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Site Suitability Analysis for Small Multipurpose Dams Using Geospatial Technologies

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Abstract

Water shortage, energy crisis and natural misfortunes are the glitches which reduce the efficacy of agricultural ecosystems especially in Pakistan where these are more frequent besides being intense. Accordingly, the agricultural water resources, food security and country's economy are at risk. To address this, we have used geospatial techniques incorporating ASTER Global DEM, geological map, rainfall data, discharge data, Landsat 5 image of Swat valley in order to assess the viability of selected sites. The sites have been studied via GIS tools, hydrological investigation and multi parametric analysis for their potentialities of collecting and securing the rain water; regulating floods by storing the surplus water bulks by check dams and developing them for power generation. Our results showed that Siat1-1 was very useful for low cost dam with main objective of as debris dam; Site-2 and Site 3 were check dams sites having adequate storing reservoir so as to arrest the inconsistent flow accompanied by catering the sedimentation effects and the debris flows; Site 4 had a huge reservoir capacity but it entails enormous edifice cost over very great flood plain. Thus, there is necessity of active hydrological developments to estimate the flooded area using advanced and multifarious GIS and remote sensing approaches so that the sites could be developed for harnessing those sites for agricultural and energy drives.

Keywords: Site suitability; Check dams; SHP; Terrain analysis; Volume estimation

Introduction

Water scarcity, power crisis and natural disasters are among one of the problems our country is facing in current era. Around 21 percentage of Gross Domestic Products (GDP) of Pakistan are based on Agriculture as well as 50% of the country's economy is dependent on agriculture [1] that is prone to the water scarcity issue. But still Pakistan is blessed by plenty of natural resources that are in need to be utilized by proper planning and development.

For the sake of development, the sustainability of land and water resources is very essential for their maximize production. Dams have provided substantial amount of benefits to the mankind. A dam is mainly a reservoir that is constructed over a path of water flow (i.e., rivers or streams) for storing the water [2].

Secondly the hydro power projects are means of clean and environment friendly sources of energy accompanied by least emission of greenhouse gases (GHGs).

Need is to utilize these physical resources for sustainable development like construction of small multipurpose hydro power projects that could cope with local power requirements as well as have potential to fulfill irrigation purpose of the agricultural lands.

While concerning geographical information system (GIS) and the tools it incorporates, GIS could prove as a best attempt to select suitable check Dams for storing the rain water [3]. In addition to that the uses of geospatial technologies as well as remote sensing have contributed a lot in selection of suitable sites for water recharging or harvesting [4,5].

Literature Review

Requirement of check dam sites

Check Dams are one of the primary sources of rain water harvesting for the sake of agricultural and drainage usage. GIS is a tool for processing and displaying of multiple spatial data one of them which is the suitable site selection for dam. Using GIS approach, an attempt was made to select suitable sites for check dams for harvesting rain water in Alur taluk of Hassan district of Karnataka that receives good rainfall but due to the hilly terrain run off was high. This area was selected on the basis of many factors such as altitude, slope, literacy, wastelands, and man to land ratio, power, irrigation and infrastructure facilities. Major part of the water in Alur taluk simply run off, therefore, an attempt was made to select suitable check dam sites for storing the rain water and improvement of rain areas. Streams of 2^{nd} and 3^{rd} order were selected from drainage map. This was selected by keeping in mind that the water available should be fairly satisfactory but not very greatly in excess of normal requirement. Then Lineament (fracture) map was overlaid over these selected streams, and removed the segment of streams which are controlled by fractures. After that streams were buffered from both sides and superimposed over contour and slop map, those contours were selected which formed the closed valley and then such areas were checked for suitable slope along the valley slope class up to 2 (i.e., up to 8%) and across the valley more steeper slope, slope class greater than 2. Few suitable sites identified and possible water in each site if constructed was drawn. These polygons were intersected with land use, soil and ground water maps to find out the respective classes within water spread areas (WSA). These classes were assigned the weightages on the basis of suitability ranking. Weightages were assigned to different classes of land use, ground water and soil maps, while assigning weightage it was kept in

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mind that only worst area gets submerged in all aspects. Then, the weightage of each class were added up for one polygon and total weightage was multiplied with the area of polygons. After the selection of seven suitable site, a polygon to each check dam drawn on the basis of slope and contour to know the current land use of the area immediate downstream of the probable check dam site. This immediate downstream area (IDA) was intersected with slope, groundwater, land use and soil maps and the weightages were assigned to different classes on the basis of requirement of water and calculated the NCWI in the same way as it was done in the case of water spread area [3].

Hydrological assessment

GIS and remote sensing is used to extract hydrological information, required to select dam site. Use of GIS and remote sensing techniques to develop thematic assessment for locating best dam site was studied in AL-Tharthar basin Northern Iraq. The input data consisted of DEM, satellite imagery and runoff. Different software (ERDAS 9.1, ArcGIS 9.3, Global Mapper 11 and Surfer 9) was used to perform analysis on the data. Database was created that describe the characteristics of the catchment and on the basis of these characteristics the suitable site for dam was selected. Multi thematic layers were generated as outcome of the study, these layers included: Land-use and land cover map, DEM map, slope and aspect maps, fill sinks and flow, contour and triangular irregular network maps, 3D surface map and drainage pattern map over the DEM. After analysis of the characteristics of the catchment, three dam sites were selected but site one was best suitable site among all sites. The reasons due to which dam site one called best site were; more lake storage, suitable rock type that supports the structure of dam and beneficial for agricultural lands in the surroundings [6].

Site suitability for small hydropower dams

Construction of Small Hydro Power (SHP) dams is very important to fulfill energy requirements. In whole world, 70% potential sites still exists where SHP dams can be constructed. Location analysis for dams is performed through different ways and methodologies. Geo-Spatial Information System (GSIS) is very helpful in site location analysis for SHP. In Korea, a study conducted to locate potential dam site using GSIS, as Korea is blessed with abundant of potential dam sites. The analysis for suitable location was performed involving these steps: (a) preparation of spatial data, (b) spatial analysis to create searching points, (c) making criteria and assigning weights, (d) overlay analysis, (e) calculating total scores with relative weights and (f) selecting location by total score. Constraint criteria and location criteria were developed to check the feasibility of the location on realistic basis. The purpose of this study was to search potential dam sites in Korea, instead of doing analysis on the purposed sites to find more suitable sites. This methodology was applied on geum river basin, Korea and as a result 6 potential sites of SHP were located.

