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Development of Water Management Modeling by Using GIS in Chirchik River Basin, Uzbekistan

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Abstract:
The management of water resources has become a critical need for Chirchik river basin in Uzbekistan due to water deficit and salt damage. Hence, plans must be developed for water efficient use through better management at the river basin level. In this paper, fundamental concept of the proposed water management modeling of the Chirchik river basin and overview of hydrological model using Geomorphology Based Hydrological Model (GBHM). Furthermore, various spatial data such as land-use layers and hydrological layers are developed in this study by conducting latest GIS (Geographical Information System) technology. By extracting ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) Digital Elevation Model (DEM) and ALOS (Advanced Land Observing Satellite) data on autumn and spring, a series of land-use classification is created using the supervised classification method. For regional-scale hydrological modeling, GBHM as a powerful tool is used to analyze the river basin by utilizing the geomorphological properties data for each catchment and hillslope hydrological processes. As a result, development of spatial modeling is obtained and GIS-based analysis is an effective method to study water management in Chirchik river basin in Uzbekistan.

Keywords: *GIS, Water Management, Landuse, Hydrological model*

INTRODUCTION

The development of water management modeling is necessary to solve the problem of water deficits and salt damage in the Chirchik river basin, Uzbekistan. The reliability of water resources management is influenced by predictability of hydrological cycle. Indeed land use, topography, soil and geology characteristic, and artificial water use (mainly agricultural irrigation) are several factor affecting the complexity of hydrological cycle in the basin. Understanding the hydrological mechanism in the basin has been a main concern in development of hydrological modeling, aiming to establish sustainable of land use and water use.
This paper presents development of a spatial data of hydrological modeling in Chirchik river basin. Therefore, GIS (Geographical Information System) tools are employed to develop geo-spatial data for hydrological modeling. The model can be used in applying Geomorphology Based Hydrological Model (GBHM).
The paper is organized as follows: firstly, fundamental concept of the proposed water management modeling of the Chirchik river basin and overview of hydrological model using GBHM. Secondly, various spatial data such as land-use layers and hydrological layers are developed in this study by conducting latest GIS technology. Finally, by extracting ASTER DEM and ALOS data on 2008 and 2010, a series of land-use classification is created using the supervised classification method.

STUDY AREA

The study area for the GIS data processing and hydrological analysis has been chosen based on

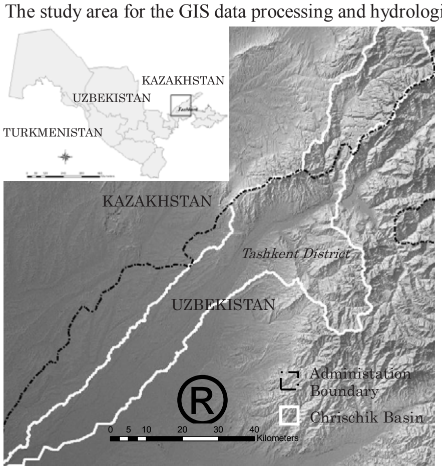

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Figure. 1. Study area of the Chirchik river basin in Tashkent,Uzbekistan

watershed boundary (Figure. 1). The lower part of the Figure. 1. Study area of the Chirchik river basin in Tashkent,Uzbekistan. Study area, has the average elevation of 250 to 290 m a.s.l, and the height part is about 3.300 to 3.500 m a.s.l.

WATER MANAGEMENT MODELING

Concept of the proposed water management modeling

Understanding of basic hydrologic processes and simulation capabilities at the river basin scale was required for development of water resources management in a large area. Therefore, several factors were examined including precipitation, evapotranspiration, management of water supplies for residential, industrial and irrigation, and exchange between the groundwater and river. Since a great deal of water has been used for rapid development of industry and urbanization, the supply of water resources for agriculture has considerably declined. Rapid development of cities and industries and the increase in farmland irrigation has doubled water demand.

