Coordinates system, map scales and projection

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Hydrology is a spatial science. Various hydrological processes take place above, over and underneath the earth surface. To bind these processes to a location, cartography comes in to play. Location information is conventionally expressed in terms of latitudes and longitudes and grid coordinates on maps. Geographic information system (GIS) is more pervasive for representing geographic information today. Location information binds with geographic information in GIS. With use of GIS, information is transferred to hydrological models as set up files. Hydrological models are also built over GIS platforms. Thus, knowledge of geographic location is very useful in integrating spatial information in hydrological models.

1.0 Coordinate systems

Coordinate system is a system of denoting spatial location of a geographic object. There are two coordinate system in use, namely geographic and projected coordinate systems. These are described here.

Geographic coordinate system (GCS)

In GCS, spatial location of an object is represented using three dimensional spherical surface of earth. Unit of measurement in GCS is angular. The measurements are with respect to prime meridian. In GCS, location coordinates are longitudes and latitudes. The angular measurements are made at the centre of the earth. In this system, the earth surface is represented in terms of a grid of meridians and parallels.

Great circle: Great circles are circles formed by intersection of sphere surface and plane passing through centre of sphere.

Meridian: Meridians are half of great circles joining north and south poles. These are north-south lines of equal longitudes.

Prime meridian: A meridian passing from Royal Observatory, Greenwich in London in U.K. is called prime meridian. Hemisphere east of prime meridian is called eastern hemisphere and that towards west is called western hemisphere.

International date line: Meridian on other side of globe to that prime meridian is called international date line.

Parallel: Parallel are circles formed by intersection of earth surface by a plane perpendicular to the polar axis. Parallels are perfect circles of unequal size. On map, these are depicted as east-west lines of equal latitudes.

Equator: When parallel is great circle, the parallel is called equator.

Latitude: Latitudes are measured along meridians. Locations at equator are assigned zero latitude. Other latitudes are assigned value some degrees North or South of equator depending upon location towards north or south of equator. Maximum value is 90 deg N or S representing north and south poles respectively.

Longitude: Longitudes are measured as angle between half meridian plane passing through prime meridian and that passing through a location. Longitudes are referred as some degree east or west depending on their location in eastern or western hemisphere. Maximum value is 180 deg E or W.

Graticule: Gridded network of meridian and parallel is called graticule.

Sphere: Spheres are based on circle. Rotation of a circle around any axis results in a sphere. For maps of scale smaller than 1:5000000, earth may be represented as sphere without any perceptible error.

Geoids: Geoids are equipotential lines that coincides the mean ocean surface.

Spheroid: Spheroids are based on ellipse. Rotation of ellipse around semi- minor axis results in a spheroid. For large scale maps (scale 1:1000000 or larger), spheroid results in more accurate representation of the location of a geographic object compared to spheres. These are also termed as reference ellipsoids. These mathematically represent Geoids. Total variation of these is less than 200 m than Geoids.

Properties of spheroid:

Semi major axis: Half of the length of larger axis (major axis) of the ellipse is called semi major axis.

Semi minor axis: Half of the length of smaller axis (minor axis) of the ellipse is called semi minor axis.

Flattening: Flattening is a difference of semi major and semi minor axis, expressed as fraction of semi major axis. Its value ranges between 0 and 1. Flattening of zero represents sphere.

Eccentricity: Eccentricity is a square root of the difference of square of semi major and semi minor axis, expressed as fraction of square of semi major axis.

Approximate values for earth are:

Semi major axis: 6378137 m

Flattening: 0.003353

Inverse of flattening: 298.257223563

Spheroid of earth

Earth has been surveyed many times and based on these measurements different spheroids are defined for the earth. These may best represent a particular region or country depending on extent of survey made. A spheroid that best represent one region may not be best for another region. Several of these surveys were made as early as second half of nineteenth century. For example, Clarke spheroid for North America was determined in 1866. Surveys are also now being carried out from satellite for earth’s gravity. These surveys revealed that the earth surface is not even perfect spheroid. For example, south pole is closer to equator than north pole. Spheroids based on these surveys are also being created. Spheroid GRS 1980 of North America is based on satellite survey. Switching spheroids involves changing coordinates for all measurements and thus spheroids are not in general switched even if they are more accurate.