Another study for the suitable site selection for small dams in Arid environment that had been conducted in Mali that had proposed 17 sites for dams construction based upon utilizing the ASTER Global DEM for extraction of the catchment area, the LANDSAT imagery for Vegetative cover (NDVI), mapping the fault lines using the geological maps, climatological properties and some urban data like distance from villages etc. The sites were selected based upon the qualitative analysis and the indices and coefficients like alluvial plan index that is the developed based upon the storage capacity and the underground dam's dimension, combined coefficient that is the alluvial flat coefficient and the rainfall regime, water holding capacity that is the capacity of soil to withhold maximum water in a barrage.

Volume estimation

This study was being conducted in the upper east region of Ghana where according to Liebee [7] worked on the estimation of reservoir capacity based upon the Bathymetric survey accompanied by the satellite imagery. In this study Landsat imagery was incorporated in order to find out the size or the spatial distribution for the calculation of surface area. Four Landsat Imageries were used that are three for the rainy seasons an done for the dry season then these imageries were compared for the sake of extraction of surface areas. After that for surface area computation, imageries were classified into different classes of water like turbid water, fresh water, water with algae etc. based upon the surface spectral reflectance. For the sake of depth measurements bathymetric surveys were conducted on a sample of 40% of these reservoirs. Outline of these reservoirs were mapped by GPS measurements and the depth of these reservoirs was calculated by using the stadia rods on a boat. In the same manner the height measurements were carried out using the 3D models by developing the area volume relationships (Figure 1).

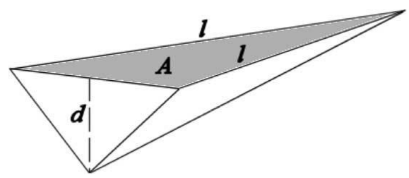

Figure 1: 3D model of area volume relationship.

And the volume would be written as Volume=1/6*A*d.

Then this equation accompanied by the field measurements was further used for estimation of volume in small reservoirs.

Objectives

- Rain water harvesting for droughts mitigation
- Managing flash floods
- Arrest the mud/debris flows
- Assessment of volumetric capacity

Methodology

Study area

The study area selected was Swat River (347' N 7143' E) that originates from Hindukush Mountains and flows from Kalam Valley to Swat district and intern diverts through Lower Dir and Malakand district, then it enters into Kabul River at Charsadda in Peshawar Valley.

Swat is in mountainous ranges, which are the sprouts of Hindukush, so the greater portion of Swat is enclosed with high mountains and hills. These ranges encircle small but very charming valleys with highly agricultural lands including 99 percent of natives of Swat valley as cultivators. Moreover the crops of Swat valley includes spring season crops (Rabee) including wheat, barley, mustard, and lentil and Autumnal crops (Khareef) include maize, rice and jute as well as

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variety of vegetables and pulses including Samchal, Shella, Kwanjay and lentil, peas.

On Swat river, there is requirement of dam construction mainly concerning the recent floods especially in 2010 that was the result of heavy monsoon rains and affected regions of Khyber Pakhtunkhwa, Sindh, Punjab and Baluchistan. About a fifth of the total area of Pakistan has been submerged (about 796,095 Km^2) and that had also affected. The region of KPK was one of the most affected. According to the Pakistan Meteorological Department, in a period of four days in KPK, there have been precipitations ten times greater than those that normally occur during the same period of the year. According to the observations of the Pakistan Agriculture Research Council (PARC), the flood also caused deep changes in the geo-morphological characteristics of the affected areas (Figure 2).

Moreover based upon the flow, rain fall and discharge patterns “In Swat river Munda Dam is one of the proposed water storage reservoir by WAPDA that is 5 Km upstream in mahmand agency that is planned to be utilized for power generation purposes an having capability of irrigation to 16940 acres of area with 740 MW electricity production.”

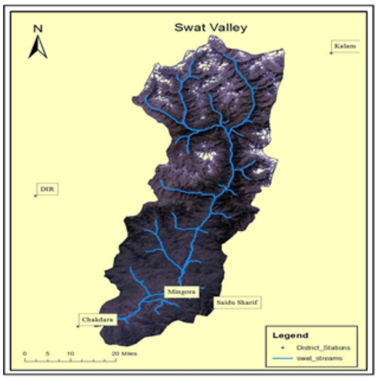

Figure 2: Figure of Swat Valley depicting selected dams site.

Data

The initial data set incorporated as

Digital elevation model: The topographic factor incorporated as ASTER Global DEM of 30 × 30 m resolution of the swat district in two tiles covering N34 E72 and N35 E72.

Geological map: Scanned documents depicting the rock formation.

Rainfall data from Pakistan Meteorological Department of Kalam and Saidu Sharif gauge stations of 8 years from 2003 to 2011.

Discharge data at Kalam (Lat: 35.50, Long: 72.59) and Chakdara (Lat: 72.28, Long: 34.65) Gauge stations of 9 years from 2002 to 2011.

Landsat 5 image of swat valley of november 2011.

The reason of using Landsat 5 was that for Landsat 8 there was very dense cloud cover in the whole scene for last few months as well as for Landsat 7 there was banding effect in imageries of consecutive last few months (Figure 3).

Workflow

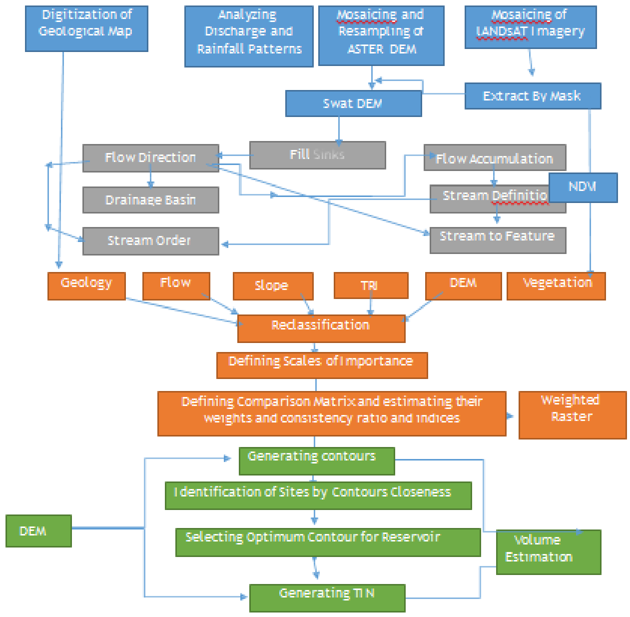

Figure 3: Figure depicting the whole workflow.

