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Abstract

Ponds are important sources of fresh water in the world. Ponds store surface runoff produced by the storms. Demarcation of the portion of land contributing runoff to the ponds has been done using topographical information of the surrounding area of the ponds in GIS interface. Point elevation data has been imported from Google Earth Inc. and tallied with Survey of India Topographical maps (1: 50,000 scale) which showed closer accuracy. The elevation data has been attributed to the nodes of the square grid superimposed over the area. The raw DEM was processed to remove sinks and the final DEM was used to generate drainage channels and demarcate catchment areas of the ponds in Hydrological Modeling ArcView 3.2.

Introduction

Rain-fed ponds are the most common type of ponds in arid and semi-arid regions. The source of water for rain-fed ponds is surface runoff. These ponds are installed in lower and mid-slope positions to intercept and collect runoff by gravity (Blanco and Lal, 2008). Topography plays an important role in the distribution and flux of water within natural land surfaces. The quantitative assessment of surface runoff depends on the topographic configuration of the land surface. Many topographic parameters can be computed directly from a digital elevation model (DEM). This information is very useful to study the hydrological characteristics of a watershed. The automated extraction of topographical parameters from DEM is recognised as a viable alternative to traditional surveys and manual evaluation of topographic maps, particularly as the quality and coverage of the DEM data increases. There are several techniques available for extracting topographical parameters from DEM such as the slope characteristics, catchment areas, drainage divides, channel networks, etc. (Jenson and Domingue, 1988). These techniques are faster and provide more precise measurements than the traditional manual techniques applied to topographic maps (Tribe, 1991). They have the potential to greatly assist in the determination of surface runoff from a watershed where the manual determination of drainage network and watershed properties is a tedious, time-consuming and error-prone process. The automated techniques have the advantage of generating digital data that can be readily imported and analysed by GIS. In this article the capabilities of the Hydrological Modeling ArcView 3.2 computer programme have been discussed. The primary objective of the computer programme is to provide a tool for rapid parameterisation of drainage network and sub-catchment properties from available DEMs for subsequent use in hydrologic surface runoff models. This is achieved by unique identification of each channel segment and consequent delineation of the drainage area. The raster map of the channel network and sub-watersheds can be superimposed to other data layers such as land use land cover map, soil map etc. and used as a template to extract data for individual sub-watersheds. Although the channel properties can be more efficiently analysed in a vector environment, maintaining all spatial data in raster format linked to attribute tables provides greater scopes for importing results to a GIS for subsequent analysis (Martz and Garbrecht, 1992).

Study area

The study area is a small village Nandgaon in Uttar Pradesh (UP), India as shown in Figure 1. The area comes under the traditional Braj area which mainly consists of Mathura and Vrindavan in UP. The area has a huge religious importance and carries a very old heritage of forests, hills and ponds. Five ponds in the village have been selected for estimating how much area is contributing runoff into the ponds. A square grid has been superimposed over the area. The elevation values at the nodes have been referenced from Google Earth Inc. which has a vertical resolution of 1 m.

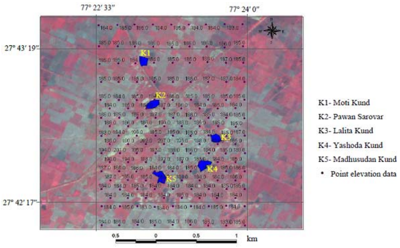
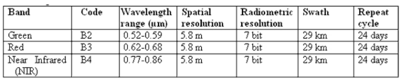


Figure 1 Location of the ponds and point elevation data at the nodes of the grid network superimposed on the IRS-P6 L4MX satellite imagery of Nandgaon village, UP, India dated 10 Oct. 2004

Data used

Satellite name: IRS P6 Resourcesat
Sensor: L4MX
Date of acquisition of image: 10th Oct. 2004
Format: BIL
Sun azimuth angle: 158.5030
Sun elevation angle: 51.1670

The L4MX sensor uses push broom scanning system based on Charge Coupled Device (CCD). The data of the L4MX sensor used for the study are given in Figure 1. The L4MX sensor acquires images in three bands, viz. Green, Red and Near Infrared.



Band	Code	Wavelength range (µm)	Spatial resolution	Radiometric resolution	Swath	Repeat cycle
Green	B2	0.52-0.59	5.8 m	7 bit	29 km	24 days
Red	B3	0.62-0.68	5.8 m	7 bit	29 km	24 days
Near Infrared (NIR)	B4	0.77-0.86	5.8 m	7 bit	29 km	24 days

