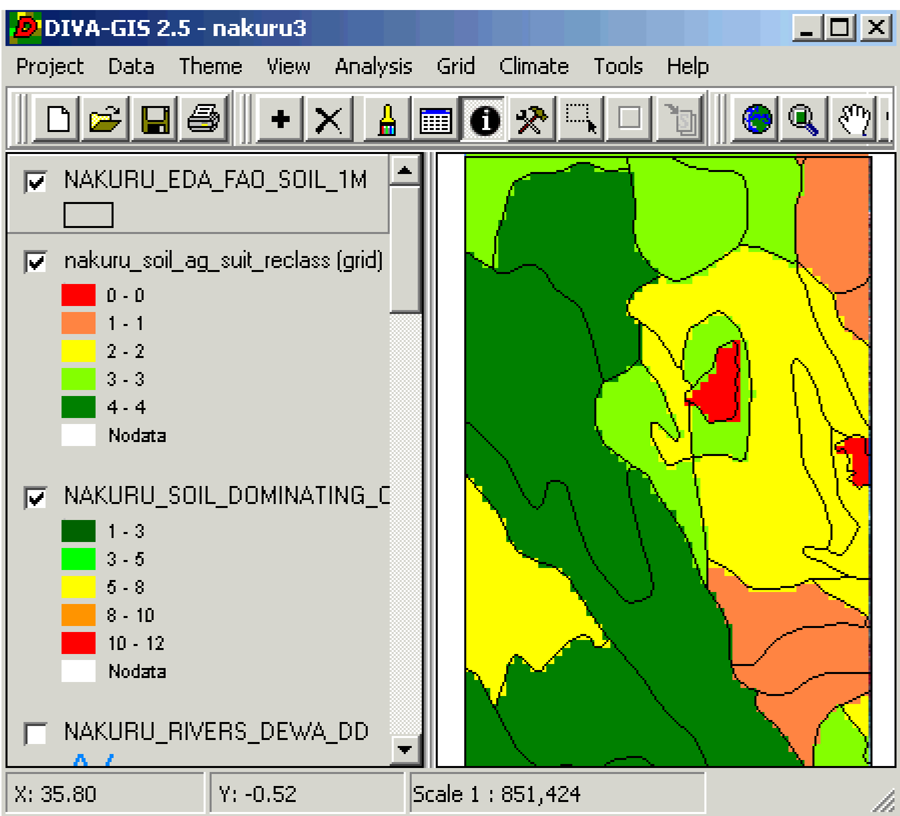
Reclassification

To reclassify grid images is a common operation in GIS. To illustrate that you will use grid themes of soils and geology. Add both the shape and the grid theme for soil (under the **Soil** directory). Put the shape theme on top of the grid theme so you can se the outlines of shape file, and make the shape file the active theme to get information on the records in the shape. Use the Identify tool,  to look at the records in the soil database. The soil grid theme is made from the **DOM1** field in the database.

Make the grid soil theme the active theme. Click Grid in the theme menu, and choose Reclass in the drop-down menu. The reclass that you will do should reflect the soil types suitability for agriculture (higher value = higher suitability). First enter a name for the Output File, you must include the full path. Then reclass the soils, you can follow the example to the right or use your own soil knowledge to do the classification. Add classification rows by clicking the Insert button, . Click Apply and add the new theme to the view. Change the symbolizing of the reclassified map to reflect suitability classes.



Put the shape soil theme over the 'soil suitability for agriculture' map. Below is an example of how it could look.