The whole methodology is divided into four steps:

- Initial processing of data

Initial hydrological assessment of area of interest

- Definition of criterion maps and estimation of their weights
- Identification of sites and their assessment as well as estimation of storage capacity.

Initial processing of data: In DEM Processing, the initially downloaded DEM was in two tiles Covering N34 E72 and N35 E72. They were first mosaiced to cover the Swat district and then projected to WGS84_UTM ZONE43-N and resampled to 20 m resolution in order to enhance the resolution to some extent (Figure 4).

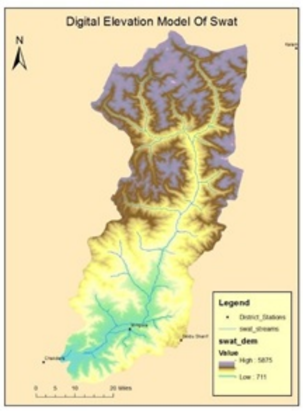

Figure 4: DEM of Swat district extracted from the Mosaiced ASTER DEMS.

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Then the resampled DEM is extracted using Swat's AOI.

The obtained geological map was in scanned document that was first extracted by mask to extract the geology of swat area using swat's shape file (Figure 5). Then the geological features lying in Swat AOI were compared with the legends and by concerning the online knowledge repositories characterized them as basic rock categories either as metamorphic, plutonic igneous rocks, volcanic igneous rocks and meta-sedimentary rocks (Table 1).

Id	Geological	Rock_Type
0	Besal Ecogites	Metamorphic rocks
0	Kohistan Batholith	Plutonic igneous rocks
0	Glaciers	Glaciers
0	U_Volcanics	Volcanic igneous rocks
0	Barul Banda Slate	Meta sedimentary rocks
0	Gligit Complex Meta sedimentary	Meta sedimentary rocks
0	Kalam Group Andesite	Volcanic igneous rocks
0	Kalam Amphibolite Complex	Metamorphic rocks
0	Chilas Complex	Plutonic igneous rocks
0	Cb Late Paleozoic Cambrian Quartzite Schist	Meta sedimentary rocks
0	Swg	Plutonic igneous rocks
0	Indus SM	Metamorphic rocks
0	Mesozoic Meta Sedimentary	Meta sedimentary rocks
0	Pzg PaleoZoic Green Schist	Metamorphic rocks
0	Kamla Amphibolite Complex	Metamorphic rocks
0	Pzg PaleoZoic Green Schist	Metamorphic rocks

Table 1: Depicting the geological units as well as their corresponding rock types.

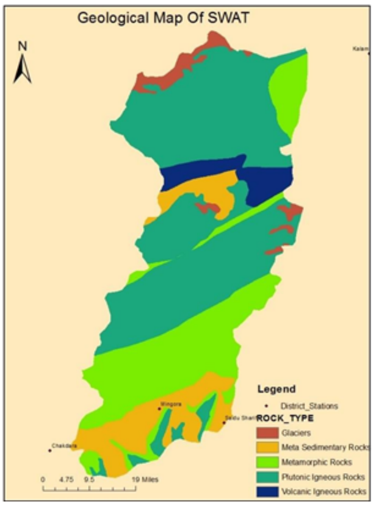

Figure 5: Geological Map of swat depicting the rock types.

Using the discharge data of the Gauge stations at downstream area "Chakdara" and the upstream region "Kalam" (Figure 6) the overall discharge pattern from 2003 to 2011 was analyzed and the results are depicted as:

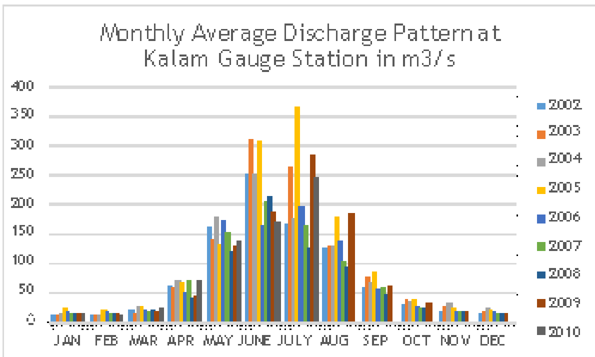

Figure 6: Discharge pattern of Kalam.

The graph clearly mentions that the peak of discharge is achieved during the months of June and July up to 360 m^3/s and falls down in the winter season especially in January and February where there is high snow fall causing decrease in river flow. However, discharge in Chakdara like Kalam (Lat=35.50, Long=72.59) station greatly increases in June up to 600 m3/s (Figure 7) which is mainly due to the snow melt in the up streams areas and like Kalam it also decreases even below 100 m3/s in the winter season.

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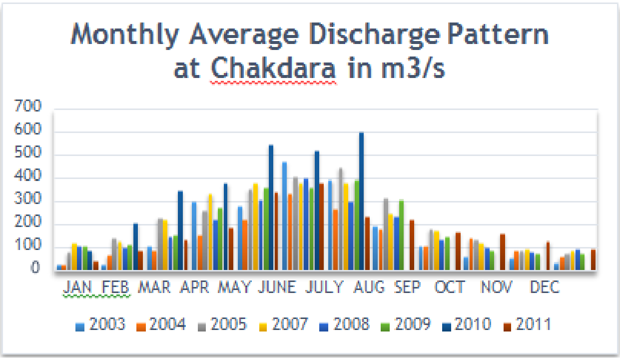

Figure 7: Discharge pattern of Chakdara.

The 8 years average rainfall pattern shows that the average rain increases in the month of June when heavy rain fall occurs during monsoon season up to 320 mm and decreases in months of december to even less than 100 mm (Figure 8).

