EX 2 – GEOREFERENCING

Introduction

A coordinate system (CS) provides a fundamental spatial framework to support the planning and development of a nation. All spatial data has a coordinate system to define locations on earth.

In Pakistan there have been several different CS, but the commonly used are, WGS1984, LCC and UTM. WGS1984 (the geographic CS) is the most commonly used geographic coordinate system, but if the area or length calculations are involved then UTM (a projected CS) should be preferred. Pakistan lies to the north of equator (0° Latitude) and to the east of Prime meridian (Greenwich, 0° Longitude)

When working with GIS it is extremely important to understand these different systems and the relationships between them. Poor understanding of these systems will most likely lead to great difficulties to combine data from different sources, difficulties in sharing maps with other departments or organizations, low map accuracy and overall inefficiency. If possible an organization should try to use one standard geographic coordinate system or datum.

This document is intended to provide theoretical background about geographic and projected coordinate systems as well as with a technical part describing and guiding people how to use the software ArcGIS as a tool to perform georeferencing and transformations.

Part I - A theoretical background about Coordinate Systems

The information in the first four chapters of this document is mainly taken from the book "Understanding Map Projections" written by ESRI 1994-2000.

1. Geographic Coordinate Systems

A geographic coordinate system (GCS) uses a three dimensional spherical surface to define locations on the earth. A GCS is often incorrectly called a datum, but a datum is only one part of a GCS. A GCS includes an angular unit of measure, a prime meridian, and a datum (based on a spheroid).

A point is referenced by its longitude and latitude values. Longitude and latitude are angles measured from the earth's center to a point on the earth's surface. The angles are often measured in degrees (or in grads) (see figure 1).
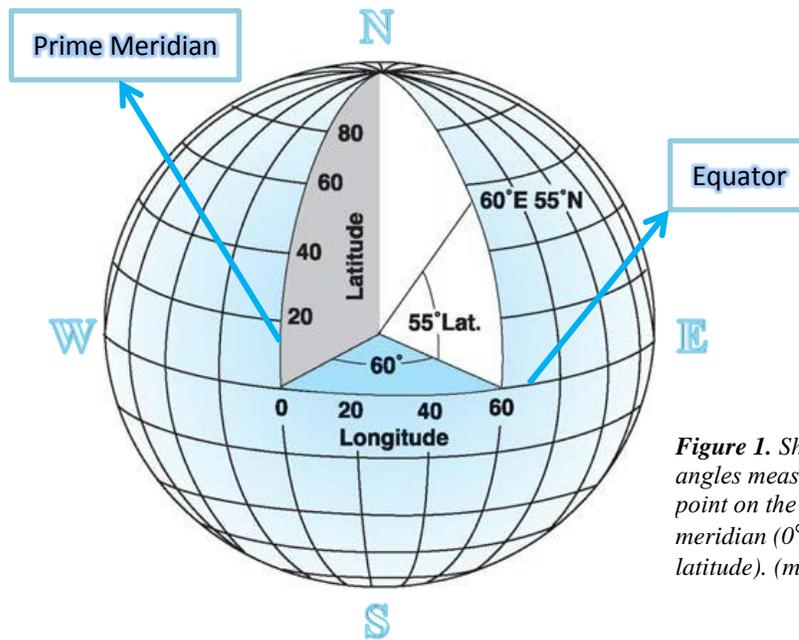
Figure 1. Showing Longitude and latitude angles measured from the earth's center to a point on the earth's surface and prime meridian (0° Longitude) and equator (0° latitude). (modified after ESRI 1994-2000).

In the spherical system, 'horizontal lines' or east–west lines are lines of equal latitude, or parallels. 'Vertical lines', or north–south lines, are lines of equal longitude, or meridians.