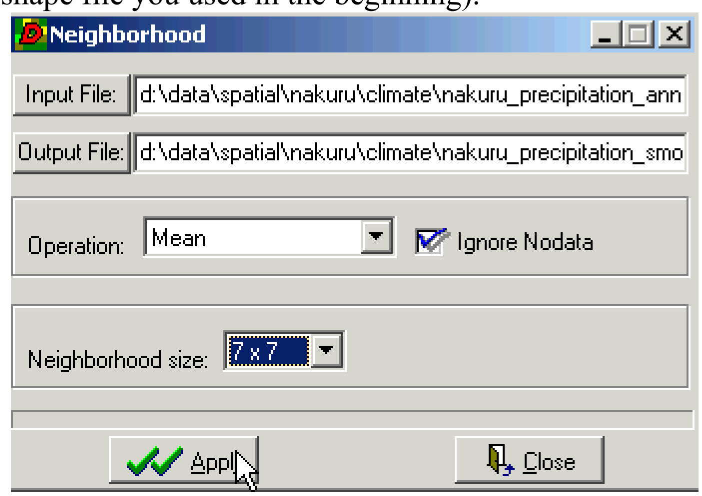


In a similar way also reclass the geology and slope maps into suitability maps for agriculture. As a hint eolian deposits are the most poor, and then usually younger intrusive rocks are better than older. The slope map derived from the DEM that you used above have higher classes for higher slopes, whereas agriculture is more suitable on flat terrain (e.g. for erosion risk purposes). You must hence invert the slope map. The slope is a continuous map from 0 to 20 degrees, but we only want 4 classes for our suitability analysis. Classify the maps into a maximum value of four. These maps will be needed for the decision support later in the exercise.

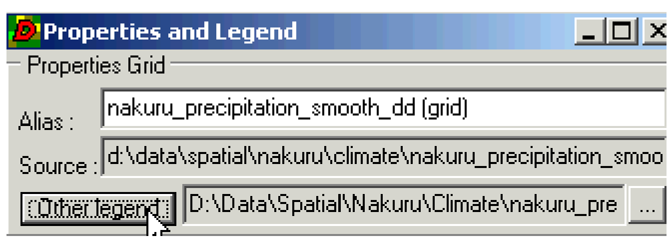
Map filtering, map algebra and expert modeling

Using algebra to derive new themes is also a common method used in GIS. Above you queried the database for locating areas suitable for rainfed agriculture defined as those areas where you have more than 100 mm of rainfall per month during the two rainy seasons. Another factor that will influence the suitability for agriculture is the amount of water available per capita in an area. If the water demands for domestic use is large, it is unlikely that water harvesting for irrigation will be possible. As there are map themes of population and precipitation available on the RELMA_GIS1.0 CD we can use map algebra for finding out the water availability for irrigation.

Add the grid theme with population data from Landscan (under the **Population** directory). Put the population map and the annual rainfall maps on top in the Legend. If you toggle between them you can see that the spatial resolution is apparently higher in the population data. The rainfall data set has from a technical GIS perspective the same resolution, but it is derived from a more low-resolution data set (the climate shape file you used in the beginning).
To smooth the crispness of the annual rainfall grid, you shall use a neighborhood filtering process. This means that the value of a single pixel will be assigned the average value of its neighborhood (including self). With the annual rainfall theme selected click Analysis in the menu bar and then Neighborhood from the Drop-down menu. Give a name for the Output File, set Operation to Mean and Neighborhood size to 7x7, and Apply.



Add the new grid theme to the Map View. To change its color ramp to the same as that for the original precipitation map open the, open the Properties and Legend dialogue, click the Other legend button and select the original precipitation map. Click OK.



The smoothed (or filtered) rainfall map theme now looks more less crisp.

You should now be ready to make the map calculation that will reveal water availability per capita in the Nakuru area. To be able to translate precipitation in mm to cubic meters (m^3) per cell you must know the surface area of each cell, which is 1 km^2. The conversion factor is hence 1000 (=1000 m * 1000 m * 0.001 m). Hence each mm of rain will generate 1000 m^3 of water per cell (km^2). However, as a rule of thumb we can assume that approximately 50 % of the rainfall can not be utilized due to evaporation and other losses. The basic water need is around 20 liters per person and day, going up to 100 liters in more developed regions, and perhaps 300 liters in industrialized regions. Let us assume a water need of 50 liters per person per day before any water can be used for irrigation. 50 liters per day translates to 18250 per year. With these figures we can write the complete formula for water availability for agriculture (expressed in mm per year):

