Quantitative Analysis of Watershed Hydrology for Kandar Dam (Kohat) using Remote Sensing and Geographic Information System (GIS) Techniques

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Abstract

Watershed management plays a significant role in water assets engineering and management. Remote Sensing (RS) and Geographical Information System (GIS) techniques provide an effective solution to manage data that signify the hydrological features of the watershed. Determination of high accuracy and imagining topographic features of the earth's surface is very vital for studying environmental applications at a local level. Land Use Land Cover (LULC) classifications is one of the most important methods of remote sensing and it is also a prime input for hydrological models. Estimation of peak runoff and total runoff volume is always required for hydrological planning. Estimation of runoff is difficult if the catchment area and its characteristics are not known. Determination of catchment area and its boundary is a tedious job through use of simple contour maps. This study was conducted to assess the accuracy and utilization of Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTERGDEM) and Arc Hydro tools for watershed delineation and catchment area calculation. Furthermore, LULC classes were determined and Weighted Curve Number (WCN) was estimated. The elevations predicted by ASTER GDEM were compared with the elevations of established benchmarks at the watershed. It was then utilized as an input to Arc Hydro tools for watershed delineation. SPOT data (image) of the study site was classified through Supervised Classification in a remote sensing tool, ERDAS Imagine 9.1. Supervised classes were then compared with observed classes. A strong correlation was found between ASTER GDEM and observed benchmarks elevations (R= 0.83with 95 % confidence level). The resultant projected boundaries of watershed obtained, were in a close relevance to observed Global Positioning System (GPS) data. However, its projected catchment area was 71.61 km^{2}instead of 72.31 km^2. The overall user accuracy of classification was 94.23 % with overall Kappa (K^) coefficient value of 93.WCN was found to be 76.42 for the mentioned catchment area. It was concluded that ASTER GDEM and Arc Hydro tools are recommended for hydrological processing of small watersheds and SPOT data is good for LULC classification.

Key Words: Hydrological processing, Watershed delineation, Arc hydro tools, Supervised Classification, GDEM.

Introduction

In the science of hydrology, watershed delineation and associated catchment area extraction is a common and prime task for which Digital Elevation Models (DEMs) play an important and exclusive role in distributed hydrological modeling supported by GIS. Morphological characteristics and accurate drainage boundaries are crucial issues of flat terrain lands. It is a difficult task to manipulate delineation of a catchment based on topographic maps with contour lines of flat terrain land. Evaluation of satellite images or thorough field survey ensures reliable catchment delineation which involves Digital Terrain Model (DTM) and a computer algorithm. This technique has the advantage of being independent of human decisions and less time taking. For distributed hydrological simulations, a GIS is usually used as an integrated and comprehensive approach for the hydrological, flood and water supply models. (Konadu & Fosu, 2009; Wu et al., 2008; Moharana & Kar, 2002; Fairfield & Leymarie, 1991). Watershed characterization for stream network and basin delineation is prerequisite for the foundation of these hydrological models generated from DEMs (Ames et al., 2009; Lacroix et al., 2002 &Jenson, 1991). Hydrological analysis and water resource management in GIS is based on extracting watershed features

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and characteristics, such as catchment delineation and stream network (Zhang et al., 2013). In past, many studies have been conducted on algorithms of watershed characteristics extraction (Zhang et al., 2013; Jones 2002; Turcotte et al., 2001; Fairfield & Leymarie, 1991). Zhang et al., in 2013 & 2009, developed an algorithm for establishing channel networks in DEMs. Numerous GIS based tools have been developed so far based on the previous research work like "Hydrology" by Esri-2004 toolset in Arc GIS which has been commonly used for DEMs pre-processing and surface stream simulation. Win Basin is a watershed analysis system that is used in automatic calculation of depression less flow directions, delineation of watersheds and sub watersheds, extraction of realistic drainage networks and calculation of geomorphological indices and hydrological responses from DEMs (Lin et al., 2008). Natural Resources Conservation Services (NRCS) Geo-Hydro is an Arc GIS application extension that can compute catchments, drainage points, drainage lines, and cross-section details for a storm event hydrological model (Merkel et al., 2008).Arc Hydro is a set of data models and tools used for hydrological information system building to be used in supporting geospatial and temporal water resources data analysis. It is used to extract topologic variables from a DEM raster for building, defining and analyzing hydro geometric networks for hydrological analysis (Dost, 2005).Arc Hydro is an Arc GIS-based system application used in water resources monitoring and analysis. Integration of Arc Hydro Data Model and Arc Hydro Tools with the generic programming framework facilitates analysis in the water resources area (ESRI 2004). With the help of Arc hydro tools, features of watershed characteristics such as stream network, flow length, catchment and channel networks can be ensured with rapid and reliable determination or extraction from DEMs (Lin et al., 2008.). The primary purpose of this research is to analyze elevation of catchment area and to assess the land cover dynamics of watershed of Kandar dam Kohat in Pakistan using Geo Spatial techniques and determine WCN using Soil Conservation Services (SCS) curve number method.