The line of latitude midway between the poles is called the equator. It defines the line of zero latitude. The line of zero longitude is called the prime meridian. For most geographic coordinate systems, the prime meridian is the longitude that passes through Greenwich, England. Latitude and longitude values are traditionally measured either in decimal degrees or in degrees, minutes, and seconds (DMS). Latitude values are measured relative to the equator and range from -90° (90° S) at the South Pole to +90° (90° N) at the North Pole, with 0° at the equator. Longitude values are measured relative to the prime meridian. They range from -180° (180° W) when traveling west, to +180° (180° E) when traveling east, with 0° at the prime meridian.

The latitude and longitude reference system assumes that the Earth is a perfect sphere. Unfortunately this is not correct. The earth is actually an oblate spheroid with flatter poles (see figure 2). To complicate matters further the surface of earth is far from smooth and regular.
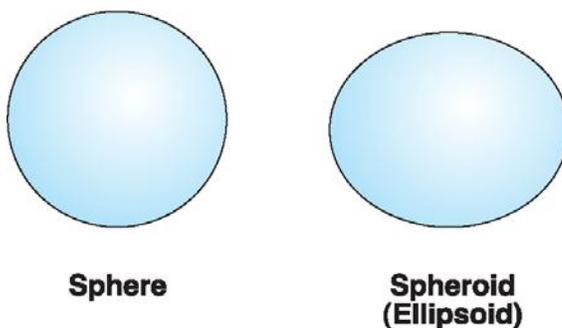
Figure 2, A representation of earth as a sphere or a spheroid. (ESRI 1994-2000).

Ellipsoid models use the major and minor axes of the earth and mathematically account for flattening at the poles (see figure 3).
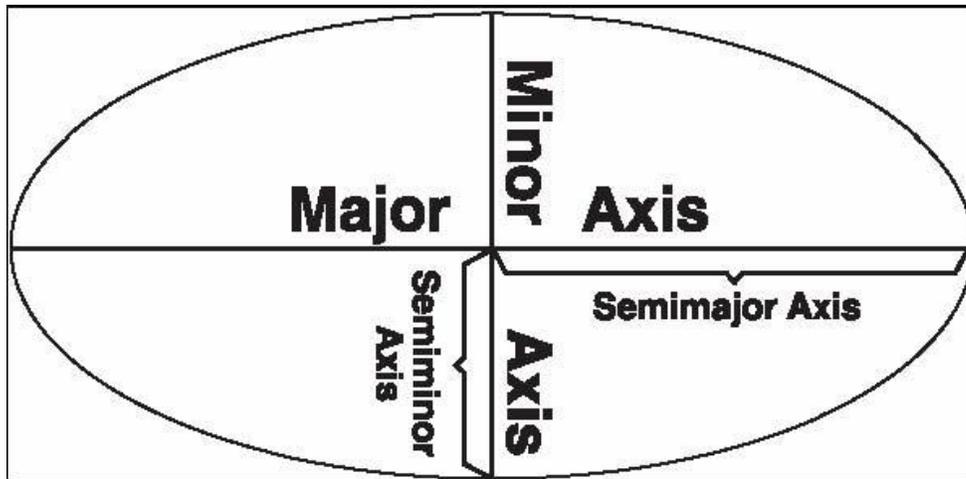
Figure 3. (ESRI 1994-2000).

For historical reasons there are several such ellipsoids in use for mapping different countries of the world. Each of these ellipsoids is generally matched to one or several countries. An ellipsoid appropriate for one region of the earth is not always appropriate to other regions (Lao National Geography Department 1997).

Another property is needed to uniquely specify geographical positions. This is the position and orientation of the ellipsoid relative to the earth. The term used to describe this fitting of an ellipsoid to the earth is the geodetic datum. Many geodetic datums exist throughout the world, each usually associated with the national survey of a particular country or continent. More recently several new geodetic datums have been successively derived, from steadily accumulating satellite and other data, to provide for a best worldwide fit.