Water management modeling proposed in this study, established the form of water use according to land use in distributed hydrological model. The integrated model of water quality was also investigated based on the advection-dispersion equation one-dimension so that hydrological and water condition of watershed can be understood. Figure. 2 shows the concept of the proposed water management modeling in Chirchik river basin. The detail information of number 1 to 10 on the figureure as follows:

1. Precipitation.
2. Canopy Interception.
3. Evapotranspiration: The potential evaporation such as variation of leaf-area-index (*LAI*), root distribution, and soil moisture has been calculated for the actual evapotranspiration. Infiltration and water flow are described in a quasi-two-dimensional at sub surface model.
4. Surface water flow: The surface water runoff is the infiltration excess and saturation excess. It flows through the hillslope and becomes lateral inflow into the river and is solved by the Manning's equation.
5. Unsaturated zone water flow: The unsaturated zone water flow is described using a vertical one-dimensional Richards's equation.
6. Saturated zone water flow.
7. Groundwater discharge: The groundwater aquifer is treated as an individual storage corresponding to each grid.
8. River flow: The exchange between the groundwater and the river water is considered as a steady flow and is calculated by Darcy's law (Yang,et al., 2002).
9. Groundwater intake: It needs to consider the use of groundwater from the aquifer by wells.
10. Urban drainage: It needs to consider the amount of wastewater of residential and industrial by drainage.

The river flow can be calculated by the Kinematic-Wave method. The water balance model divided into a grid of 1-km as described above, the calculations processed sequentially from the most upstream toward the downstream of water flow in basin analysis. The surface runoff flows through the hillslope into the stream via kinematic wave.

Hydrological Modeling by using GBHM

GBHM is hydrological modeling, which can be analyzed from the catchment geomorphological properties and hillslope hydrological processes in large catchments. By this approach, the topography and other spatial variables of the modeled catchment are represented by one-dimensional functions with respect

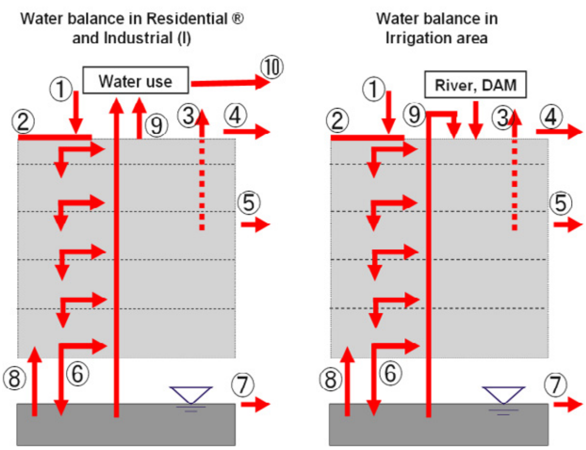


Figure. 2. Concepts of the proposed water management modeling in Chirchik river basin.

to the flow distance from the outlet. The GBHM has the characteristic of (1) physically-based subgrid hydrological parameterization based on the available spatial information; (2) kinematic wave model for river network routing; (3) potential applicability to water resources management (Yang.D, 2002).

A physically hydrological modeling is necessary when the spatial distributions of hydrologic variable are essential. The considering in this study, for a physically hydrologic modeling, the catchments are divided into a number of small grids. Therefore, development of computationally fast and easy to implement models is an important task. Hydrological modeling has employed the geomorphologic area function, and width function to reduce the catchment lateral dimension from two to one was available (Yang.D, 2002).

A Basin Subdivision Scheme

In GBHM program, for the delineation and codification of the catchment is based on Pfafstetter scheme (Verdin, 1999). It was based on founded upon concepts first articulated by the late Otto Pfafstetter (Verdin, 1999), an engineering with the Department Nacional de Obras de Saneamento (DNOS). The concept of codification has been used in GBHM program, that based upon topographic control of area drained on the Earth's surface and the topology of the resulting hydrographic network (Verdin, 1999). The DEM and GIS technique are used to reach the target automatically. Here, the Pfafstetter scheme (Yang et al., 2000; Yang, Koike, Tanizawa, 2004) is applied for subdividing the catchment and for numbering the flow sequences among the subcatchments. The catchment in Chirchik river basin is divided into nine subcatchments systematically using this scheme (Figure. 7). From the catchment area, trace from inlet to outlet of the river, and identify the four tributaries with the greatest drainage area, and the catchments containing these four tributaries are sub basins (Furnans and Olivera, 2001). Inter-basin is the catchments that water flow exists to the main river.

Sub-grid Parameterization Scheme

The sub-grid parameterization used in this study includes representations of the sub-grid variability in topography and other spatial variables.

The topographical parameterization uses the catchment geomorphologic properties, which represents a grid by a number of hillslopes. The grid size in the hydrological model is 1000 meters. The hydrological simulation is carried out for each land use group. Figure. 3 shows the concept of the sub-grid parameterization used in the grid-based distributed hydrological model. A hillslope of unit width is called a hillslope element. The length of a hillslope element is calculated from the 30 m resolution DEM as:

$$l = a(r,c)/2\sum L \qquad (1)$$

Where *a(r,c)* is the area of the grid at location (r,c), which is 1 km^2 here; $\sum L$ is the total length of streams were extracted from 30 m resolution DEM. The slope angle is taken to be the mean slope of all sub-grid in the 30 m resolution DEM.