Materials and Methods

Description of the Study area

The study was conducted in district Kohat on the watershed of Kandar dam as shown in Figure 1 and on the topographic sheets number 38 O/10 and 38 O/14 of Pakistan Geological Survey Maps. The topography of study area is mostly hilly with little planes having a few settlements and rain fed agricultural land.

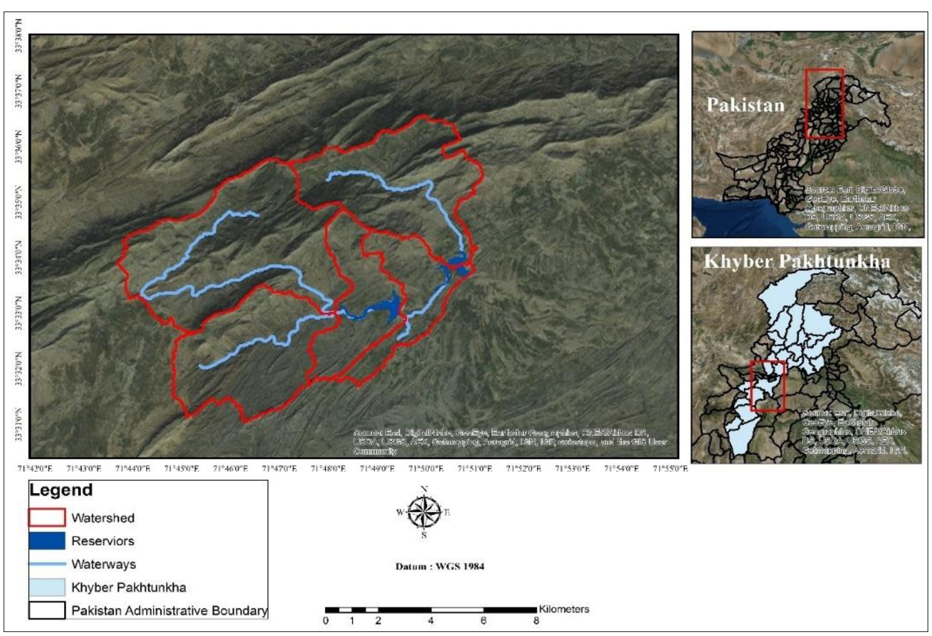

Figure 1: Study Area

ASTER GDEM and Delineation of Watershed

Delineation of watershed mostly considers the identification of the boundaries of watershed. Arc Hydro tool version 1 beta 2 in Arc GIS 9.3 was used to generate sets of hydrological maps based on DEMs analysis (Abdal, 2007). Analysis focused on surface water drains and watersheds delineation. Freely downloadable (http://srtm.usgs.gov/) GDEM 30 m was used as starting point to carry out analysis of surface water drains and watershed delineation. The elevations determined through GDEM were compared with observed data for the accuracy to achieve the confidence of dependency on model prediction. Figure 2 and 3show the comparison of observed with DEM elevations. Based on correlation analysis, the watershed of the study area was delineated. To conform that Arc hydro tools have drawn the correct boundary lines, the actual boundary lines and divide points were visited and tracked through GPS device. The total projected catchment area was compared with the real catchment area.

