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INVESTIGATION OF POTENTIAL WATER HARVESTING SITES AT POTOHAR USING MODELING APPROACH

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Agriculture is the largest employing sector that involves 44.7% of manpower of Pakistan's total population and participates about 23% in GDP of Pakistan but on the other side, country is facing the shortage of water. The 60% of population lives in rural and hilly areas while implementing the schemes of water in hilly areas is not feasible because of high expenditures and less progress. Moreover, supplying of water in hilly areas is time consuming, unsafe and expensive work therefore, hilly areas rainwater harvesting is the most appropriate and feasible technique. This paper represents the study of runoff pattern and to investigate the potential water harvesting sites in Potohar Plateau of Pakistan. The techniques, such as Geographic Information System, Remote Sensing, HEC-GeoHMS and HEC-HMS were used for delineation of water channels, drainage line and for estimation of runoff generation. The results revealed that 60% of the study area has potential for rainwater harvesting in order to accumulate and store runoff generated from annual rainfall.
Keywords: Potohar, water harvesting, modeling, HEC-GeoHMS, HEC-HMS, remote sensing

INTRODUCTION

Water is essential for growth, bio-diversity, environment, agriculture and all types of living organisms. Presently, fresh water availability has become world human right issue due to continuous depletion of fresh surface and groundwater resources. World's quarter population living in developing countries is facing the harsh scarcity of water for domestic and agricultural purposes. In Pakistan, the availability of potable water and irrigation water has always a serious problem especially in rural, hilly and mountainous regions where accessibility of fresh water is a major problem (Ahmad *et al*., 2010). The North Punjab (Potohar), particularly, includes four districts in arid region i.e. Rawalpindi, Attock, Jhelum and Chakwal and the natives rely on water sources from rainfall and groundwater by pumping, tube-wells and mini dams. Pakistan is an arid to semi-arid country and on an average, about 750 mm of rainfall occurs annually in areas of Potohar (MINFAL, 2010). Unfortunately, its groundwater as well as surface water resources are at risk, therefore, Pakistan is now considered as water scarce country in spite of having biggest Indus Basin irrigation system.

To overcome the shortage of irrigation water for agriculture, there was a need to move towards water storage techniques like rainwater harvesting (Glendenning and Vervoort, 2011). The assessment of rainwater harvesting is also important for flood forecasting studies. Rainwater harvesting was a technique applied to accumulate, transmit and store rainfall from comparatively clean surfaces, where the rainwater fell, such as a mountainous catchment, bare surface or rooftop surfaces, for further use in future in the same area at a later time (Mbilinyi *et al*., 2005). There might be two rainwater harvesting techniques for the accumulation of rainwater, used for different purposes: land-based and roof-based (Glendenning and Vervoort, 2010). Various factors, such as rainfall, land cover and land use, topography and terrain profile, soil texture and soil depth, hydrology of the area, socio-economic and transportation conditions, ecology and environmental effect would be considered for the identification of most suitable sites for rainwater harvesting (Prinz and Anupam, 2002).

The most important component for rainwater harvesting is runoff that is generated from the heavy rainfall and has a significant influence on the hydrological cycle. The assessment of runoff was also important for flood forecasting (Ratika *et al*., 2010). The watershed or basin of river was considered as principle-managing unit because it contained a fundamental resource that was water that made the whole eco-system interconnected directly (Magesh *et al*., 2012). Asghar and Bandaragoda (1997) found that most of the water harvesting sites, mini and small dams were located in Potohar region which has total area of about 16800 km^2. Rainwater harvesting, as a water resource, is obtaining a great significance for supplying water to the dry regions of Potohar where the shortage of surface and groundwater is significant for domestic and agriculture purposes.

The dry mountain regions, where the inconsistency of rainfall, continuous melting of snow cover, evapotranspiration and temperature was already high, were facing the varying climate conditions significantly (Tripathi and Pandey, 2005). In dry and hilly areas of Potohar, the major advantage of rainwater harvesting is supplying water for irrigation and domestic purposes. The uncertainties of the rainfall and limited supplies of water are the major disadvantages of the rainwater harvesting, moreover, for longer dry period it is not a reliable source of water. This research was carried out to study the runoff pattern in the Potohar Plateau of Pakistan and to investigate the potential water harvesting sites in Potohar Plateau of Pakistan.