Detailed specifications of IRS P6 L4MX sensor

Hydrological modelling overview

The approach for defining drainage networks from raster DEMs is based on overland flow simulation across the landscape. This approach was introduced by O’Callaghan and Mark (1984). This approach essentially identifies the steepest downward slope between each cell in the raster DEM and its neighbours and cumulating catchment area downslope along the flow paths connecting adjacent cells. A major difficulty in using O’Callaghan and Mark’s (1984) approach to map sub-catchment areas and drainage network is the existence of sinks in the DEM. Sinks are cells which have no neighbours at a lower elevation and consequently, have no downslope flow path to a neighbouring cell. A number of methods have been developed for treating sinks in DEMs for catchment area and drainage network analysis. Band (1986) simply increases the elevation of sink cells until a downslope flow path to an adjacent cell became available, under the constraint that flow may not return to the sink cell. This method is effective only for the simplest topographic situations. Jenson and Dominique (1988) provide methods for treating sinks in a more general and effective manner. These methods cope with complex topographic situations such as nested depressions, depressions within flat areas, and truncation of depressions and flat areas at the edge of the DEM. They involve "filling" each depression in the DEM to the elevation of the lowest overflow point out of the sink. Martz and de Jong (1988) first accumulate catchment area along flow paths determined from the DEM prior to depression-filling, and then modify catchment area after depression-filling to simulate the overflowing of a depression at the lowest point on its perimeter. Because only one overflow is allowed, an arbitrary selection must be made between several potential overflows. The steepest flow path downslope from the overflow is followed and total catchment area of the flat area is added to the catchment area of each downstream cell along the flow path. The flow direction algorithms permit flow in only one direction away from a DEM cell. This fails to represent adequately divergent flows over convergent slopes. Although a multiple flow direction algorithm seems to give better results in the head water region of a source channel, a single flow algorithm is better in the regions of convergent flow (Freeman, 1991). As the primary objective is the delineation of the drainage network with well-developed channels, the use of the ArcView hydrological modelling which uses a single flow-direction algorithm seems more appropriate.

DEM preprocessing

The hydrological modelling ArcView analyses DEMs which represent landscapes at a resolution that allows the extraction of hydrologic variables. In this study, DEM of the area of interest has been prepared by overlapping a square grid over the area and attributing point elevation data to the nodes. The elevation data have been referenced from Google Earth application which has a vertical resolution of 1 m. The accuracy of elevation information has been checked by tallying with the benchmarks in the Survey of India (SOI) topographical map (1:50,000 scale) and it has been found that RLs (reduced level) of the points in the map matches exactly with Google earth data. A fundamental problem in using these DEMs of this order of resolution for hydrological analysis is the presence of sinks in the data. Sinks or depressions are group of raster cells completely surrounded by other cells of higher elevation. Though a few of the sinks may represent real landscape, the majority of the sinks arise from the interpolation errors during the DEM generation, truncation of interpolated values on output and the limited spatial resolution of the DEM grid (Martz and Garbrecht, 1992). They represent a major difficulty for DEM processing procedures that are based on downslope flow routing concept because the existence of a downslope flow path at every cell is assumed. In case of a depression, there is no outflow and procedures based on assumed downslope flow path are bound to fail.

A DEM free of sinks, i.e., a depressionless DEM is the desired input to the flow simulation process. The presence of sinks results in erroneous flow-direction raster. Sinks can be located using the sink function that identifies all sinks in the data. Sinks can be filled using the fill function. The fill function uses the ArcView Spatial Analyst function to create a depressionless DEM. Before a hydrological model can be generated, a DEM must be corrected to remove problems identifying unassigned flow direction. If flow enters a sink, the GIS flow direction algorithm can’t discern where the water would flow thereafter. It is important to note that sinks occur in the land between the stream channels and do not necessarily occur only in the streams. The hydrologic modeling program deals with sinks by identifying them and filling them in the DEM using SINKS and FILLS subroutines in ArcView. Two assumptions are implicit to this approach: (1) depressions are spurious features that arise from interpolation errors or insufficient precision in elevation values; and (2) all depressions are due to underestimation of elevation and should be filled (Garbrecht, Martz and Starks, 2001). Once isolated sinks are corrected, flow direction modelling can occur without logic dilemmas posed by the sinks. It is possible to generate flow directions without removing sinks, but the resulting model of streams will be obviously in error compared to traditional maps because streams are fragmentary and do not match known stream locations (Jenkins and McCauley, 2006). Various methods have been developed to remove sinks from DEMs so that a continuous flow path is defined from every cell to the edge of the data set or the watershed outlet. The pit filling algorithm described by Jenson and Domingue (1988) is coded into ArcView software and is used for pre-processing DEM data. The algorithm raises the elevation of all cells in a sink to the elevation of the lowest pour-point on the edge of the sink. Figure 2(a) shows the spatial distribution of sinks in the DEM of Nandgaon village in U.P. The sinks are mainly concentrated in lower elevation areas.