Hillslope Hydrological Processes

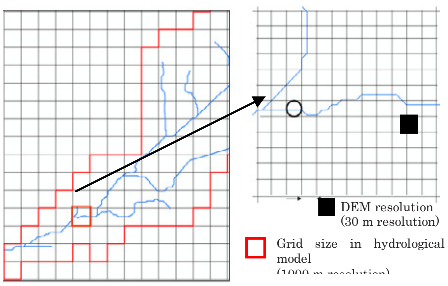
A physically-based model is used to simulate hillslope hydrological response, in which the vertical plane is divides into several layers, including canopy, soil surface, unsaturated zone and groundwater aquifer (Yang et al., 2002). The top soil of each hillslope element is extracted into a number of layers with the same depth.

For different vegetation or crop species, or different time periods, the canopy interception ability is different. The interception capacity ($S_{co}(t)$) is the total of maximum interception ability of the vegetation in a year, vegetation coverage (K), and the leaf-area-index at time (*LAI*) each the maximum leaf-area-index of vegetation in a year (LAI_o). The potential evaporation is estimated according to the available data, either by Priestley-Taylor's method (Brutsaert, 1982) or from observation point.

Actual evapotranspiration can be from the canopy water storage, root zone, surface storage and soil surface. The unsaturated zone water flow is described using a vertical one-dimensional Richards's equation. The unsaturated zone is considered to have a maximum depth of 4 meters, and it changes when the level of the groundwater table increases (Yang et.al., 2002). Flow routing on hillslope surface is treated as a steady flow that solved by the Manning equation. The lateral inflow of a flow interval is the contributions from all hillslopes including surface and subsurface flows. River flow in the main stream is solved using the kinematic-wave method.

DEVELOPMENT SPATIAL DATA BY USING GIS TECHNOLOGY

The methodology used for water management is carried out by applying GBHM for simulation the hydrological modeling. The collection of digital geographical information related to study area for building a digital spatial data of the basin was required to development of
water management modeling. A digital elevation model
(DEM) was a source data which important, because used to define the target basin, and target basin is



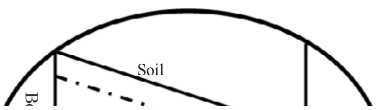


Figure. 3. Concept of the grid-based hydrological model in Chirchik river basin.

subdivided into a number of sub-catchments unit for

hydrological simulation. The catchment parameters related to topography, land use, and soil are then calculated for each simulation unit. Figure. 4 shows the general structure of hydrological model by using GBHM program. The component of hydrological model includes geo-spatial data as the data input, the hydrological simulation and the resulting output. The study area is divided into a discrete grid system, and the grid is represented by a number of geometrically symmetrical hillslopes. The river network is divided into sub-catchment of an appropriate size. The hydrological simulation part includes runoff generation from the hillslopes and the flow routing in the river network. The reservoir operation is merged with the river flow routing.

Data Preparation

In this paper, that the required data of GBHM program has been processed using GIS technology. The following information layers have been collected for the study area:

a. DEM. The source for the DEM was the ASTER GDEM 30 meter. The DEM data are used to make elevation map, to calculate slope dan slope length of the study area, and to determine of watershed boundary.
b. Soil. The soil layers in the study area were digitized from the soil map of Uzbekistan Government at 1: 200,000 scales. The information