(([precipitation]*500)-([population]*18250))/1000

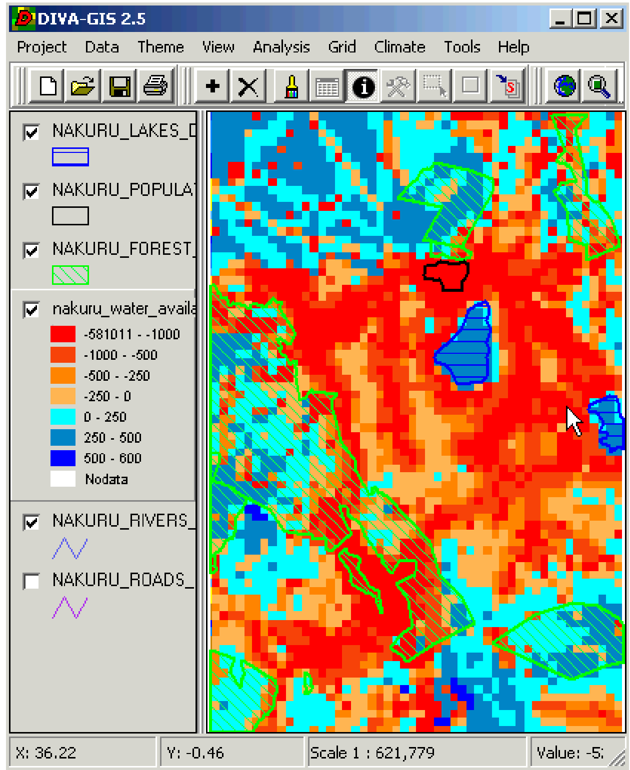
Click on Grid in the menu bar and select Calculate in the drop-down menu. Write the formula shown above as the Expression to evaluate. You must include the parentheses. The two grid themes can be entered using the Add Grid button. Give an Output File with full path, in the example it is put in the **Hydro** directory. Click Apply, and add the new grid theme to the Map View.

Change the color ramp for the water availability theme to representative colors, and put some of the shape themes on top to get a better understanding of the water availability, as in the example below.

The agricultural water availability map is an example of a data (or forward) driven expert generated map. The algorithm you used for deriving the map was based on (expert) knowledge of

- Rainfall
- Evaporation
- Population, and
- Per capita water use,

as well as knowledge on how to combine these in a 'model'. Also the method for identifying areas suitable for rainfed agriculture above is an example of a forward driven expert system.



Decision Support and Multi Criteria Evaluation

To derive at a decision tool using GIS usually involves many steps. This is true both for the conceptual work of defining what decision criteria to use, and also how to represent and weigh these criteria in the GIS. To fully understand how a map can be created that represents the evaluation of multiple criteria you should follow this section in detail. As this will involve many GIS processing steps it will take some time. Hence you can instead read through the text and only execute the formula given towards the end of this section. You can simply copy this formula and paste it into the Grid Calculator.

In this exercise you have created a set of maps that now can be used as Decision Support for identifying areas suitable for agricultural commercialization in the Nakuru area. In your project you should now have the following 'suitability' or 'decision criteria' maps:

Rainfed agriculture
Soil
Geology
Slope
Water availability

Apart from those decision *factors*, commercial farming is also dependent on access to markets. Two additional decision factors hence are:

Proximity (distance) to Nakuru town
Proximity to road network

But there are also other criteria that must be included, namely maps that contain *constraints* that will either allow or forbid agriculture. One type of constraint is obviously land cover – it is difficult to have agriculture in lakes. Land use is another constraint; to have agriculture in the town of Nakuru is also not possible. There are also legal constraints; agriculture is not allowed in the lake protected area or in the protected forest. This gives us the following list of constraints:

Water areas
Urban areas
Protected areas (lake shores and natural forests)

The constraints are straight forward to use, they are Boolean factors either allowing (1) or forbidding (1) the activity to be evaluated. Note however that the original maps showing lakes, towns and protected areas need to be inverted as they (logically) have the numerical value of one (1) for the features they contain. Hence you must reclass the four map layers to have a value of 0 for the feature (forbidden area) and 1 for all other (allowed) areas.