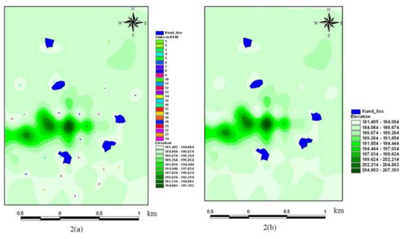
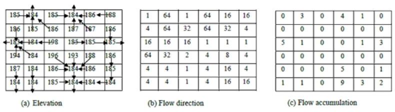


Figure 2(a) Raw DEM. Isolated dots are showing the sinks. 2(b) Processed DEM

Flow direction, drainage area analysis and sub watershed delineation

There are several models for defining a grid of flow directions based on a DEM. The simplest and most widely used method is termed as the D8 (deterministic eight-neighbour) method developed by Fairfield and Leymarie (1991). The flow vector algorithm scans each cell of the modified DEM (after sink removal) and determines the direction of the steepest downward slope to an adjacent cell. The D8 flow direction function is available in ArcView software and is used for flow direction. In the D8 model, eight possible flow directions are assigned for a single cell and it is assumed that a water particle in each DEM cell flows towards one and only one of its neighbouring cells that cell being the one in the direction of steepest descent. To assign a flow direction value to a cell, the "distance weighted drop" to each of eight neighboring cells is computed by taking the difference in elevation values and dividing by for a diagonal cell and 1 for a non-diagonal cell. The flow direction for a cell is assumed to be in the direction with the highest distance weighted drop. Where more than one downward slope maxima exist, the flow vector is arbitrarily assigned to indicate the direction of the maximum first encountered. At cells on the edge of the defined DEM (i.e., cells in the outer rows or columns), the flow vector points away from the defined DEM if no other downward slope to a neighbour is available. A matrix within the elevation grid of the area has been shown in Figure 3(a).



185	184	185	184	186	188
186	185	186	187	187	186
183	184	198	185	185	185
194	184	196	193	188	186
187	184	186	184	186	185
184	184	185	184	184	184

(a) Elevation

1	64	1	64	16	16
4	64	32	64	32	4
16	16	16	1	1	1
64	32	2	4	8	4
4	4	1	4	16	4
4	4	1	4	16	16

(b) Flow direction

0	3	0	4	1	0
0	0	0	0	0	0
5	1	0	0	1	3
0	0	0	0	0	0
0	0	0	5	0	1
1	1	0	9	3	2

(c) Flow accumulation

Figure 3 (a) A portion of the grid showing elevation at the nodes; (b) Flow direction at the nodes determined from the D-8 algorithm; (c) Catchment area at each DEM cell after flow paths have been traced from all cells

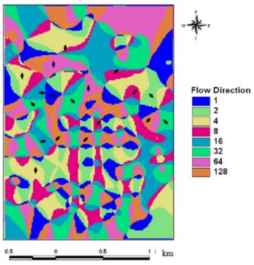


Figure 4 Flow direction map

All flow originating on or entering a cell is assumed to move in the direction indicated by the flow vector, and no divergent flow out of a cell is accommodated (Jenson and Domingue, 1988), shown in Figure 3(a).

The catchment area of each grid cell is determined using the method of Martz and de Jong (1988). The flow vectors are used to follow the path of steepest descent from each cell to the edge of the DEM, and catchment area of each cell along this path is incremented by one. After a path is initiated from each cell, the catchment area value accumulated at each cell gives the number of upstream cells which contribute overland flow to that cell as shown in Figure 3(c).

The boundary of the watershed to be analysed is also determined from the flow vectors. The user specifies the location of the grid cell at the watershed outlet, and all grid cells which contribute overland flow to the outer cell are identified. In this case, the cells representing the ponds are treated as watershed outlet and the drainage channels which contribute flow into the kunds are identified and subsequent catchment area demarcation is carried out, as shown in Figure 6.

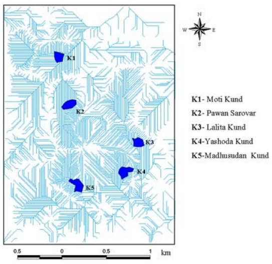


Figure 5 Generation of channels from flow direction map surrounding the ponds

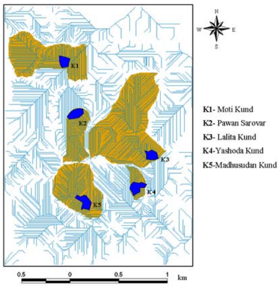
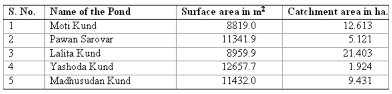


Figure 6 Demarcation of catchment areas of the ponds

Results

The catchment areas of the ponds calculated in the above manner are shown in Table 1 which shows that there is a wide variation in the catchment areas of the ponds due to the flow direction channels.



S. No.	Name of the Pond	Surface area in m^2	Catchment area in ha.
1	Moti Kund	8819.0	12.613
2	Pawan Sarovar	11341.9	5.121
3	Lalita Kund	8959.9	21.403
4	Yashoda Kund	12657.7	1.924
5	Madhusudan Kund	11432.0	9.431

Table 1 Catchment area demarcation of the ponds

Conclusions

Catchments area calculation for small water bodies is not frequently done since the elevation data of high resolution are usually not available or conducting field survey with a total station is a time consuming and laborious work. Fortunately, Google Earth Inc. provides elevation values at 1 m. vertical resolution. This data has been manually attributed to the nodes of the square grid. This procedure will be cumbersome for large watershed areas since huge number of point elevations will be needed but this is useful when small areas, as in our case, are encountered.

Acknowledgement

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