A local datum aligns its spheroid to closely fit the earth's surface in a particular area. A point on the surface of the spheroid is matched to a particular position on the surface of the earth. This point is known as the origin point of the datum. The coordinates of the origin point are fixed, and all other points are calculated from it. The coordinate system origin of a local datum is not at the center of the earth. The center of the spheroid of a local datum is offset from the earth's center (see figure 4). Because a local datum aligns its spheroid so closely to a particular area on the earth's surface, it is not suitable for use outside the area for which it was designed. The Lao national datum 1997 is an example of a local datum, which has a spheroid with a good approximation to the size, and shape of the sea-level surface in the region of Lao PDR.
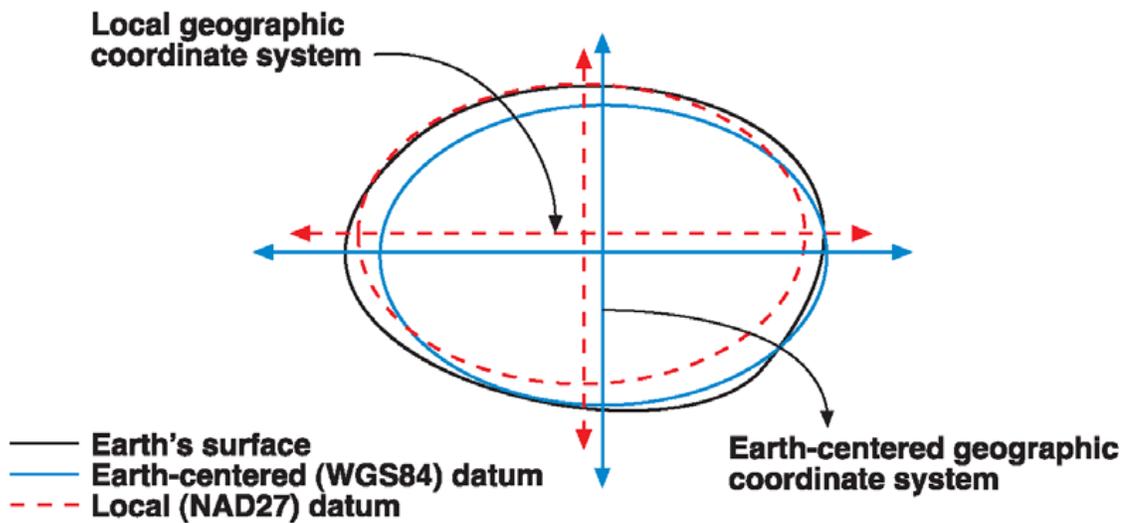
Figure 4. *(ESRI 1994-2000).*

2. Projected Coordinate Systems

A projected coordinate system is any coordinate system designed for a flat surface such as a printed map or a computer screen. Whether you treat the earth as a sphere or a spheroid, you must transform its three-dimensional surface to create a flat map sheet. This mathematical transformation is commonly referred to as a map projection. A map projection uses mathematical formulas to relate spherical coordinates on the globe to flat, planar coordinates.

There are three main ways to project a map:

2.1. Azimuthal or Planar Map Projections

Planar projections project map data onto a flat surface touching the globe (see figure 5). This type of projection is usually tangent to the globe at one point but may also be secant. The point of contact may be the North Pole, the South Pole, a point on the equator, or any point in between. This point specifies the aspect and is the focus of the projection. The distortion is the smallest at the point of tangent. Planar projections are used most often to map Polar Regions.
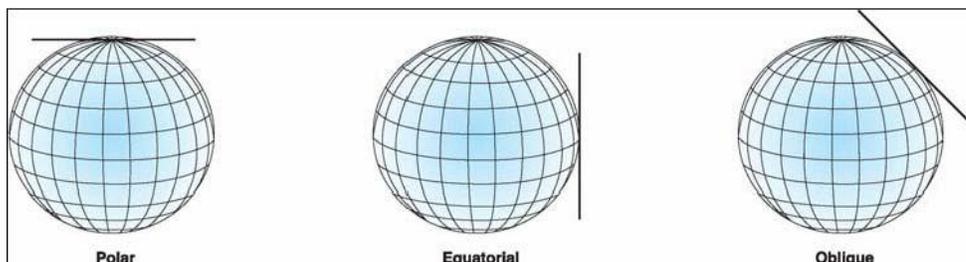
Figure 5. *Planar projections project map data onto a flat surface touching the globe (ESRI 1994-2000).*