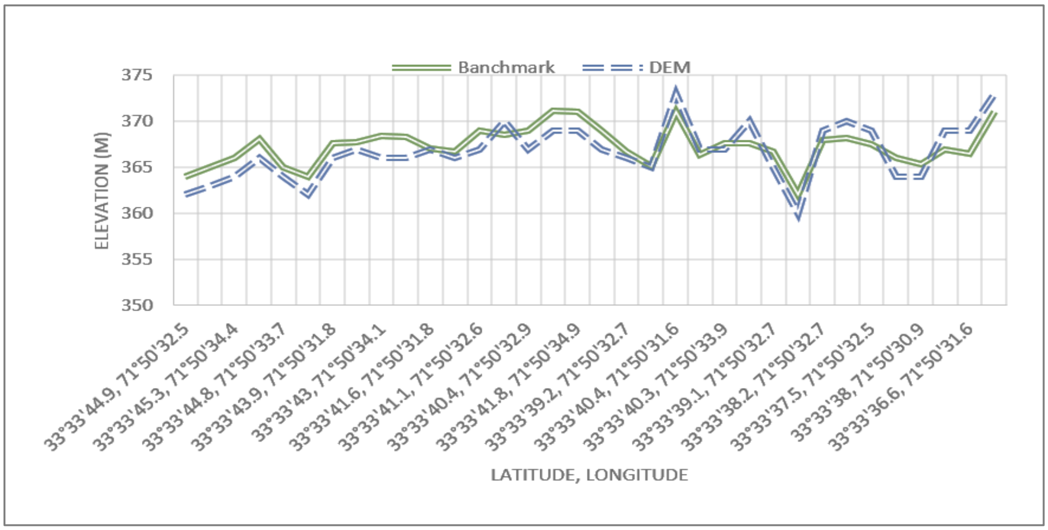

Figure 2: DEM and Benchmark's Elevation Comparison

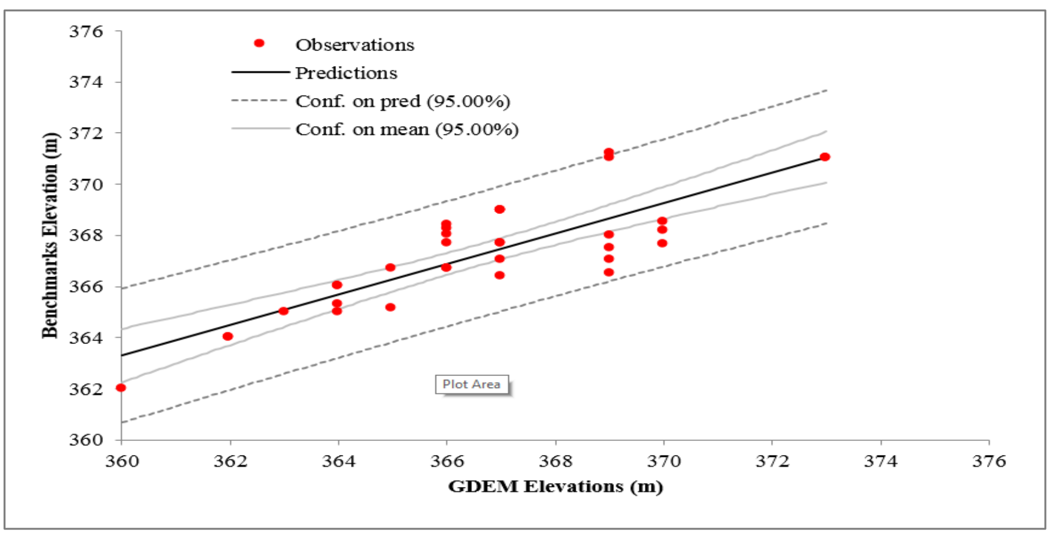

Figure 3: Sensitivity analyses of the ASTER GDEM

Land Use and Land Cover (LULC) Classification through Supervised Classification

Number of remote sensing image classifications methods have been used for LULC data such as Unsupervised Classification, Fuzzy Classification and Supervised Classification (Elaalem, 2013). In this study, Supervised Classification, that is Maximum Likelihood Classifier techniques employed and derived land cover map using SPOT data. Supervised Classification is a method for quantitative analysis of remote sensing data (Richards, 2013). In this study, Image Classification was done in three steps. Firstly, image was preprocessed for eliminating any possible source of spatial errors and radiometric errors. Secondly, the spectral signatures of different classes were analyzed using signature editor tool and made land cover classes. Once the classes were made, the Maximum Likelihood classification (MLC) classifier was then used to classify land cover classes.