The GIS technology has the ability to capture, store, manipulate, analyze, and visualize the geo-referenced data (Abolghasem *et al*., 2010; Winnaar *et al*., 2007) and therefore, was used in this study. The Hydrologic Engineering Center's for Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) software used in the study is a public-domain software package for use with the ArcView Geographic Information System. HEC-GeoHMS uses ArcView and Spatial Analyst tool of ArcMap to develop a number of hydrologic modeling inputs. The Hydrologic Engineering Center's for Hydrologic Modeling System (HEC-HMS) was generation software being developed for rainfall-runoff simulations that supersede the Hydrologic Engineering Center's HEC program. HEC-HMS provided a variety of options for simulating rainfall-runoff processes (Zakaria *et al*., 2012; Ali *et al*., 2011).

MATERIALS AND METHODS

Study Area: The research was carried out at the Potohar Plateau which includes Jhelum, Attock, Chakwal and Rawalpindi as shown in the Fig. 1. The Potohar Plateau included total area of 2.2 million hectares (mha). The geography of the region was undulating with average slope of 8-40% and inclined from about 32.5˚N to 34.0˚N latitude and about 72ºE to 74.0ºE longitude. The yearly precipitation in the study area varied from 450 mm in South West to 1750 mm in North East with 70% precipitation in the monsoon season (Cheema and Bastiaanssen, 2012). River Haro and River Soan were the two seasonal stream channels flow in this plateau.

Data Collection: The precipitation records of Potohar region for the five years (2005-2009) were obtained from Soil and Water Conservation Research Institute, Chakwal. The elevation data were used for determining the stream flow direction, drainage lines and for runoff determination. The Digital Elevation Model (DEM) SRTM of 90m was used as a source of elevation data for the Potohar catchment areas as shown in Figure 2.

The HEC-GeoHMS and HEC-HMS softwares were used for runoff prediction in the Potohar Plateau, which worked as spatial extension for terrain processing. These softwares were also used to determine fill sinks, flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon process, drainage line processing, adjoint catchment processing and point delineation. In HEC-GeoHMS, terrain preprocessing was considered as initial step. The grid representation of steam links was converted into vector representation as drainage line features as shown in Fig. 3.