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2.2. Conical Map Projections

This way to project a map is based on that you place a cone over the globe (Eklundh et al 1999) (see figure 6). The simplest conic projection is tangent to the globe along one line of latitude. This line is called the standard parallel. In general, the further you get from the standard parallel, the more distortion increases.
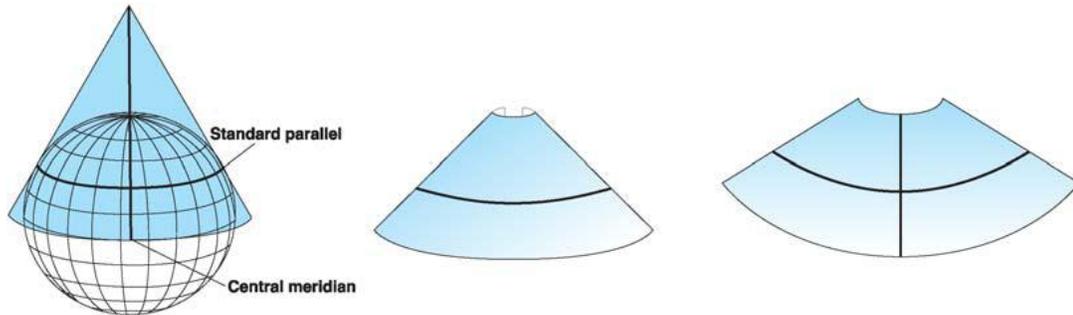
Figure 6. The conical map projection (ESRI 1994-2000).

Conic projections are mostly used for mid latitude zones that have an east–west orientation, for example Canada. Conic projections can also have contact with two locations on the globe (see figure 7). These projections are called secant projections and are defined by two standard parallels.
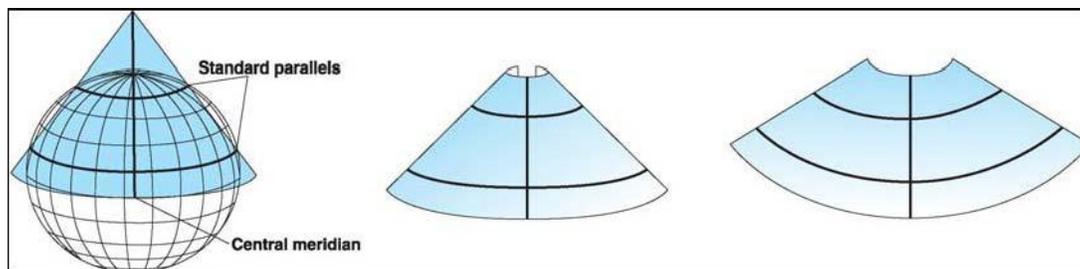
Figure 7. Conic projections - two standard parallels (ESRI 1994-2000).

Generally, a secant projection with two standard parallels has less overall distortion than a tangent projection with one standard parallel. An even more complex conic projection is called oblique where the axis of the cone does not line up with the polar axis of the globe.