The factors have ordinary scales (in our case from 1 to 4), and you must also set weight to the factors so as to reflect their relative importance *vis-a-vis* each other. This can be done in a variety of ways, but usually involves participatory discussion panels. In this sense decision support systems are more participatory than expert models.

As we have multiple criteria for identifying suitable areas for agriculture you will use Multi Criteria Evaluation (MCE). As you will be looking for the *most* suitable area in a relative sense, there will always be a result. Even if there are no *absolutely* really suitable areas, you will still find some areas. In this sense most decision support systems, or tools are goal driven (as opposed to being data driven).

Before setting weights and running the MCE you must prepare some more maps. The Rainfed agriculture suitability map is a constraint map is it now stands (the map values are 0/1). It is suggested that you change this into a factor map by reclass (or grid calculation). For example set suitable areas (1) to 4 and unsuitable areas (0) to 1. Then you must reclass the Water availability map into 4 classes. Then you must also add and reclass the two proximity maps. They are in the directory **Proximity**. Proximity (or distance) analysis is a standard GIS method, but not supported by the DIVA GIS freeware. Reclass also the proximity maps to have values between 1 and 4.

The only thing that now remains before running the MCE is to decide on factor weights. Use weights between 1 and 10. The following table is an example of weights.

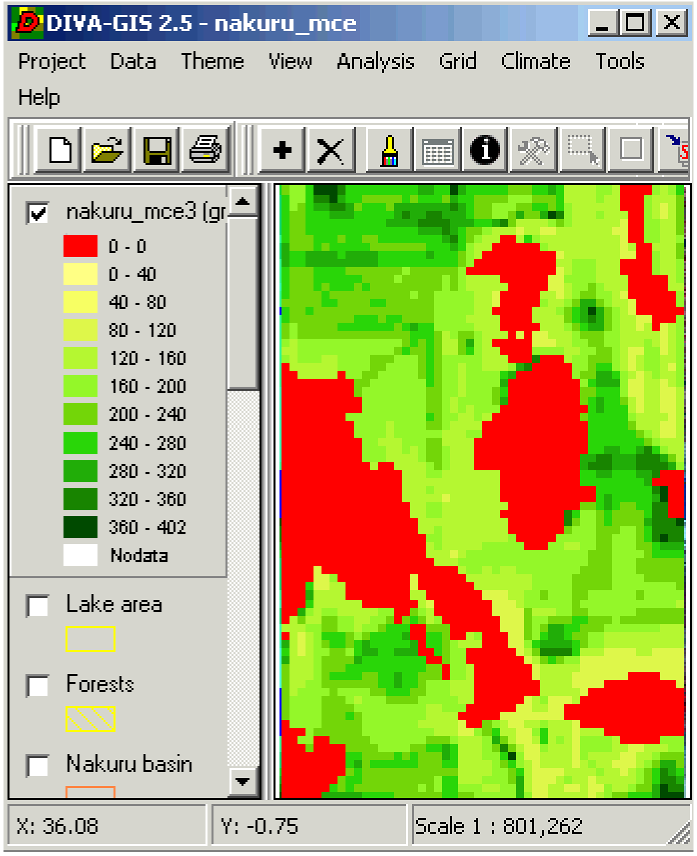
Factor	**Weight**
Rainfed agriculture	5
Soil	8
Geology	1
Slope	4
Water availability	6

Proximity to Nakuru town	2
Proximity to road network	3

As computers do not have an exact precision in carrying large numbers between calculations, there might be a problem executing the formula. Also you might have done some mistakes, which likewise might cause the MCE formula to not execute. To simplify matters all the constraint and factor criteria are available in the **MCE** directory. Use the Grid Calculator to execute the MCE. The formula derived from assigning the given weights for the map layers in the **MCE** directory is given below. If you want to make a shortcut just copy the formula below and paste it into the Expression to evaluate window in the Grid Calculator.