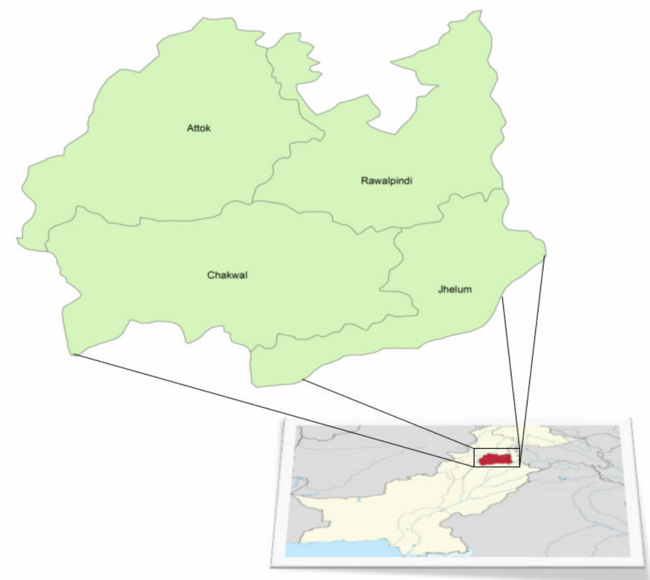


Figure 1. Location of study area

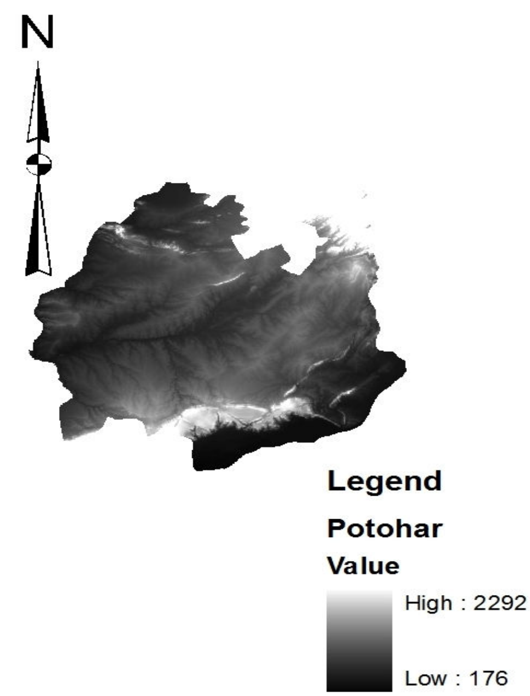


Figure 2. Digital elevation model for study area

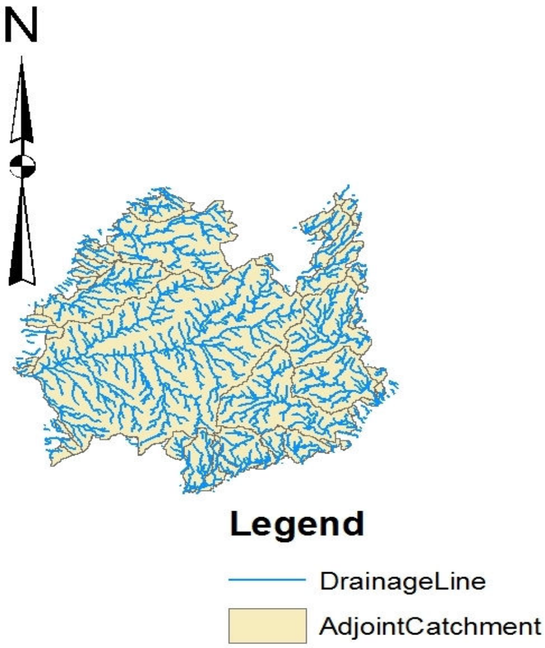


Figure 3. Drainage lines in the study area

The basin merge process was used in order to merge the small basins into one basin so that a considerable area could be delineated for suitable rainwater harvesting site as shown in the Figures 4a and 4b.

The HEC-HMS model was used to simulate the rainfall-runoff pattern of watershed system. HEC-HMS included large river basin water supply and flood hydrology of natural watershed runoff. HEC-HMS has four main components i.e. basin model, meteorological model, time series data and the control specifications. Development procedure of all these components is briefly described below.

Basin model was created in HEC-GeoHMS of ArcMap while other three components were developed in HEC-HMS. The loss method used was deficit and constant method which was used for continuous change in the moisture content under single soil layer conditions. The initial deficit refers to the initial amount of water required by the soil to come to saturation. When the soil layer is saturated, the constant rate refers to the infiltration rate. Runoff transformed method was Snyder's Unit Hydrograph Method which is a synthetic unit hydrograph and only computes the peak flow by using original data as a result of unit precipitation. The values used for standard lag and peak coefficient were 27.407 and 0.501, respectively. The Constant Monthly Average method was used for base flow method. The meteorological model and control specification methods were used to analyze and simulate the meteorological data and time span respectively.

In HEC-HMS model, the first objective for this research was to carry out the flow simulation for the Potohar plateau. For this purpose, whole project was prepared which included basin model, metrological model, control specifications and time series data was added for the model. For flow simulation, two processes were included in HEC-HMS model. These processes were