LULC Classification Accuracy Assessment Test

Accuracy assessment is necessary for finding the authenticity of classified images. In this process, LULC classes observed at the watershed are compared with classified image classes. Accuracy assessment test enables user reliability on software classification. According to Anderson et al., 1976, the minimum level of interpretation accuracy in the identification of LULC categories from remote sensing data should be at least 85%. The most widely promoted classification accuracy is in the form of error matrix which can be used to derive a series of descriptive and analytical statistics (Liu et al., 2007; Foody, 2002; Smits et al., 1999 & Congalton, 1991).The accuracy assessment was carried out in ERDAS Imagine 9.1 by collecting GPS points selected randomly on 30 locations from the study area. After classification of images, producer's accuracy, user's accuracy, overall accuracy and Kappa coefficient values have been calculated with the help of confusion / error matrix. Higher the values of all of these indices, the greater will be the classification accuracy.

Weighted Curve Number (WCN)

Curve numbers of each unique land use-soil group were assigned within the boundaries. These were based on standard SCS curve number which was derived from the standard categories typically used for hydrological analysis using the SCS methodology (NRCS). The weighted curve number for the watershed was calculated by using the following equation;

$$WCN = \left(\frac{A_1}{A} * CN_1\right) * \left(\frac{A_2}{A} * CN_2\right) * \left(\frac{A_3}{A} * CN_3\right) * \ldots \left(\frac{A_n}{A} * CN_n\right) \ldots\ldots\ldots\ldots \quad (1)$$

Where WCN is weighted curve number of watershed CN1,CN2,CN3,CN7, are curve number of class 1, 2, 3…7 and A1,A2, A3, A7, are the areas of the class and, A is total area of watershed.

Results and Discussions

ASTER GDEM Comparison with Benchmarks

Evaluation and the sensitivity analysis of ASTER DEM have been shown in Figure 2 and 3.Figure 2 shows comparisons of the elevations projected by ASTER GDEM and available actual benchmarks for the same location point. There was lesser difference between the actual benchmark elevations with similar trend. The analysis showed a coefficient of determinant (R^2) as 69 % for 83 % correlation (R) between the projected and actual elevations. Figure 3 shows sensitivity analysis of the ASTER GDEM. It is clear from the figure 2 that all the projected elevations are within the range of 95 % confidence level.

Watershed Delineation

The whole watershed along with waterways and spillways including auxiliary and main Kandar dam has been delineated using Arc Hydro Tools. Figure 4 shows GPS points noted in terms of latitude and longitude at each of the drainage divide point which confirmed the accuracy of watershed delineation. Delineation was also confirmed by importing boundary shape file to Google Earth and validated satisfactory results. After that area of the delineated watershed was calculated from the derived region based model. It was estimated that the area to be71.61 km^2 which was 97 % of the real catchment area (72.31 km^2). Hence it is an approximately equal and is acceptable for watershed processing and modeling.