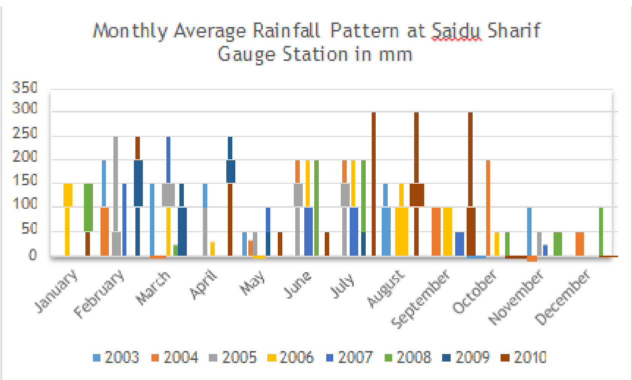

Figure 8: Rainfall pattern of saidu Sharif.

In Kalam mainly high precipitation occurs in winter that is in January and February up to 320 mm (Figure 9) and very minimum in the summer season that in term causes the melting of snow and increase in discharge in months of June and July.

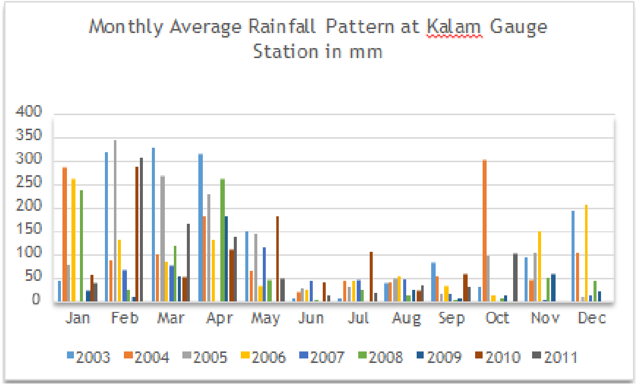

Figure 9: Rainfall pattern at Kalam.

So the discharge and precipitation data depicts that high rainfall occurs in downstream areas in summer season accompanied by high snow melt in the upstream areas that in turns enhances the flow greatly but the opposite scenario occurs in the winter season. While summarizing the patterns the swat river holds sufficient rainfall as well as river discharge that greatly enhanced in the summer season accompanied by monsoon rain falls and the river has a great capability for carrying out multipurpose dam construction on it and there is a requirement of water storage in this area for seasons of low flow/ discharge.

The initial water shed assessment phase was carried out by using ArcGIS hydrology/ArcHydro tools. While assessing the watershed, first of all, Fill sink tool was applied on the resampled projected dam of Swat in order to remove any sinks present in the dam to make it depression less. The following flow chart depicts the basic hydrological analysis carried out on the depression less DEM of Swat (Figure 10).

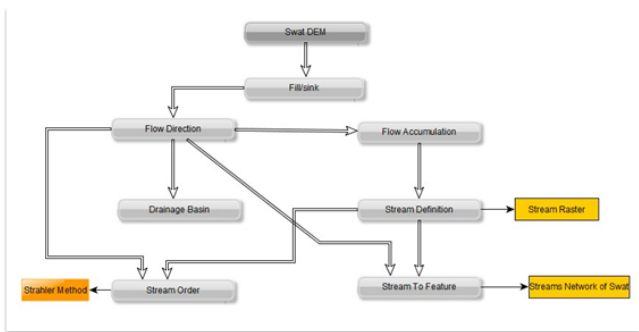

Figure 10: Initial hydrological assessment chart.

Declaring the criterion maps and reclassification: In multi criteria analysis, for dam construction, in literature different people have proposed different factors like flow characteristics, indices of flow as well as human disruptions, flood frequencies, peak average and annual discharges but now a days there is a requirement of a multi vitiate approach [8,9]. In addition to that the different terrain param like that is elevation, slope stability; geology acts as basic key for dams construction as well as their economic viability [5]. Hence, followings are one of the most important criteria involved:

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- Site geology and soil data
- Flow and discharge
- Slope stability
- Terrain smoothness for reservoir
- Elevation
- Vegetation covers for soil erosion

The criterion maps used in weighting were standardized by reclassifying into three classes from 1 to 2 to 3 that is best to medium to worst.

Site geology and soil conditions greatly affect the dam construction parameter [5] but for the Swat river, the soil data was not available as well as the geological data that was available in the form of geological rocks/minerals were interpreted into main rock types i.e., metamorphic, plutonic igneous rocks, volcanic igneous rocks and meta-sedimentary rocks by studying their detailed description with the legends of the geological map of North Pakistan and after that detailed description was searched in online resources to categorize them into these basic rock categories.

As the geology suggests that all of the rocks were stable and hard i.e., there were no sedimentary rocks which are basically unstable rocks and hence not suitable for dams. Hence they were not included in the weighted overlay because nearly whole Swat area had stable rocks geology (Figure 11).

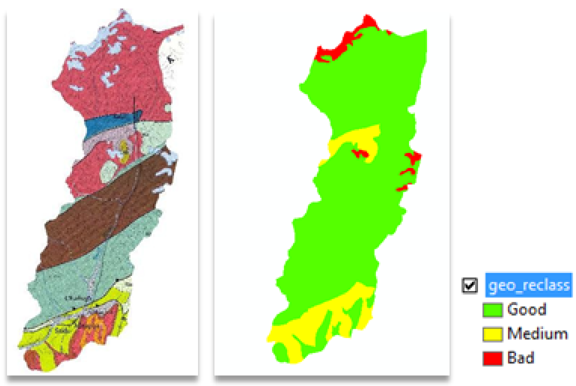

Figure 11: Scanned swat geological map and digitized (reclassified map).

However, the geological layer was reclassified as good for igneous and metamorphic rocks medium for meta-sedimentary and bad for glaciers and this reclassified layer was used along with vegetation cover as a secondary criteria.

Second criteria defined as the flow and discharge data. As dam is most appropriately generated at tertiary streams by (Strahler method) that have high flow. The flow accumulation as well as stream order could be used as criteria. As Padmavathy et al. [3] utilized the stream ordering and using the tertiary streams as a proposed site for dam construction.

There was a problem occurring with stream order that it gives only a linear series of selected pixels of flow that create problem in the weighted overlay tool for computing the dam zone moreover high flow is always on tertiary streams so flow accumulation map was used instead of stream order map.