1. Parameter optimization and model calibration
2. Validation of the model.

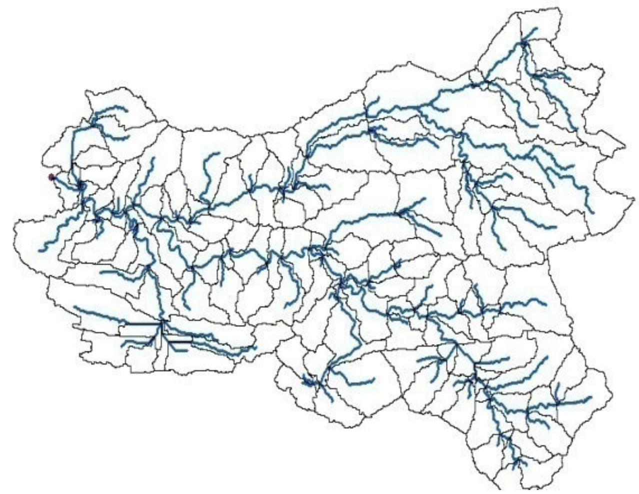


Figure 4a. Before merging the basins

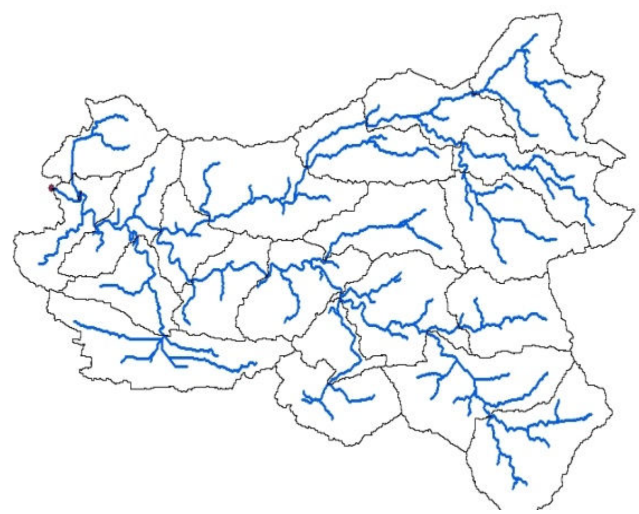
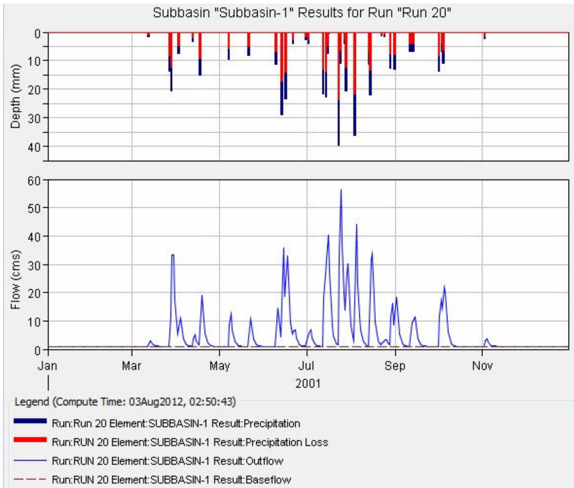


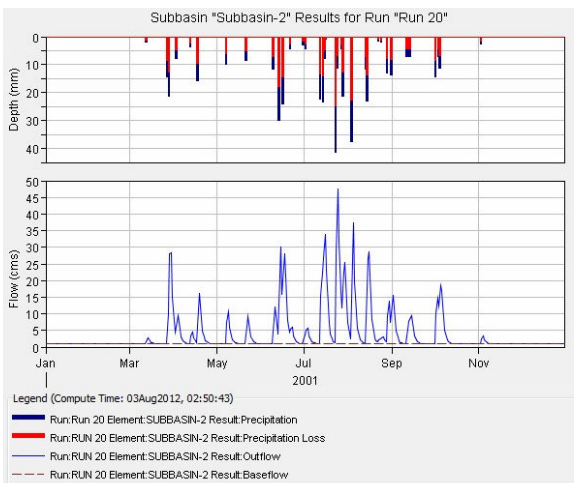
Figure 4b. After merging the basins

RESULTS AND DISCUSSION

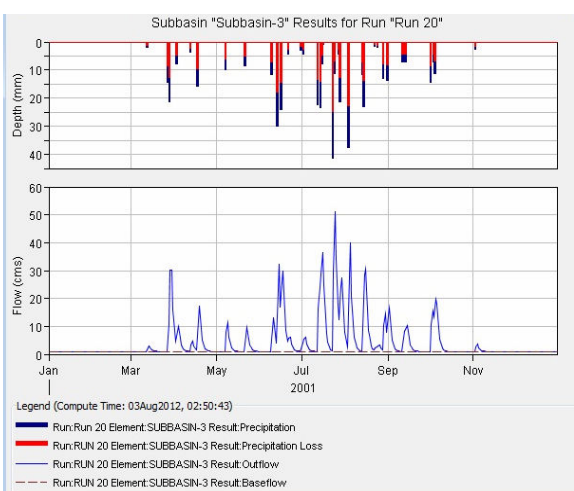
The flow simulation was carried out using HEC-HMS and a particular basin was selected for the calibration of the model and runoff simulation for an area of 1779 km^2. The basin was subdivided into further 3 sub-basins on the basis of existing streams so that the performance of the model could be easily determined. The maximum matching points of the peak discharge were selected for the model calibration, are shown in the Figure 5.