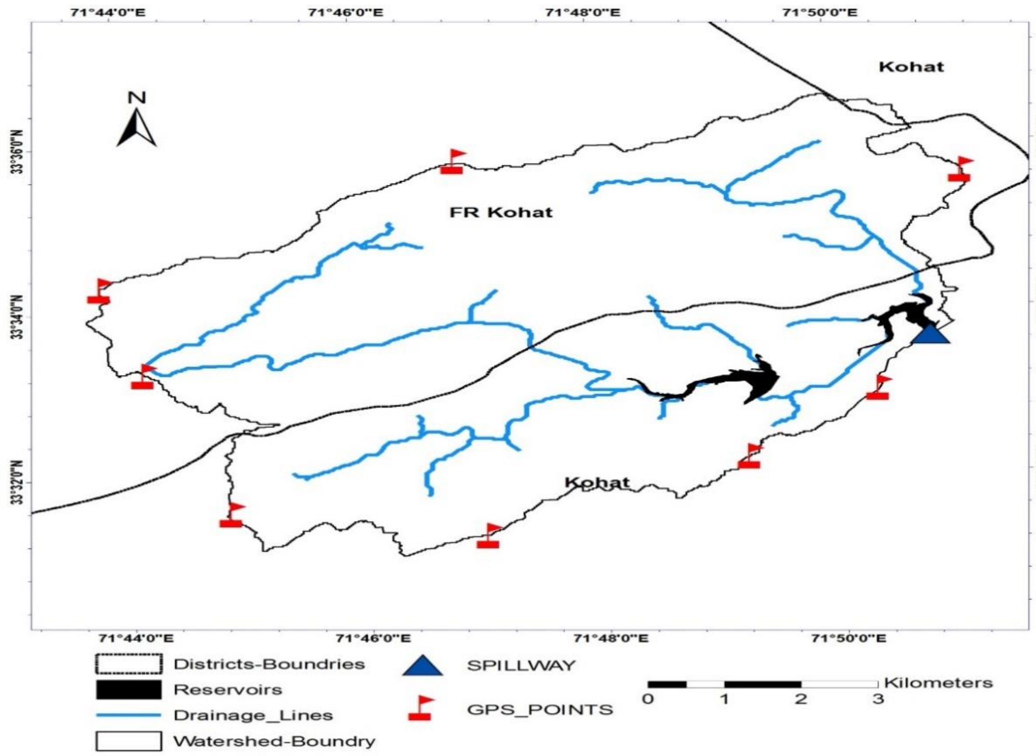

Figure 4: Kandar Dam watersheds with GPS Confirmatory points

Land Use and Land Cover Classification

Catchment area of Kandar dam was mainly divided to seven dominant classes based on Supervised Classification techniques conducted in ERDAS Imagine 9.1. Spatial representation and percentage of the corresponding classes have been showed in Figure5 and 6 respectively. It was observed that in the whole watershed, range land was dominant class which is 34.9 %followed by agricultural land that is 20.9 %. The fallow (bare) land is 16.76 % followed by rocks (impervious) as13.96 % and forest as 11.17 %. Residential area and water bodies covered a small area in the watershed which presented in figure5 and 6.