The Strahler method is effective as it takes the small tributaries and makes them as order 1 i.e., primary and increases their order when two same order streams meet each other and the resulting stream is numbered as 2 and so on as shown in figure below (Figures 12-14).

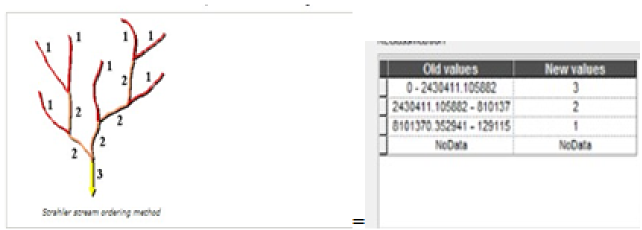

Figure 12: The Strahler method showing small tributaries and order values.

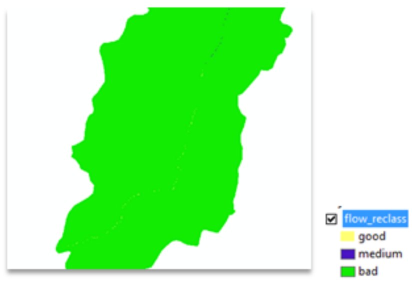

Figure 13: Streams order by Strahler method and reclassification of flow accumulation based upon natural breaks.

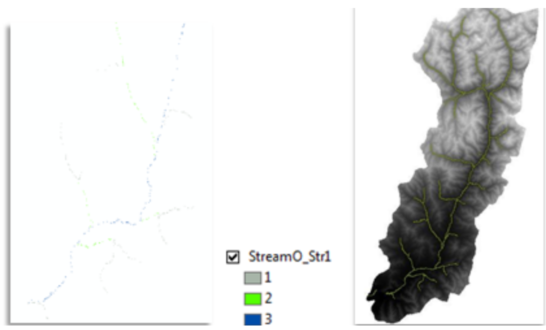

Figure 14: Flow accumulation and respective stream order and streams network of swat.

Thirdly slope stability Sachpazis [10] is the main concern for stability analysis of slopes as well as studying the soil param. For slope stability the slope greater than 15° is strongly avoided because it is not suitable for building satisfactory wall (Figure 15). Ahmad et al. [11] classified Slope into three categories:

Stable (0-15 degrees)

Medium (15-30 degrees)

Low (>30 degrees)

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Then the slope was reclassified into a standard scale from 1 to 3 from best to worst.

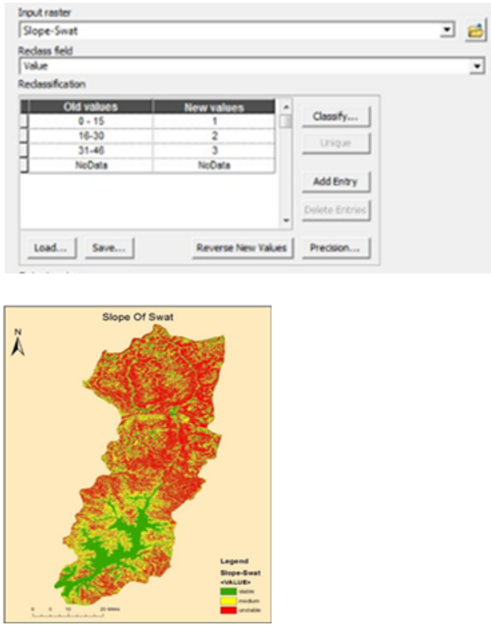

Figure 15: Reclassified slope.

The next criteria was TRI terrain roughness/ruggedness index the TRI is the first basic factor for management of watersheds as well as influences the different factors like gravity and movement of water in the catchment area and most of the times incorporated in the modelling in flow paths of the river's runoff [12]. As well as the ruggedness index is very vital to manage and analyze the natural resources [13].

TRI was computed using the method proposed by Riley et al. [14] by first creating the two raster. Min DEM was computed by the minimum value from 3 × 3 neighborhood using Focal statistics toolset.

Max DEM which is computed by the maximum value from 3 × 3 neighborhood using Focal statistics toolset (Figures 16-18). And then, using these two Dems in this formula in Raster Calculator:

Square root (Abs (square ("dem_max")-square ("DEM_Min")))

Then the computed TRI was classified by Riley into

Level=0-80 m

Nearly level=81-116 m

Slightly rugged=117-161 m

Intermediately rugged=162-239 m

Moderately rugged=240-497 m

Highly rugged=498-958 m

Extremely rugged=959-4367 m

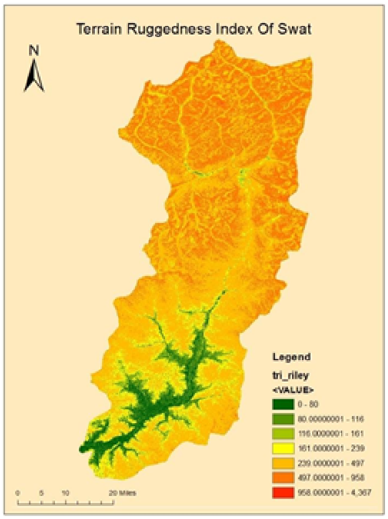

Figure 16: Terrain ruggedness index.

TRI was reclassified as: Good=0-116 m, medium=117-497 m, worst ≥ 497 m

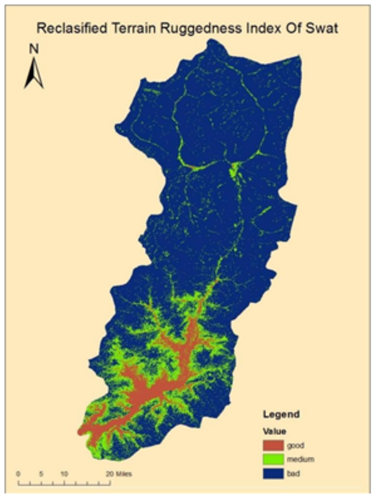

Figure 17: Reclassified slope.

As Elevation along with slope stability is a key factor for dam construction [5]. Hence, the last primary criteria used for multi criteria analysis was the DEM itself as the dam site should be on lower elevation to capture maximum flow from the catchment area, but it's not always necessary, hence, it was the least important criteria.