Everest

Everest geodetic datum and spheroid is adopted in India. The datum is non geocentric. The centre of reference ellipsoid is 1 km away from the centre of earth. The spheroid was given by Sir George Everest in 1830.

Table 1 Spheroid parameters

Spheroid	a in m	b in m

Clarke 1866	6,378,206.4	6,356,583.8
GRS 1980	6,378,137.0	6,356,752.31414

Datum

Datum defined the position of the centre of spheroid with respect to centre of the earth. Angular measurements of longitudes and latitudes are measured at datum. Example for change in geographic coordinate with change in datum for control point Redlands is shown in table.

Table 2 Datum comparison

Datum	Longitude	Latitude
NAD 1927	-117 12 57.75961	34 01 43.77884
NAD 1983	-117 12 54.61539	34 01 43.72995

World Geodetic System (WGS) 1984

WGS 1984 spheroid is based on satellite measurement of the earth. It is best earth- fitting spheroid. The spheroid is also geocentric i.e. datum coincides with the centre of the earth. It is widely used and provides framework for location measurement worldwide e.g. GPS measurements.

Projected coordinate system

In projected coordinate system, earth is represented on flat two dimensional surface. Location of a geographic object is specified in Cartesian coordinate system, abscissa and ordinate values. These values have unit of lengths. The projected coordinate systems utilize a map projection, spheroid and datum.

Map projection

Map projection is a mathematical transformation. In this, three dimensional surface is transformed to two dimensional surface. It is not easy to develop a three dimensional surface of shape sphere or spheroid. The transformation is achieved by projecting rays from an origin. The rays crosses sphere or spheroid surface and reaches developable projection surface such as cylinder, cone, plane etc. The surface is then developed to create two dimensional surface. The coordinate system so achieved is called projected coordinate system. Each point on this projected surface corresponds to a point on sphere or spheroid. This is achieved through suitable mathematical transformation equations.

Conformal map projection

In the projection system, local shapes are preserved. Graticules intersect at right angle in the system.

Equal area projection

In equal area projection, area of features is preserved and thus the projection is useful in hydrological studies. In equal are projection, other properties of a map, namely shape, angle and scale are distorted, especially for in large region.

Equidistant projection

In equidistant projection, distances between certain points are preserved i.e. scales are maintained along these points. For example in sinusoidal projection scale along equator and all parallels are maintained. In other equidistant projections scales along equator and all meridian or all distances from one or two points are maintained. It is not possible to maintain true distance along all points in map projections.

Projection family

Projections are classified according to type of developing object used, whether the developing object touches or intersects sphere or spheroid and orientation of the developing object. These are described here.

Projection type based on developing object

Mainly three developing objects are used in map projection, namely plane, cylinder and cone. Based on these developing objects, the map projections are called azimuthal or planar, cylindrical and conical.

Projection type point of contact developing object

The developing object may touch or intersect the sphere or spheroid. If the developing object touches the sphere or spheroid, the projection is called *tangent* map projection. In *secant* projection, object intersects the developing object intersects the sphere or spheroid.

Tangent projection: The object may touch at a point or along line. In planar map projection, the plane touches at a point. In other map projections, the object touches along line. Scale at or near the point and along the line of contact is true scale.

Secant projection: In secant projection, the object may come in contact with the sphere or spheroid at one or two lines. In azimuthal projection, point of contact will be a line. In other projection, there will be two lines of contact. Scale at the point of contact is true scale.