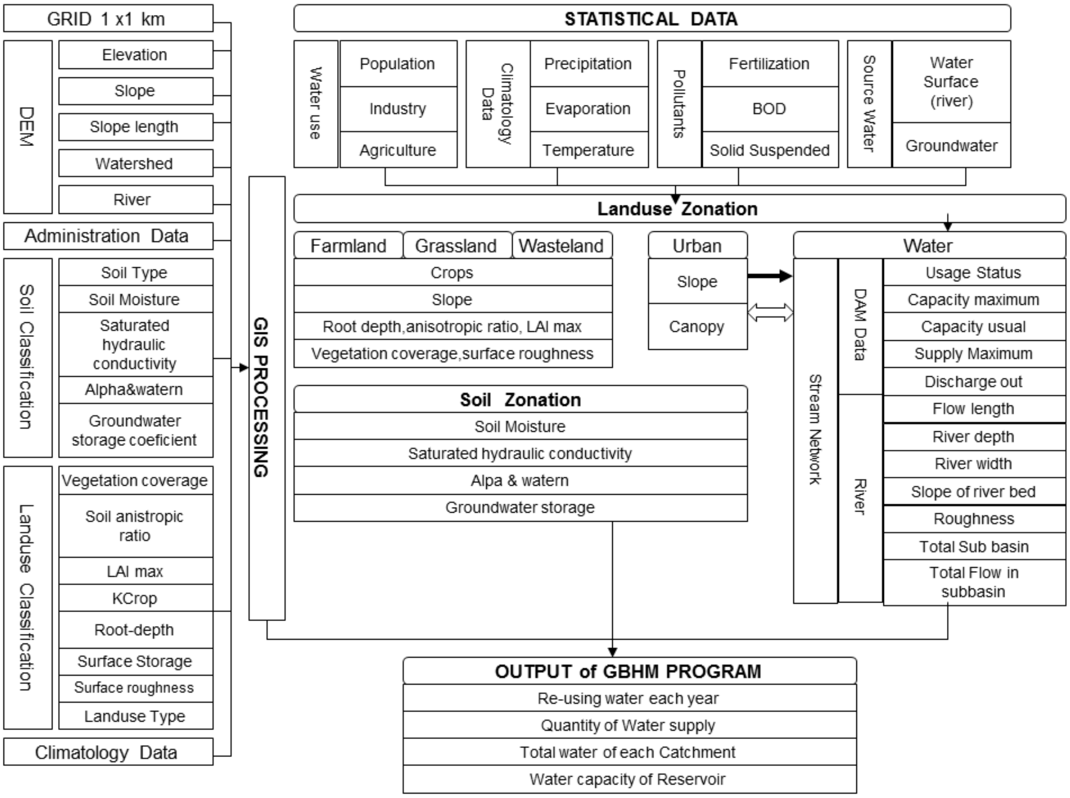


Figure. 4. General structure of the hydrological model by using GBHM.

have been obtained from soil map such as soil type and soil characteristic. Moreover, soil parameters that have been obtained from Uzbekistan Government such as soil moisture, saturated hydraulic conductivity, hydraulic conductivity of groundwater, and groundwater storage.

c. Geology. The thematic layer of geology was prepared from existing maps obtained from the Uzbekistan Government.
d. Land use. The source for land use was the ALOS AVNIR-2 data on autumn and spring.
e. Climatology. The gauge data are available from National Climatic Data Center (NCDC) provided by the Commerce Government, United Stated Department of Commerce. These data sources are available at 1 day resolution. A few of the NCDC gauges measure four parameters: precipitation, evaporation, maximum temperature and minimum temperature.
f. Administration data. The thematic layer of administration map was prepared from existing maps obtained from the Uzbekistan Government.
g. Irrigation area. Available data of irrigation area are including the number of irrigation area, the number of reservoir, irrigation parameter, and reservoir parameter.
h. NDVI. The source data of NDVI was obtained from Alos Avnir-2 of the study area.

Define of Watershed Boundary

In order to determine a watershed as study area, the elevation data of Chirchik river basin with the resolution of 30 meter resolution DEM, was utilized to generate a DEM and subsequently to create a hillshade. This paper presents DEM generation from ASTER DEM. Watershed boundaries, i.e. ridge lines, were extracted based on the hillshade by using the hydrology analysis tool available in GIS. A DEM is an ordered array of numbers that represents the spatial distributions of elevations above some arbitrary datum in a landscape (Moore et al., 1991). A DEM forms a very basic and important input in any study of the earth's surface feature. Performance and reliability of hydrology models are highly dependent on the quality of terrain elevation representation, in term of accuracy and resolution. In hydrology, the using of terrain analysis based on digital elevation models is being increasingly. The square of watershed boundary was calculated about 3729 km^2.

Elevation,Slope, and Slope length

As mentioned above, the finest DEM is available at 30 m spatial resolution. In order to represent the topography accurately, the hydrological model should also use the same grid size. In this study, the grid size in the hydrological model is 1000 m that derived from GIS tool by Fishnet tool, and then can be used development geo-spatial data before applying the GBHM program.

Elevation. Elevation map has been calculated by using block statistic tools in GIS. Input data for elevation was 30 m resolution DEM. However, the mosaic processing of 30 m resolution DEM must be conducted before it used as input data to the block statistic processing. Raster outputs have the same cell alignment or the same alignment as an existing raster by using snap raster environment in block statistic tool. The grid size in the hydrological model was used in snap raster environment.