2.3. Cylindrical Map Projections

Like conic projections, cylindrical projections also have tangent or secant cases. There are three main different cylindrical map projections (see figure 8). A normal cylinder projection has a cylinder in which the equator is the line of tangency. A transverse cylinder projection has its tangency at a meridian and an oblique cylinder is rotated around a great circle line, located anywhere between the equator and the meridians. In all cylindrical projections, the line of tangency or lines of secancy have no distortion and thus are lines of equidistance.
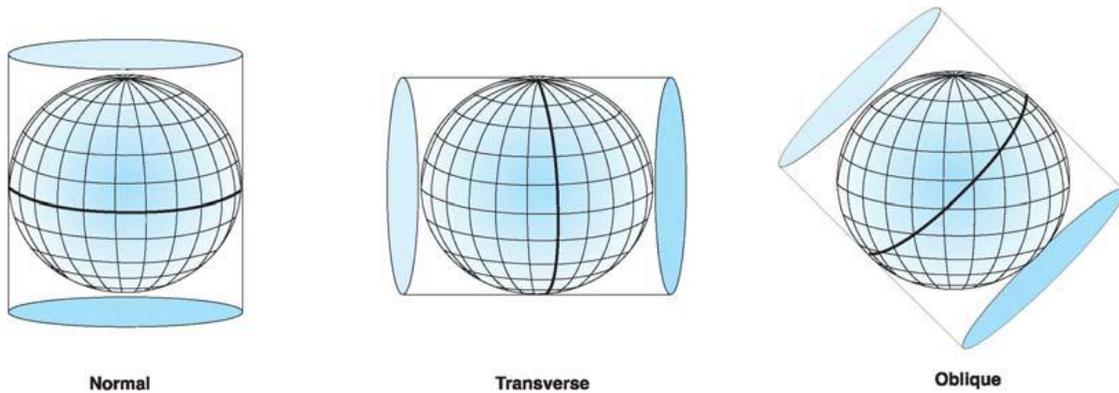
Figure 8. Types of cylindrical map projections (ESRI 1994-2000).

There are three main properties of a map projection related to distortions. Some projections preserve both distances and directions from a single given point. Such projection is called "equidistant". There are also projections, which preserve directions at any point on the globe. Such projections are called conformal. Finally, there are projections, which preserve area sizes, and they are called "equal area". However, no projection can possess more than one of the three qualities: conformality, equidistance, and equal-area.

2.4. Conformal Projections

A conformal projection shows perpendicular graticule lines intersecting at 90-degree angles on the map and therefore keeps the shape of objects. For example, the angles between two roads should be the same in the map as in reality (Eklundh et al 1999). There are four conformal projections in common use: The Mercator, the Transverse Mercator, and Lamberts Conformal Conic with two standard parallels, and the Stereographic Azimuthal Mercator's Projection (Robinson et al 1995).

2.5. Equal-Area Projections

Equal area projections preserve the area of displayed features. This is an important quality if you want to calculate areas (Eklundh et al 1999). In equal area projections, the meridians and parallels may not intersect at right angles like in the conformal projection. In some cases, especially maps of smaller regions, shapes are not obviously distorted, and distinguishing an equal area projection from a conformal projection is difficult unless documented or measured. Commonly used equal-area projections are Alberts Equal –Area Conic Projection, and Lambert's Equal-Area.

2.6. Equidistant Projections

An equidistant map keeps the distances between certain points. Scale is not maintained correctly by any projection throughout an entire map; however, there are, in most cases, one or more lines on a map along which scale are maintained correctly. Most equidistant projections have one or more lines, for which the length of the line on a map is the same length (at map scale) as the same line on the globe.   Keep in mind that no projection is equidistant to and from all points on a map.

PART II - ArcGIS as a tool to transform between different coordinate systems

Introduction:

Frequently digital geographic data are acquired by scanning aerial photographs or paper maps. Once the data are input they need to be assigned their proper map coordinates so that they will occupy a real world space.

Georeferencing defines the location of a dataset using known map coordinates and assigns it a coordinate system. This allows for the dataset to be viewed, queried, and analyzed with other geographic data. Typically in a GIS environment such as ArcMap, raster datasets (such as images) are georeferenced using a control layer. This layer contains known coordinates and is used as a point of reference for the georeferencing process.

Georeferencing is a tool that allows you to transform paper maps or other images into an ArcGIS layer. It is not always possible to find maps or aerial photos (raster images) that are digitized and georeferenced. Historic maps, aerial photos, and other maps found online or in print are often not georeferenced. This step by step process will guide you towards georeferencing.

This first part of the tutorial shows you the steps involved in georeferencing a scanned map that contains reference ticks or graticules in a known Coordinate System and Datum.