The Elevation layer was reclassified into natural breaks into 3 classes from min to maximum elevation as 1 to 3.

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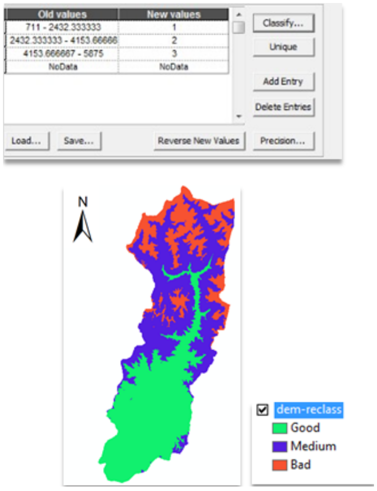

Figure 18: Reclassified DEM.

Vegetation is very important for the dams construction especially in terms of normalized Difference Vegetation Index (NDVI) greatly helps to understand the zones where soil having capability of storing or carrying water in it [15] (Table 2).

In addition to that landslides are also very frequently related with dam site construction that may induce landslides floods.

But by the use of remote sensing techniques it has been made easier the landslides hazard management to provide real time information and provides ability to analyze the information and inaccessibility problems over large areas [16].

Moreover soil erosion or mass wasting that is normally derived from landslides. Holben proposed the NDVI values (Figure 19) for various cover types as:

Cover Type	RED	NIR	NDVI
Dense vegetation	0.1	0.5	0.7
Dry Bare Soil	0.269	0.283	0.025
Clouds	0.227	0.228	0.002
Snow and Ice	0.375	0.342	-0.046
Water	0.022	0.013	-0.257

Table 2: Representing the optimum NDVI values for different cover types.

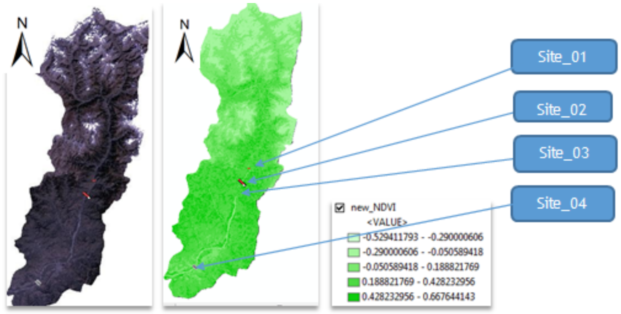

Figure 19: Original Landsat Image NDVI image values and sites that were proposed.

For dams site selection the criteria vary based upon the area as well as the economic and social param hence to reduce (Figure 20) the complexity weights of criterion maps were computed using Pairwise comparison method proposed by Saaty [17].

Intensity of importance	Definition
1	Equal Importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong to extremely strong importance
9	Extreme importance

Figure 20: Scales of importance.

The Criteria in decreasing order of importance:

- Flow
- Geology
- Slope
- TRI
- Land Use
- Elevation

Reason for excluding vegetation and geology from weighted overlay:

The Geology data was mainly of the metamorphic rocks and igneous rocks and are reclassified as "good for dams" described earlier so their inclusion in the Multi criteria analysis caused a high suitable zone in the output weighted map even away from dams site zone as they have high weight of importance. While regarding vegetation cover it was included as secondary criteria on the selected dam zone computed from Multi criteria Analysis (Tables 3-5).

Criterion Maps	Flow	Slope	TRI	DEM
Flow	1	4	3	5
Slope	1/4	1	2	3
TRI	1/3	1/2	1	2

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DEM	1/5	1/3	1/2	1
Sum of column	1.78	5.83	6.5	11

Table 3: Depicting the comparison matrix.

Criterion maps	Flow	Slope	TRI	DEM	Average of row (weight)
Flow	0.561	0.686	0.4615	0.4545	2.163/4=0.54
Slope	0.1404	0.1715	0.307	0.2727	0.8916/4=0.229
TRI	0.1853	0.0857	0.1538	0.1818	0.6066/4=0.15165
DEM	0.112	0.05	0.07	0.0909	0.3222/4=0.083

Table 4: Estimation of weights.

Criterion maps	Flow	Slope	TRI	DEM	
Flow	0.54*1	0.229*4	0.156*3	0.0839*5	2.345/0.54=4.34
Slope	0.54*0.25	0.2291	0.156*2	0.0839*3	0.9287/0.225=4.127
TRI	0.54*0.33	0.229*1/2	0.156*1	0.0839*2	0.4764/0.1565=4.15
DEM	0.54*0.2	0.229*1/3	0.156*1/2	0.0839*1	0.34585/0.0831=4.16

Table 5: Consistency ratio.

The value of lambda=4.34+4.127+4.15+4.16/n=4.19 where n=number of criteria used.

According to this method the value of lambda should be greater than number of criteria i.e., 4.19>4.

Computation of consistency index: CI=lambda-n/n-1=4.19-4/4-1=0.063

Computation of consistency Ratio CR: CR=CI/RI=0.063/0.91=0.0692 where 0.91 is from above table as criteria are 4.

Where RI is random index provided by Saaty [17] (Table 6).

Saaty stated that if CR<0.1 then there exists the consistency among the criteria. Hence,

Weight of flow is 0.54 i.e., 54%,

Weight of slope is 0.23 i.e., 23%,

Weight of TRI is 0.15 i.e., 15%,

Weight of elevation is 0.08 i.e., 8%

n	RI
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Table 6: Consistency ratio values.

After estimating the weights of different criterion maps these weights were assigned to the weighted overlay tool to compute the (Figure 21) dam zone.

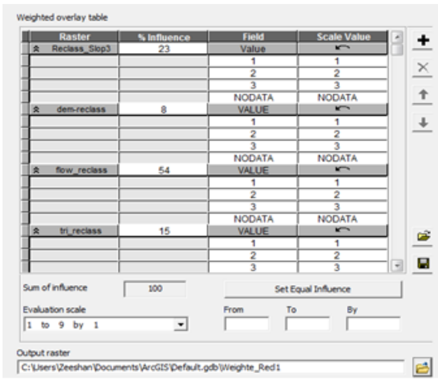

Figure 21: Showing the assigned weights to the primary criterion maps.