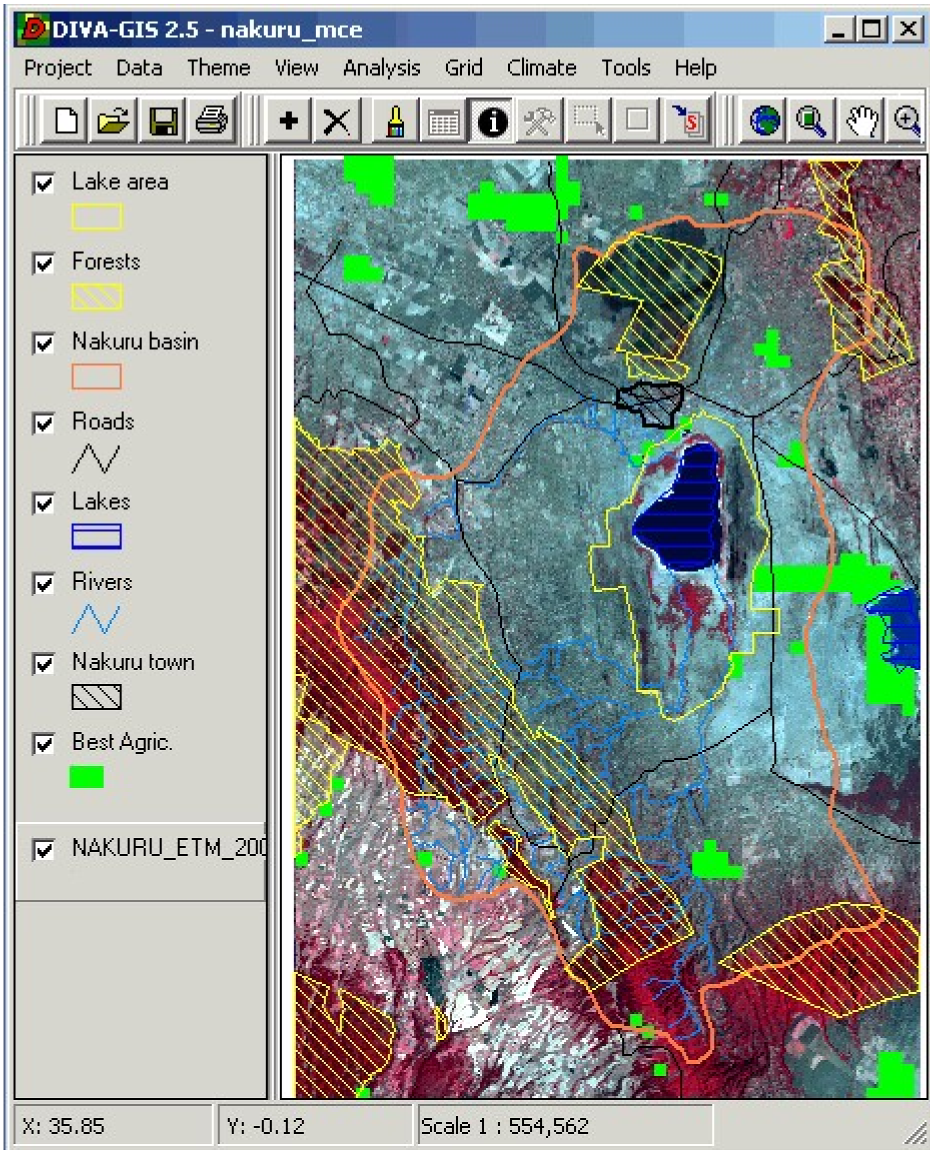
([D:\Data\Spatial\Nakuru\MCE\nakuru_distance_to_nakuru_ag_suit.grd]*2+[D:\Data\Spatial\Nakuru\MCE\nakuru_distance_to_roads_ag_suit.grd]*3+[D:\Data\Spatial\Nakuru\MCE\nakuru_geology_ag_suit.grd]+[D:\Data\Spatial\Nakuru\MCE\nakuru_rainfed_ag_suit.grd]*5+[D:\Data\Spatial\Nakuru\MCE\nakuru_slope_ag_suit.grd]*4+[D:\Data\Spatial\Nakuru\MCE\nakuru_soil_ag_suit.grd]*8+[D:\Data\Spatial\Nakuru\MCE\nakuru_water_ag_suit.grd]*6)*[D:\Data\Spatial\Nakuru\MCE\nakuru_forest_con.grd]*[D:\Data\Spatial\Nakuru\MCE\nakuru_lake_protected_con.grd]*[D:\Data\Spatial\Nakuru\MCE\nakuru_nakuru_town_con.grd]*[D:\Data\Spatial\Nakuru\MCE\nakuru_lakes_con.grd]