a) Sub basin 1



b) Sub basin 2



c) Sub basin 3

Figure 5. HEC-HMS calibration

The Fig. 5 shows that the loss parameter constant rate about 1.5 mm/hr has a great effect on the runoff simulation which has maximum matching among the rainfall and the flow generated. All the three sub-basins are shown in Fig. 6, which represents the total flow of the basin selected from the Potohar. The observed flow and simulated flow using HEC-HMS model for 5 years (2005-2009) for all three basins are presented in Fig. 7.

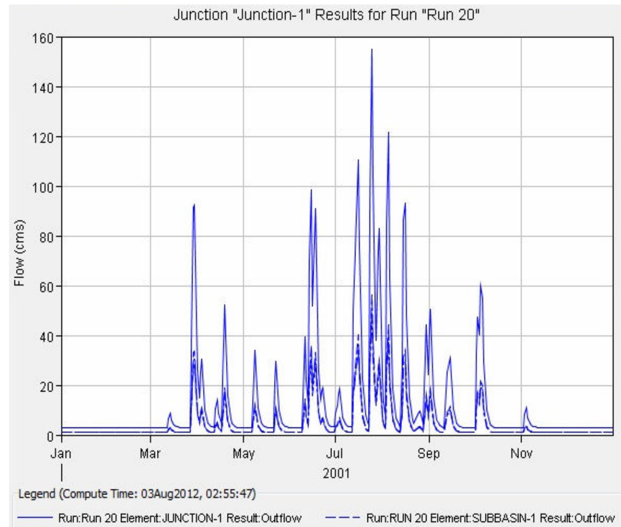


Figure 6. Combined result of three basins

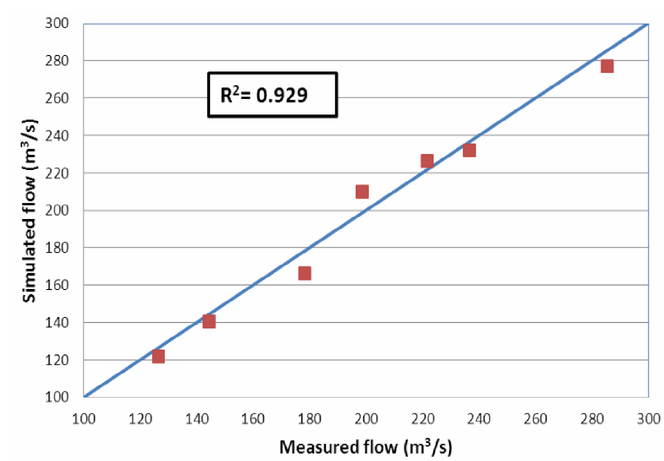


Figure 7. Simulated vs measured flow

Figure 7 shows that during the estimation of peak discharge, the percentage error was within the limits of 7% through the HEC-HMS model. The maximum error within a considerable range could be up to 15% for the model but the results were within the permissible range.

Ali *et al*. (2011) used HEC-HMS model and investigated the variation of hydrological cycle due variation in land use in Lai Nullah Basin in Pakistan. The observed and simulated values were compared and results found were satisfactory with 76-98% efficiency. Ramakrishnan *et al*. (2009) studied the kali sub-watershed where the annual rainfall is 900mm and GIS tool was used to analyze, integrate and storing the spatial data of drainage, slope and runoff sites for water harvesting. The precision of sites identification were found from 80-100%. Saadat *et al*. (2008) studied and compared the landform classifications and mapping of soil of Iran through conventional and GIS method. It was found that conventional method gave very low, 50% accuracy than the GIS method with on an average 96.7%, after conducting ground-truthing.