Projection type based on orientation of developing object

With respect to the axis of earth's rotation, the developing objects may have different orientations. In normal orientation for cylindrical and conic projection, the polar axis coincides with the axis of the developing object. For cylindrical projection, when axis of the cylinder is perpendicular to polar axis, the projection is called transverse projection. For planar projection, normal orientation is plane resting over poles. Other orientations for planar projection are equatorial and oblique. Other orientation of conic and cylindrical projection is oblique orientation.

Conic projection

In conic projections the axis of cone in general coincides with the polar axis. Tangent and secant conic projections have one or two line respectively along which the scale is true scale. These lines are parallels and called standard parallel. There are scale distortions at points not on the standard parallels. The projection is useful for area in mid latitude zone with east- west orientation. Parallels are circular arcs. Meridians are straight lines. Secant projection has overall less distortion.

Equidistant conic: In the projection, the parallels are spaced equally and thus the north- south distances are maintained.

Lambert conformal conic: In the projection central parallels are spaced more closely. The shapes are preserved in both small and large scale maps. The projection is used in many states in USA (primarily in states elongated in east west direction). The projection is also used by European Environmental Agency for scales 1:500,000 or smaller. The projection is also used navigation.

Albers equal area conic: In the projection the spacing of parallels in the northern and southern edges are more closely spaced in central parallels. The areas are preserved. The projection is used USGS, US Census Bureau etc.

Oblique conic projection: In the projection, the axis of the cone is at an angle with the polar axis.

Cylindrical projection

In cylindrical projection, the axis of the cylinder coincides, oblique or perpendicular to the polar axis. When axis is perpendicular to the polar axis, the projection is called transverse projection.

Mercator projection: This is commonly used projection. In the projection, the axis of cylinder coincides with the polar axis. The equator is line of tangency. The parallels and meridians are perpendicular to each other and are straight lines. Meridians are equally spaced. The distance between parallels increases towards poles. The projection is conformal.

Transverse Mercator: In the projection, the axis of cylinder is perpendicular to the polar axis. The cylinder touches along a meridian to the sphere or spheroid or intersects along lines parallel to the meridian.

Planar projection

In planar projection, a plane is used as projection object. Plane touches pole, equator or any other point on sphere or spheroid. The projections are called polar, equatorial or oblique respectively. Perspective points for the projection are centre of earth, opposite point to the focus on sphere or point in outer space. With perspective point at centre of earth and opposite point to the focus on sphere, the projection is called *Gnomonic* and *Perspective* respectively. When point of perspective is located at infinity, the projection is called orthographic.

Polar projection: In the projection, parallels are concentric circles and meridians are straight lines originating from focus.

Other projections

Sinusoidal projection

The projection is pseudo cylindrical projection. In the projection all parallels and central meridian are straight lines. Other than central meridian, others are sinusoidal curves. Meridians are equally spaced. Distortions near outer meridians may be reduced by interrupting the continuity of projection along oceans and locating centre of continents as central meridians. The projection better represent areas near equator. The projection is an equal area projection.

Universal Transverse Mercator

The projection is Transverse Mercator, with parameter defined for 120 zones in earth. Globe is divided in to 120 zones (60 each for northern and southern globes) of 6 deg each. Limit of zones are 84 def N and 80 deg S. Zone 1 starts at -180 deg W. Zone 31 starts at 0 deg E (at prime meridian). Central meridian and equator forms the origin of each zone. Central meridian is located 3 deg away from each end of a zone. The origin is shifted by using false easting and false northing. For northern globe the values are 500,000 and 0 and for southern globe the values are 500,000 and 10,000,000 respectively.

Polyconic

Polyconic is a special type of conic map projection. The projection parameters are varied continually as parallel changes. The map projection is adopted of topographic mapping in India.