1. Open **ArcMap** and create a new empty map.

2. In the main menu, go to **View**, **Toolbars**, and add "**Georeferencing**" tool bar. If it is floating, you can dock it in the position of your choice.
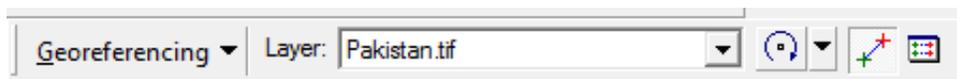
   Within this toolbar, there are several georeferencing tools that can be used.

   - This tool will rotate your image.
   - This tool adds control points.

3. Click on the Add Data button and *browse* to your D:\ GIS Training\Exercises\EX2_Data\

   Folder
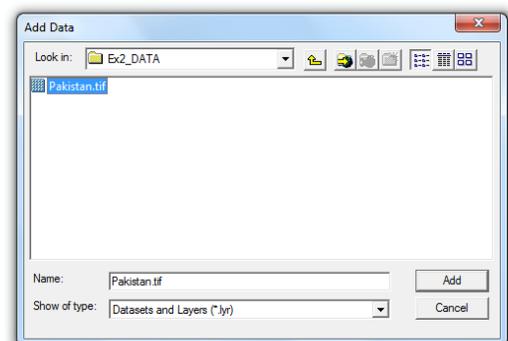
4. Select Pakistan.tif file and click the Add.

5. A dialogue box will appear asking if you want to build pyramids. Choose **yes**.
   Do not worry if you get an error message saying that the image lacks projection information **'unknown spatial reference'**. That's what you're about to do.

6. The very first step towards gereferencing is to set the properties of the data frame. You can do it either by right clicking on the **layers** in the table of content and selecting **properties** or by selecting the **data frame properties** from the view menu.

7. A new window will pop up as shown in figure at the right. From the

8. A new window will open, from the window either

   i.   Select the already created coordinate systems (projected or geographic) from the **select a coordinate system** tab, or
   ii. Import from any of the spatially referenced data (it could be any spatially referenced map or shape file, but should have the same coordinate system that you are interested in) by clicking **import** option and selecting the respective file, or
   iii. By creating a new one for your region (e.g. LCC in case of Pakistan) by clicking on the **new** option and filling the fields with appropriate information.
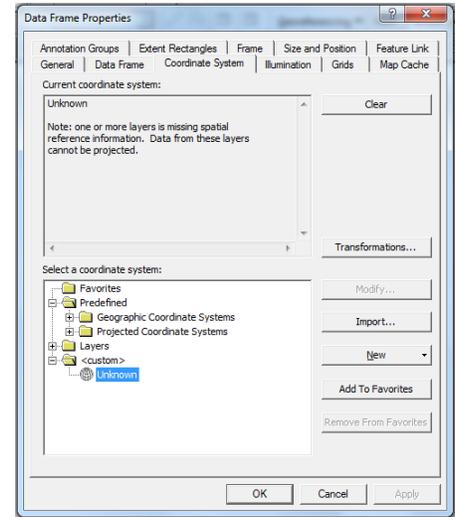
   Note that coordinate systems commonly used in Pakistan are WGS1984 (GCS) or UTM zones (PCS). Moreover, the UTM zones for Pakistan are 41N, 42N and 43N (Pakistan lies to the north of the equator).

9. Select from the predefined CS from **select a coordinate system** tab.

10. You have 2 options either select Geographic CS > world > WGS1984 or Projected CS > UTM > WGS1984 > UTM zone 42N. For now go with the GCS > world > WGS1984.