There were many water harvesting sites which could store potential quantity of runoff generated from rainfall annually. The dots were placed on the meeting point of the river channel or where there was a considerable depression which could accumulate and store a potential quantity of water as shown in Fig.8.

The results obtained from the Geographic Information System (GIS) showed that there were 123 sites suitable for the rainwater harvesting but when the ground truthing was carried out then it were found that there were only 74 sites, which were suitable for rainwater harvesting. It means that the 60 percent rainwater harvesting sites found to be reliable for accumulating and storing the runoff generated from the rainfall annually. The longitude and latitude of these sites obtained from the GIS and then compared with the satellite imagery along with field observations have been shown in the Table 1.

Table 1: Longitude and latitude of rainwater harvesting sites in Potohar

Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
72°22'37"E	33°52'57"N	73°30'50"E	33°13'22"N	72°02'22"E	33°25'05"N
72°28'27"E	33°52'57"N	73°18'53"E	33°14'31"N	72°09'16"E	33°25'41"N
72°41'46"E	33°51'35"N	73°22'31"E	33°12'56"N	71°57'07"E	33°23'04"N
72°37'46"E	33°50'09"N	73°24'59"E	33°11'40"N	72°03'46"E	33°21'36"N
72°34'52"E	33°49'34"N	73°21'47"E	33°10'07"N	72°10'53"E	33°22'33"N
72°45'07"E	33°47'36"N	73°16'53"E	33°11'28"N	72°28'54"E	33°25'54"N
72°40'17"E	33°46'50"N	73°17'19"E	33°08'59"N	72°26'58"E	33°23'20"N
72°43'06"E	33°44'19"N	72°45'31"E	33°11'04"N	72°58'44"E	33°23'43"N
72°30'23"E	33°47'27"N	72°40'26"E	33°13'41"N	73°23'30"E	33°25'36"N
72°26'04"E	33°45'44"N	72°41'17"E	33°10'53"N	73°27'38"E	33°21'33"N
72°19'01"E	33°44'22"N	72°19'07"E	33°16'25"N	73°15'30"E	33°22'34"N
72°14'48"E	33°44'25"N	72°13'25"E	33°14'10"N	72°57'53"E	33°20'54"N
72°06'15"E	33°39'05"N	71°45'31"E	33°14'33"N	72°50'57"E	33°20'15"N
72°21'50"E	33°41'19"N	72°05'31"E	33°09'59"N	72°45'16"E	33°21'07"N
72°24'44"E	33°41'55"N	72°20'80"E	33°07'47"N	72°24'35"E	33°18'51"N
72°28'46"E	33°42'09"N	72°31'10"E	33°09'30"N	72°41'22"E	33°17'16"N
72°20'09"E	33°38'27"N	72°36'26"E	33°09'36"N	72°58'40"E	33°16'43"N
72°36'26"E	33°39'52"N	71°45'16"E	33°07'48"N	73°19'35"E	33°18'05"N
73°15'34"E	33°46'20"N	72°39'05"E	33°06'25"N	73°26'57"E	33°16'34"N
73°22'42"E	33°45'29"N	72°44'55"E	33°04'21"N	73°35'30"E	33°14'17"N
73°26'07"E	33°42'50"N	72°41'30"E	33°02'47"N	73°16'10"E	32°51'06"N
73°20'55"E	33°40'37"N	72°46'40"E	33°01'35"N	73°04'33"E	32°56'46"N
73°28'19"E	33°40'10"N	72°41'18"E	33°01'11"N	73°04'31"E	32°54'03"N
73°23'21"E	33°36'42"N	73°05'15"E	33°02'13"N	73°03'01"E	32°51'54"N
73°17'18"E	33°35'14"N	73°17'48"E	33°02'33"N	72°55'59"E	32°55'54"N
73°21'12"E	33°33'52"N	73°26'29"E	33°03'15"N	72°36'47"E	32°55'27"N
72°33'53"E	33°36'59"N	73°19'18"E	33°01'21"N	72°44'52"E	32°51'04"N
72°39'53"E	33°37'22"N	71°49'03"E	33°01'30"N	72°30'07"E	32°55'17"N
72°04'26"E	33°35'07"N	71°54'56"E	33°03'49"N	72°08'01"E	33°01'21"N
72°42'47"E	33°33'59"N	72°02'53"E	33°06'20"N	72°03'01"E	32°56'35"N
72°46'20"E	33°33'12"N	72°06'53"E	33°06'38"N	72°09'17"E	32°55'23"N
73°02'41"E	33°31'28"N	72°22'49"E	33°03'47"N	72°17'42"E	32°52'44"N
73°16'02"E	33°31'10"N	72°29'50"E	32°59'28"N	71°53'39"E	32°53'32"N
73°31'44"E	33°32'49"N	72°47'31"E	32°57'55"N	72°01'32"E	32°45'22"N
72°01'34"E	33°29'23"N	73°20'59"E	32°59'33"N	72°31'14"E	32°49'22"N
72°11'14"E	33°29'28"N	73°27'15"E	32°58'59"N	73°14'55"E	32°35'52"N
72°15'16"E	33°29'42"N	73°35'21"E	32°58'50"N	73°07'19"E	32°36'30"N
72°21'32"E	33°30'06"N	73°31'45"E	32°57'38"N	72°53'50"E	32°39'39"N
72°35'36"E	33°29'37"N	73°22'50"E	32°54'54"N	72°36'12"E	32°39'36"N
72°53'12"E	33°28'43"N	73°30'30"E	32°46'34"N	72°42'46"E	32°31'14"N
73°01'18"E	33°27'58"N	73°22'07"E	32°45'55"N	72°55'27"E	32°32'51"N
72°05'59"E	33°27'36"N	73°17'09"E	32°46'21"N		