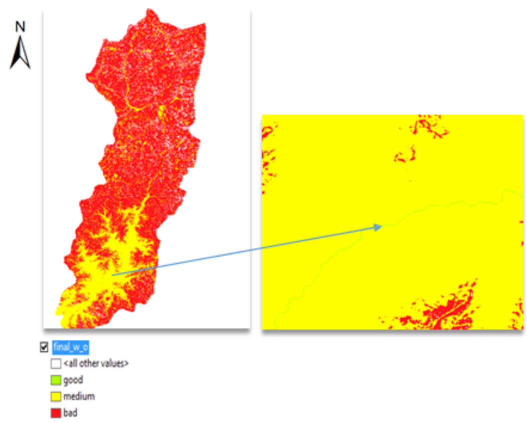

Figure 22: Showing the computed dam zone.

Green zone shows the best location for snapping the pour points

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Identification of potential dams sites: The dam zone that was computed in as good has optimum flow, slope, terrain roughness and elevation.

Now in this good zone computed from weighted overlay tool 4 sites for dam construction were selected based upon the following three further param.

Four sites were proposed as formation of a valley shaped is appropriately achieved so as to minimize the cost of dam wall construction, the geological factor already mentioned was suitable in the overall area. Secondly, the land use factor that was least in the site 1 and site 2 and 3 but was considerable for site 4 as it was closer to the Mingora district.

So using these above criteria four dam zones with dam walls were selected as the distribution of contours in all of these 4 identified sites is closer to each other very effectively that corresponds to the formation of a natural valley for dam construction.

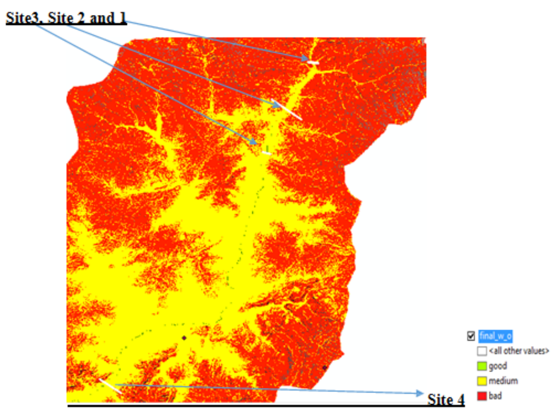

Figure 23: Depicting the selected dams zones with dam walls.

The distribution of contours in all of these 4 identified sites is closer to each other very effectively that corresponds to the formation of a natural valley for dam construction.

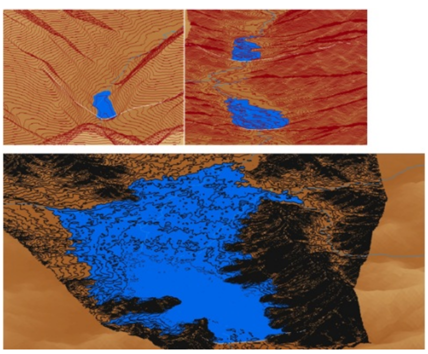

Figure 24: Representation of identified dams sites based upon contours closeness.

Secondly the next step of assessment was the estimation of volume of reservoir using 3D analyst extension at these dam sites that is divided into three steps:

The reservoir volume is very necessary in order to compensate the droughts or irrigation requirements of the area. Hence the reservoir capacity should be such that it should not be too small and should not be two large that it could not be easily fulfilled [18,19].

Padmavathy et al. [3] proposed the selection of sites by using the natural closeness of contours so how effectively they form a natural valley.

For the upstream area near Kalam where the first dam site is being proposed here basically discharge is normally less or reaches to only 350 cubic m per second in July. Hence keeping the flow here this site is proposed as a debris dam by keeping minimum height of 20 m that is from surface of river having elevation of 1332 to the height of wall by selecting the contour of 1355th elevation.

In the Same manner the dam site 2 and 3 were also proposed as check dams to initially store some water in these preliminary reservoirs and hence for check dams the height was kept low 30 m for both site 2 and 3. The selected contour height for dam wall of site 2 was 1290 m i.e., 30 m high from the surface and for site 31220 m that was also 30 m high (Figures 22-27).

Now the main reservoir or dam site that is the site 4, it is located in the downstream area near Mingora district that is the actual proposed water reservoir as it carries highest catchment area. The height of Dam wall was kept 100 m high by selecting the contour of 920 m elevation in order to capture the maximum water as the discharge and rainfall pattern suggests that the flow (in Chakdara that is the closer to this dam site) goes up to 600 m cube per second in summer season. Hence this site carries the greatest capability to harvest the rainy and flow water for the power generation purposes and the agricultural drives.

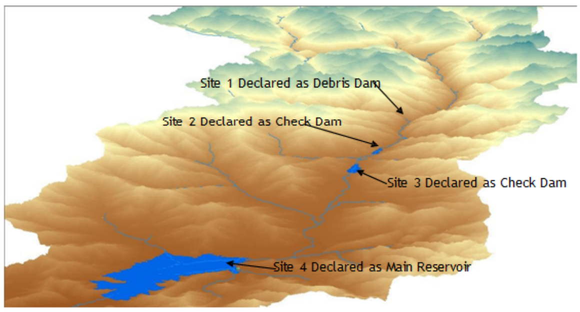

Figure 25: Depicting the selected reservoirs and their operational purposes.

After selecting the contours these contours were closed and converted to polygons by feature to polygon tool. Based upon the contours of the sites triangulated irregular network layers were generated using ArcGIS 3D Analyst Extension.