11. Make sure that the **Pakistan.tif** layer is selected in the **Layer:** field of the Georeferencing Toolbar.

12. Click on the **Georeferencing** Button and select **Fit To Display** to bring your **Pakistan.tif** layer into view.

13. Select **ZOOM IN** button and zoom into the left corner of the map by dragging the box as shown in figure.
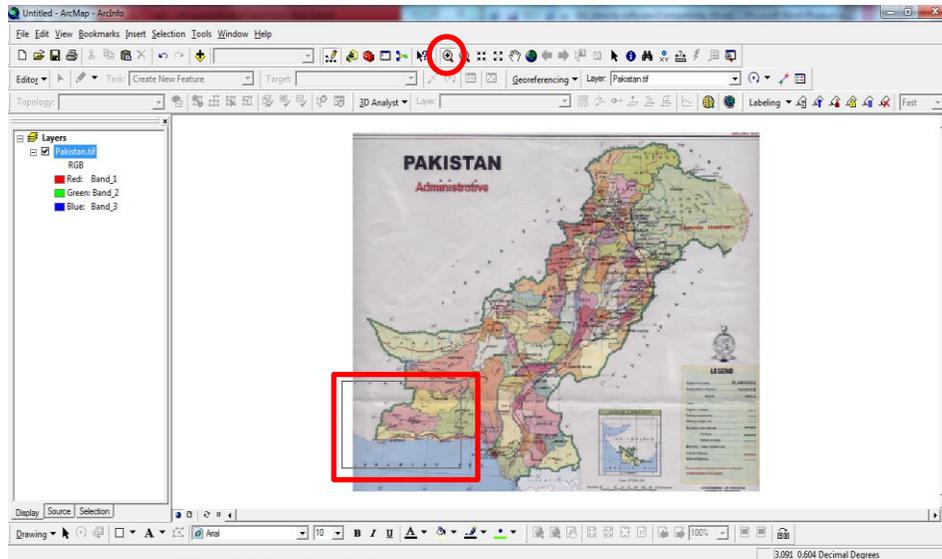
14. Select the **Add Control Points** Tool from the **Georeferencing** Toolbar and Add a control point by clicking on the scanned map cornermake sure you click at the point where Lat/Long Lines meet (as shown in figure below), then right click on the added point and select **input x and y data**.

    *Note: Vertical lines (Longitudes) increase along the x-axis, whereas horizontal lines (Latitudes) increase along y-axis, therefore, we take **Longitude** along **X** field and **Latitude** along the **Y** field.*
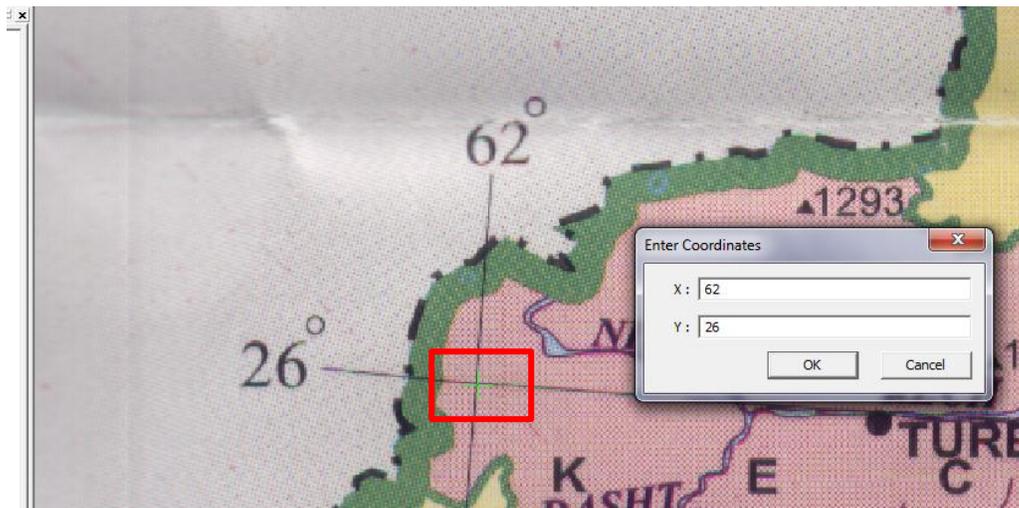
15. Continue adding control points, add at least four points in such a way that they cover the map i.e. try to take control points at four corners of the map.