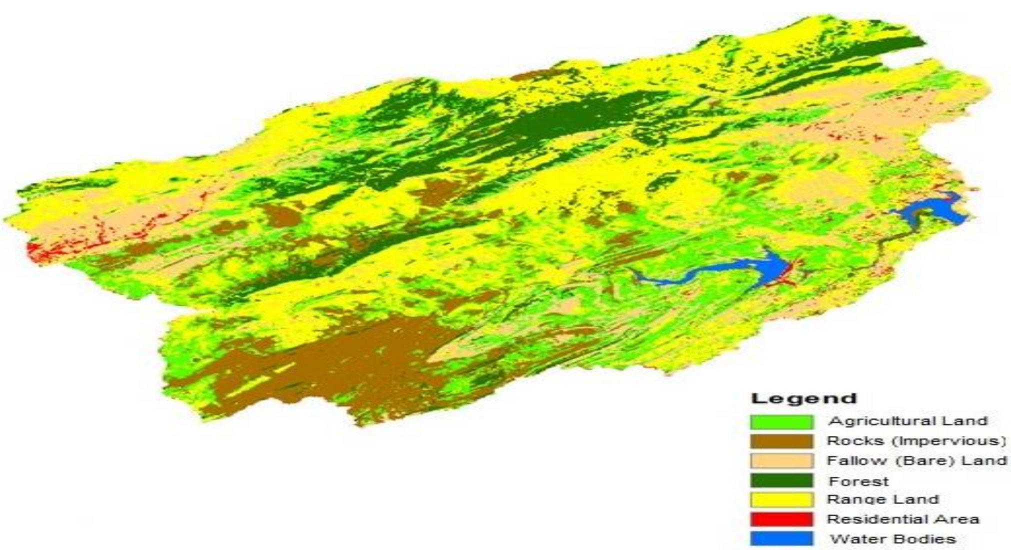

Figure 5: Land Use and Land Cover Classification Map of the whole Watershed

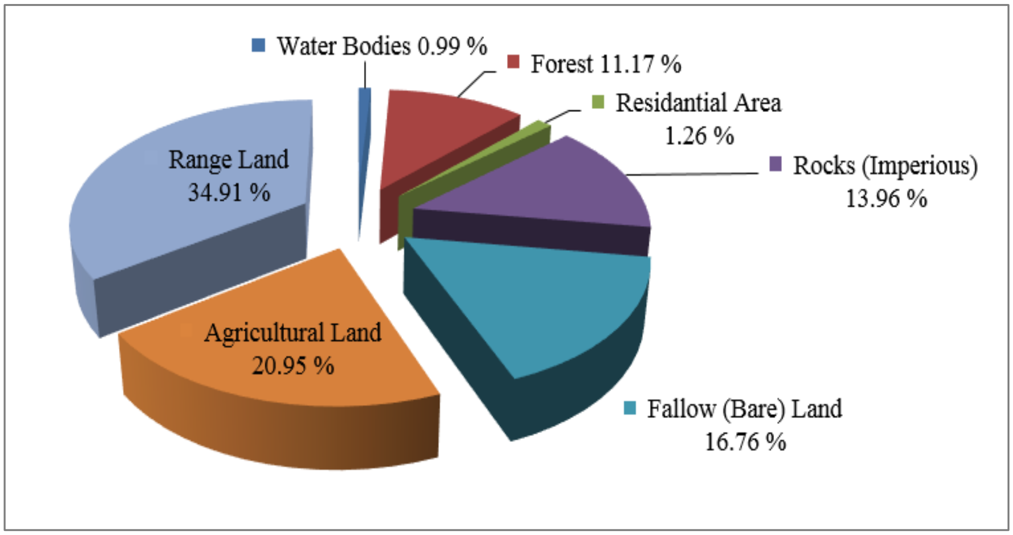

Figure 6: Land Use and Land Cover Classification Pie Chart of the wholeWatershed

LULC Classification Accuracy Assessment Test

Table 1 shows results of accuracy assessment test. Overall classification accuracy achieved was found to be 94.23 %. The overall Kappa (K^) coefficient was found to be 93. The producer accuracy for range land and agriculture land was relatively low due to rain fed agriculture in the area. So more resemblance was found in these two classes while it was 100 % for remaining classes. Overall these accuracies are good and are useful for watershed processing.

Table 1: Results off accuracy assessment test

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy (%)	Users Accuracy (%)
Water Bodies	4	4	4	100	100
Forest	6	6	6	100	100
Residential Area	4	5	4	100	80
Rocks (Impervious)	7	7	7	100	100
Fallow (Bare) Land	8	10	8	100	80
Agricultural Land	9	8	8	89	100
RangeLand	13	11	11	85	100
Total	52	52	49		
Overall Classification Accuracy = 94.23%					
Over All Kappa (K^) Statistics = 93					

Weighted Curve Number (WCN)

Table 2 shows the curve numbers assigned to the classes (according to the standard SCS method, 1986) and their corresponding areas with weighted curve number for the watershed. The weighted curve number found for the watershed was to be 76.42.

Table 2: Weighted Curve Number calculations

S. No	LAND CLASS	CN	Area (km^2)	Area (%)
1	Water Bodies	100	0.71	0.99
2	Forest	55	8.00	11.17
3	Residential Area	68	0.90	1.26
4	Rocks (Impervious)	98	10.00	13.96
5	Fallow (Bare) Land	85	12.00	16.76
6	Agricultural Land	77	15.00	20.95
7	Range Land	71	25.00	34.91
Total Area			72.0	
WCN			76.42	

Conclusion

It was found that ASTER GDEM provided good representation of ground elevations at 5 % significance level. Arc Hydro tools have predicted accurate boundaries of watershed which shows that Arc Hydro is capable of performing watershed modeling with satisfactory performance. Study also concluded that lower stream threshold value can enhance the catchment delineation accuracy. Furthermore, results accuracy provides scientific base to use Remote Sensing and GIS techniques for continuous mapping and monitoring on ecological issues of watersheds areas of Pakistan.

Recommendations

Freely available DEM of 30 m is recommended for watershed delineation and catchment Area calculation. A study is required to compare and asses DEM accuracy with surface (grid). Such studies, if done considerately, can help not only in monitoring of watershed areas of Pakistan but also will provide immense information about better watershed management practices in Pakistan.

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