Table 3 Map projections

Projection	Type (Plotting surface)
Equal area	
Albers, one standard parallel	Conic, tangent
Albers, two standard parallels	Conic, secant
Lambert zenithal	Azimuthal
Cylindrical equal area	Cylindrical
Mollweide	Special
Interrupted	Special
Conformal	
Lambert conformal, one standard parallel	Conic, tangent
Lambert conformal, two standard parallel	Conic, secant
Stereographic	Azimuthal
Mercator (e.g. Universal Transverse Mercator or UTM)	Cylindrical
State plane (US)- Transverse Mercator- secant and Lambert conformal with two standard parallels	-
Military grid (US)- UTM and universal polar stereographic (UPS)	-

2.0 Scale

Maps

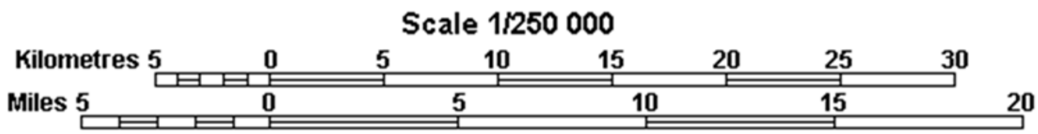
Maps dates back to as early as 5^{th} or 6^{th} century BC. Primary use of maps has been to communicate information. Earlier maps subjectively depicted information and were not very accurate. With developments in science of cartography information is depicted objectively and accurately. Maps are graphic representation of real world. Real world contains infinite details and complexity. It is not possible and desired to represent real world completely in maps. Only selected information is depicted on maps and thus maps are abstraction of reality. Maps are also smaller in size than the real world. Maps depict cultural and physical features of the earth. For example maps may contain roads, rail, village, city, monuments, river, lakes, ponds, wells, springs, political boundaries, contours, land use etc.

Map types

Maps are of two types, namely reference and thematic. In reference maps, natural and man-made objects are depicted. Example of reference maps are atlases and topographic maps. In thematic maps geographic distribution of a phenomena or spatial association of multiple phenomena are depicted. Example of thematic maps are land use and cover, soil, lithology, groundwater level, groundwater depth, rainfall, population density etc.

Scale

Feature of maps are always smaller than their actual size of earth. The ratio of map to earth distance is called map scale. For example, on a map of scale 1:250,000, a feature of length 1 km on earth will be represented as of 4 mm length. Map scales are depicted as fractions (e.g. 1/250000) or representative ratio (e.g. 1:250000). Scales are also shown graphically of maps. In graphical representations, a line is drawn, divided into equal lengths and equivalent earth distances are shown. One of the divisions may have further subdivisions.



3.0 Georeferencing

In georeferencing, through transformations, the coordinates are assigned to image rows or column values. A table of row and column values and corresponding geographic coordinate values are prepared. An inverse transformation matrix is computed for transformation of geographic coordinates to rows and columns. The pixel size of the georeferenced image is selected. For the pixel size, a grid of georeferenced image is prepared. The points on this grid are transformed in to rows and columns locations. These transformed grid location lie in the neighbourhood of input row- column grid points. An interpolation technique, e.g. nearest neighbor, bilinear or cubic convolution etc., is used to find values at transformed grid locations. In these techniques one, four and 16 nearest values are used respectively.

Following is an example of transformation polynomial:

$$x' = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2 + a_6 xy^2 + a_7 x^2 y + a_8 x^3 + a_9 y^3$$
$$y' = b_0 + b_1 x + b_2 y + b_3 xy + b_4 x^2 + b_5 y^2 + b_6 xy^2 + b_7 x^2 y + b_8 x^3 + b_9 y^3$$

Bilinear interpolation: In bilinear interpolation, first linear interpolation is done in X direction, at X location of the transformed grid. Four neighbours will have two X direction resulting in two values. These two values will be values at two Y locations. These values are interpolated linearly for transformed grid Y location.

Cubic convolution: In cubic convolution, 16 neighbours are used in interpolation with interpolation equation used as follows:

$$p(x,y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} x^i y^j$$

Reference

Kennedy M. (2000), Understanding map projections ArcInfo 8, http://kartoweb.itc.nl/geometrics/map%20projections/understanding%20map%20projections.pdf