Slope. Slope represents the rate of change of elevation for each DEM cell which derivative of a DEM. In this study, the output of slope map has been calculated by slope tool in degree unit and 1000 m resolution DEM.

Slope length. Slope length is the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that the flow connects to a river system or deposition begins (Wischmeier and Smith, 1978). The elevation data which 1000 meter resolution has been used as input data for calculate slope length. The technique for estimating the slope length was proposed by Moore and Burch (1986a) using equation as follow:

$$LS = (Flow\ Accumulation \times (Cell\ size/22.13)^{0.4} \times \sin(slope/0.0896)^{1.3} \quad (2)$$

The technique for estimating of slope length was required flow accumulation and slope of the study area.

Landuse data

In this study, the digital image of ALOS AVNIR-2, which has a 10-m spatial resolution, was processed using ERDAS IMAGINE software. In multispectral remote sensing data, accurate registration is essential for analyzing land use and land cover condition of a particular geographic location. ALOS AVNIR-2 and ASTER GDEM data were projected to WGS_1984_UTM_Zone_42N projections. Image enhancement refers to a number of image processing procedures that improve the visual interpretability of an image by applying algorithms (Aronoff, 2005). In this study, image enhancement has been done for change the contrast, brightness, and color of feature in the image. Figure. 5 shows land use classification of Chirchik river basin in autumn and spring. The study area reveals five main land use classes that consists of farmland, water surface, urban, grassland, and wasteland. By applying supervised classification methods to the 4-band image from ALOS AVNIR-2, land use status can be assessed, and information about changes can be obtained. The land use properties used for the hydrological simulation, including the vegetation coverage, maximum LAI in a year, root depth, soil anisotropic ratio, maximum surface water detention, surface roughness, and evaporation coefficient of crop.

Soil data

The soil map (scale 1:200,000) was digitized and attributes soil properties were entered in the tabular database. It is developed by using the Russian soil classification. The soil properties used for the hydrological simulation are including the saturated soil moisture, residual soil moisture, saturated hydraulic conductivity, hydraulic conductivity of groundwater, and groundwater storage coefficient. The soil properties are obtained from the soil map of Tashkent Province, Uzbekistan government, 2005 (Sektimenko.et.al., 2005), and soil chemical salinization in USSR, 1976. Combining the two soil data sets, the soil type and properties were considered as uniform within a 1000 m resolution. Figure. 6 shows soil type in Chirchik river basin, that soil class can be divided as seven class, water table and no data at upstream of river.

Meteorological Data

The climate data are available for daily temporal resolution at two gauges includes precipitation, temperature, and evaporation (Figureure 7). The required of hydrological simulation inputs are interpolated from the gauge data by using the Thiessen method (Yang et.al., 2002). Incorporating meteorological data and the available geographic information have been applied to simulate the hydrological component by GBHM.

Reservoir and Irrigation Data

The GIS information of reservoir parameter and irrigation area is necessary for developing an irrigation model linking with the hydrological simulation. Based

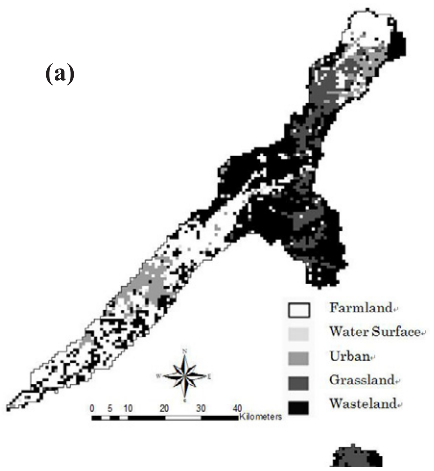


Figure. 5. Land use classification of Chirchik river basin**.**
on land use for irrigation, irrigation infrastructure, and
irrigation scheme should be considering, which calculate the water content of irrigation area, quantity of water supply, and capacity of each reservoir.

Administration and population Data

The administration and population data are obtained from the Uzbekistan Government such as image data .and statistical data. Based on overlay processing of the thematic map of Tashkent province administration and boundary, Chirchik river basin has been divided into ten districts.

NDVI Data

The NDVI data of each land use are obtained from ALOS AVNIR-2. To calculate of NDVI value, tool of image analysis in GIS processing has been used in this study. Based on the NDVI value, the study area can be divided in two classes: (1) 0-0.4, and (2) 0.41-0.54. The thematic map of NVDI has been converted to raster and ASCII format for hydrological simulation. Based on NDVI data, canopy interception each land use can be calculated.