16. If you make a mistake or want to delete a control point, click on the view link table option ⊞ . A table of control points will appear. Delete those points you do not want.

17. Once four control points have been added, you will be able to see the residual error calculated for each point and an RMS error in your link table. The RMS error measures the accuracy of the control points and can be used to find inaccurate entries. For best results, your residual error should be as close to one map unit as possible, you're your RMS error should be less than 1. Acceptable error levels depend on the accuracy required for the project and the data being georeferenced

18. Delete the control points with larger residual errors and add new ones to make it a better fit.
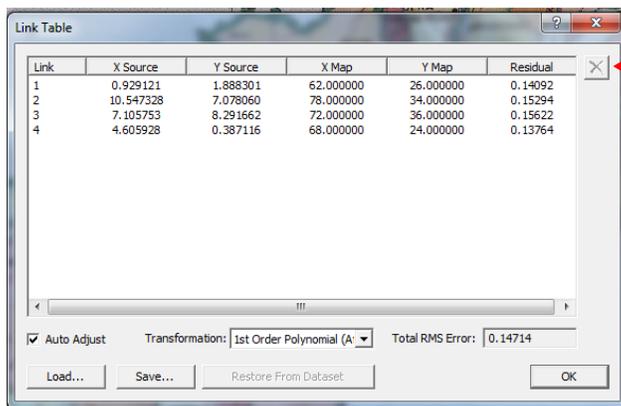
Select the bad points in the list and use this button to delete them

19. Once you are satisfied with your results, you can permanently register your image so it is already georeferenced next time you wish to use it. If you have write access to this image, you can choose Update Georeferencing from the Georeferencing drop-down menu. This saves the spatial information directly into your raster image. You can also choose to Rectify, which will save your image as a new TIFF or Imagine image file or other formats. This means your original image has not changed, and you should be able to add more control points as necessary. Keep in mind that Rectifying might take a while to complete, and rectify may change your color map. Rectify is normally used to output to a TIFF that can be read, as a georeferenced image, in other software.
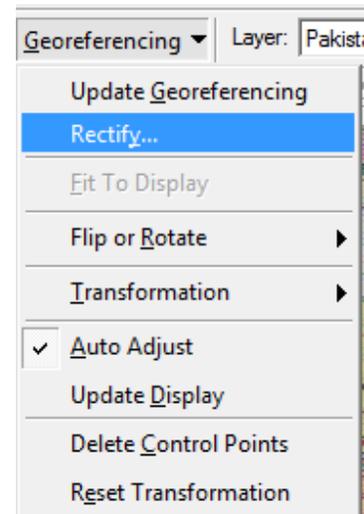
20. In the dialog box that appears, accept the default for cell size and resample type.

21. You can change the **output location**, **name** and **format** of the layer.
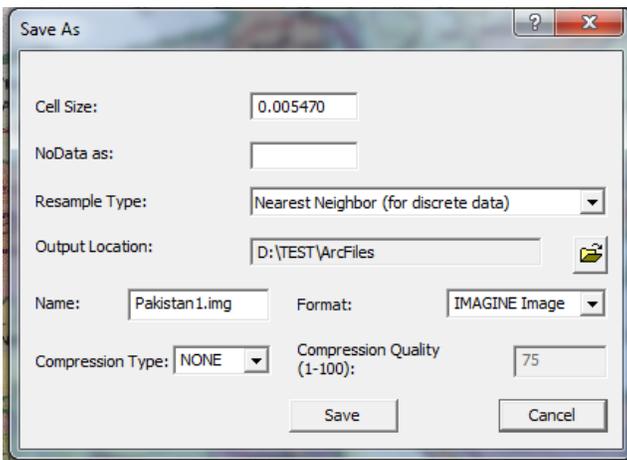
22. The image will now be saved as a new file. Add the saved file to your project. Right click on the layer, select "properties" and under the "extent" tab, you will see that your image now has spatial information.

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