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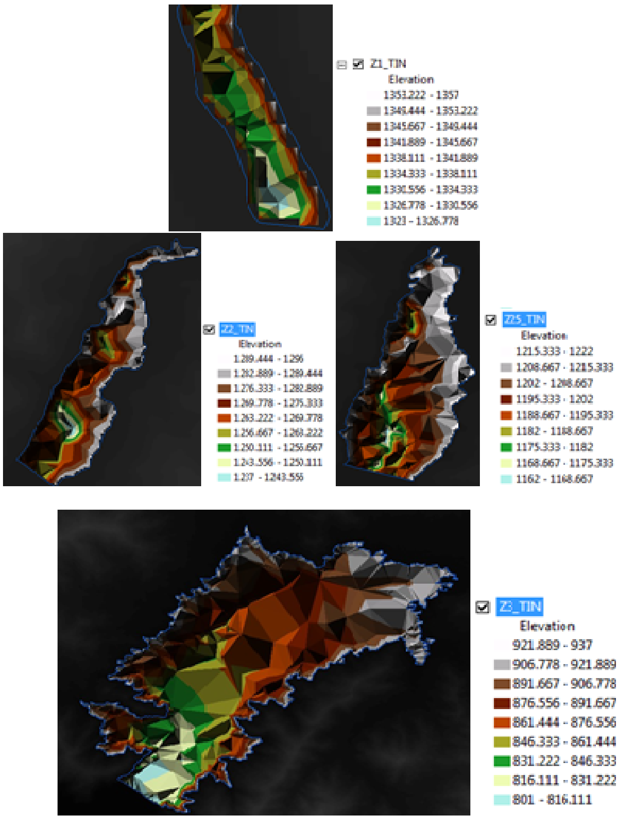

Figure 26: Depicting the generated TIN layer and reservoirs of four dams sites 1, 2, 3 and 4.

The generated TIN and the contour polygon were used to compute the reservoirs volume using 3D analyst -> polygon volume tool and the computed volume for dam site 1 was 670932.70934 m^3.

Z1_poly

FID	Shape	Id	height	Volume	SArea
0	Polygon	0	1350	670932.70934	80968.846153

Z2_poly

FID	Shape	Id	height	Volume	SArea
0	Polygon	0	1290	16974427.405	1145660.15925

Z25_Poly

FID	Shape	Id	Volume	SArea	height
0	Polygon	0	44645527.39	2450304.08893	1220

Z3_Poly

FID	Shape	Id	height	Volume	SArea
0	Polygon	0	920	2613924342.68	62271423.0722

Figure 27: Volume for sites 1, 2, 3 and site 4 respectively.

Results and Discussion

The selected three sites were assessed based upon the different following parameters (Table 7).

Parameters	Streams order	Slope	TRI	Vegetation cover	Finalized weighted map	Dam type	Degree of contours closeness
Site 1	Tertiary	~15	Slightly rugged	High	Good Class	Debris Dam	Highly Closed contours forming perfect V shaped Valley
Site 2	Tertiary	<15	Nearly Level	High vegetative cover	Good Class	Check Dam	Optimally closed contours
Site 3	Tertiary	<15	Nearly Level	Medium	Good Class	Check Dam	Optimally Closed
Site 4	Tertiary	<15	Level	Medium	Good Class	Hydro Power	Contours are closed to some extent but incorporating large flood plain
Parameters	**Volumetric capacity (hm)**	**Surface area (m^2)**	**Geological stability**	**Economic feasibility**			
Site 1	67.0932	80968.84615	Stable zone	Highly Economical			
Site 2	1697.4427	1145660.159	Stable Zone	Low cost			
Site 3	4464.5527	2450304.089	Stable Zone	Low cost			

Site 4	261392.4343	62271423.07	Stable Zone	High Cost			

Table 7: The Assessed Results of Selected Sites based upon the criterion maps.

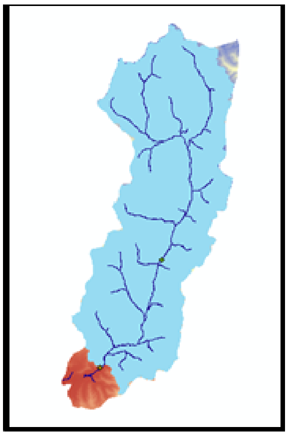

Figure 28: Watershed area of the main reservoir.

While discussing the results the first site has been nominated as a Debris dam that is a small reservoir and small catchment area but based upon the flow in that upstream portion can have capacity to accumulate the sediments and the debris flows in case of any mud flows or mass wasting. Similarly the second and the third dam sites are normally have sufficient volumetric capacity and are utilized as check dams because their optimum volumetric capacity makes them able to store considerable amount of water as well as to cater for the mud flows accompanied by the storing the excessive sediments (Figure 28).

So the Construction of 3 preliminary small reservoirs not only be utilized for initial storage of water but also will capture the excessive sediments that in turn would greatly enhance the life period of the actual Water Reservoir that is proposed as dam site 4. In addition to that the cleaning or removal of sediments from these first three reservoirs with regular time period would also be very economical.

The last suitable dam site i.e., site 4 is situated at the downstream area where the swat valley ends up by the facilitation of good hydraulic head and construction of turbines in the downstream plane areas of Chakdara. Additionally site 4 has very large reservoir capacity but while concerning its feasibility it requires huge construction cost over very large flood plain moreover as it is closer to the Mingora district so another constraint is the Urban Population of this area that needs to be adjusted or evacuated but it has the capability of accumulating water if water is initially stored in it for a longer period as well. Additionally another aspect of this site is that it has considerable head as the river comes out of the swat valley to supply accumulated and stored water to the downstream areas like Batkhela and Malakand Divisions [20-25].

Conclusions and Recommendations

The Dam sites selected could be effectively used for efficient storage of water especially in the winter season when the discharge decreases to very least extent. As well as the site 1 was very effective for construction of low cost dam with optimally used for cater of the mud flows. Similarly the second and the third dam sites would also play a role of check dams for initially storing the excessive water. Moreover the main reservoir is situated near Mingora and facilitates good hydraulic Head for the downstream plane are as the Swat valley ends up here hence would facilitate high power generation and agricultural and irrigation purposes.

Recommendations include the incorporation of High Resolution DEM to enhance the accuracy of results. Moreover highly precise Geological Faults as well as Formations are also required. For effective planning of dams construction the rain fall and discharge data should be of past 30 years. As Land use factor is also very important regarding evacuation and re adjustment of population for dams construction so for land use high resolution satellite imagery either IKONOS or QUICK BIRD should be used. In addition to that the incorporation of soil maps in order to ensure the soil stability for construction of dams is also recommended for the future studies.

The flood of 2010 is one of the examples of the past floods in the Swat Valley. Hence, there is a need of effective hydrological modeling to compute the maximum inundated area especially in case of any breakage in dam's structure or if flow enhances the maximum reservoir capacity.

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