To the right is an example (derived from the formula above) of a suitability map for commercial agriculture over the Nakuru region in Kenya. The map has an ordinal scale reflecting suitability. These values have no physical meaning, which is typical for goal-driven decision support derived maps. But if you look for, say 1000 hectares to be developed into commercial agriculture, then you just select the 1000 hectares with the highest suitability. In this way you will always be able to identify 1000 hectares.
Compare this with the expert model of water availability (p. 13) that has a physical meaning (mm of water available per year), and is typical for forward driven expert models.



Your turn

To complete the exercise you should create a map layout showing the most suitable areas for commercial agriculture. In the example below all the constrains used are put on the map to show that commercialization is not considered on those areas. When you are satisfied Print or Export the final map (under Project in the menu bar).



Appendix 1: How to get DIVA-GIS from the internet

Use a web-browser (Netscape, Internet explorer) and navigate to the homepage of DIVA-GIS at the International Potato Centre (http://www.cipotato.org/diva). Read about DIVA-GIS and then press Download (version 2.5 is the latest at the time of writing this instruction). Download both the file **diva2e.zip**, also download the User Guide, **DIVA-GIS2b.pdf**.

Close all windows applications that are running on your PC and install DIVA-GIS by executing the program **diva2e.zip** (the program that you downloaded). To be able to install DIVA-GIS you must have administrative rights on the computer you are using – if you do not have that you must ask your system administrator to help you. When you install the DIVA-GIS the default path for installation is "**Program files\DIVA-GIS**". It is recommended that you accept that.

If you get stuck or do not understand a command, please refer to the User Guide that you downloaded (**DIVA-GIS2b.pdf**). This document is in pdf format, which you can read using Adobe acrobate reader. If you do not have acrobat reader on your computer you can download it from http://www.adobe.com/. Installation is done in a similar manner as the DIVA-GIS installation described above.

Appendix 2: Free data from the internet used in this exercise

For more comprehensive information on data available over the internet see the document Spatial Data and Applications for Environmental Studies in Africa. The exercise GIS Data Mining on Internet introduces using ArcExplorer for direct linking to map resources on the internet. It also includes examples of how to find and download other datasets, including Digital Chart of the World (DCW), which is a comprehensive dataset with global coverage. DCW data covering the RELMA countries (Uganda, Ethiopia, Eritrea, Tanzania, Kenya and Zambia) is available on the RELMA_GIS1.0 CD (under **…data/spatial/DCW**). To import the DCW to ArcExplorer you must use special software (Import71), which is also supplied on the RELMA_GIS1.0 CD. It is however not trivial to import this data, but you can find the instructions in the exercise Data Mining on Internet.