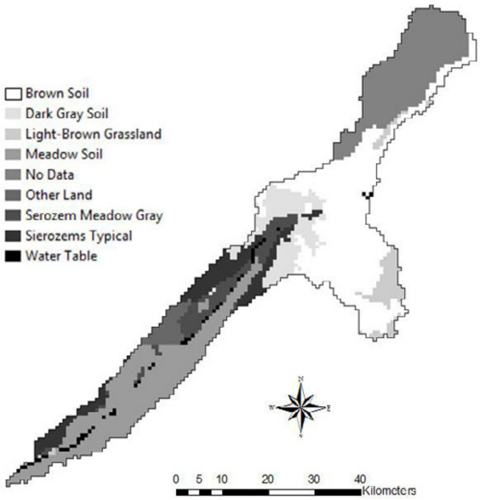


Figure. 6. Soil type in Chirchik river basin.

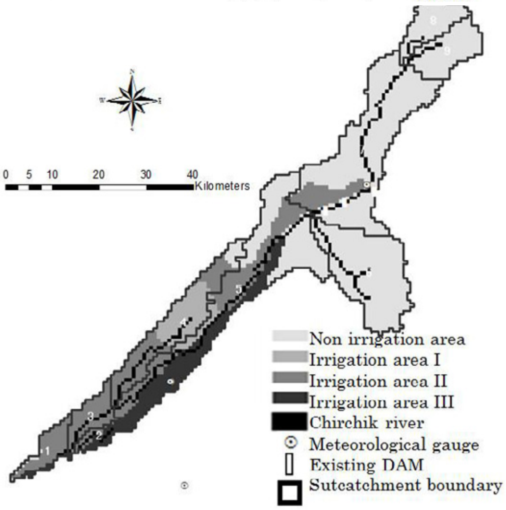


Figure. 7. Existing irrigation area and reservoir in Chirchik river basin.

CONCLUSIONS

Spatial data for physically-based hillslope hydrological model have been developed using 1000 meter resolution. The results in this study were geo-spatial modeling such as elevation, slope, slope length, land use, soil depth, soil, administration and population, NDVI, meteorological parameter, sub-catchment, irrigation area and reservoir, and river parameter. Development of spatial modeling is obtained rigorously and GIS-based analysis is an effective method to study water management. Further research, developed spatial modeling will be utilized in the GBHM tool for detail water modeling simulation for Chirchik river basin, Uzbekistan.

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REFERENCES

Aronoff.S.,*Remote Sensing for GIS Managers*.ESRI Press, 1st edition, Redlands,California (2005).

Brutsaert.W., The unit response of groundwater outflow from a Hillslope, Water Resour.Res,30(10), 2759-2763 (1994).

Furnans.J,Olivera.F,*Watershed Topology- The Phafstetter System*, Center For Research in Water Resource,The Univeristy of Texas at Austin.（2001）.

Moore, I. D., Grayson, R. B., Ladson, A. R., *Digital terrain modeling: a review of hydrological geomorphological, and biological applications*. Hydrological Processes, 5, 3-30 (1991).

Moore.I,Burch.G., *Physical basis of the length-slope factor in the universal soil loss equation*.Soil Sci soc.Am J 50:1294-1298 (1986).

Sektimenko.et.al., *Soil Map of Tashkent District, Republic of Uzbekistan*, Scale 1: 200.000, Uzbekistan Government (2005).

Verdin.K.L.,Verdin.J.P., *A topological system for delineation and codification of the Earth's river basins*.J*ournal of Hydrology 218*,1-12 (1999).

Wischmeier,W.H. and Smith,D.D., *Predicting rainfall erosion losses-A guide to conservation planning*. Agricultural Handbook no.537,Sci. and Educ.Admin.,U.S.Dept.Agr.,Washington,D.C (1978).

Yang,D.,Koike,T.,Tanizawa.,*Application of a distribured hydrological mode and weather radar observations for flood management in the upper Tone River of Japan*.*Hidrological Processes 18*:3119-3132 (2004).

Yang.D,Herath S,Musiake K., *Hillslope-based hydrological model using catchment area and width functions.* Hydrological Sciences Journal 47(1): 49-65 (2002).

Yang,D.,Oki.T.,Herath.S.,Musiake.K.,*A geomorphology -based hydrological model and its applications*. Mathematical models of small watershed hydrology and applications 2002 pp. 259-300 (2002).