The results obtained by HEC-HMS simulation were compared with the observed results and found that considerable runoff was generated which could be stored in at different suitable sites corresponding to the agriculture or domestic purposes or for both.

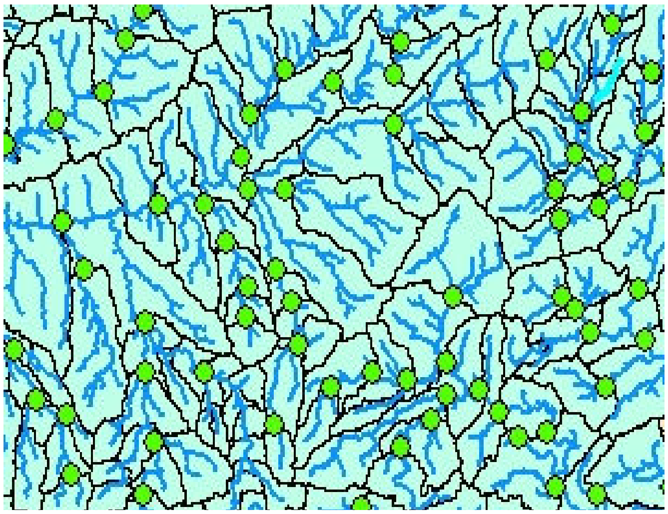


Figure 8. Potohar part showing water harvesting sites

Ali *et al*. (2011) simulated the HEC-HMS model and values were used for the prediction of future land use. The outcomes point out with the purpose of prospect land use because predictions within the planning was expected to enhance entire runoff among 51.6 and 100.0% and peak discharge between 45.4 and 83.3%. Munyao *et al*. (2010) gave a methodology for identification of sites for potential harvesting of rain water using GIS and Remote Sensing. On the basis of pixel scale, the runoff was determined by using soil conservation service method and investigate that about 84% runoff was generated by slope of flat and undulating areas. Using present and skillful knowledge, micro-catchment validation for RWH showed that 10% suitable sites were unsuitable, 10% in marginal and 80% in most suitable areas.

***Conclusions*:** There were a large number of small basins, where water harvesting techniques could be applied by considering the amount of runoff generated. The farmers in Potohar, who were suffering shortage of irrigation water and could not grow their crops throughout the year due to less availability of irrigation water, would be able to perform agriculture practice through rainwater harvesting. The rainwater harvesting be performed where the agricultural land was available or where the purpose of water harvesting was for domestic and livestock usage.

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