Use of GIS for Small-Scale Hydropower Development in Tajikistan

Yvo Weidmann
GeoIdee.ch, TJ-734003 Dushanbe, yweidmann@yahoo.com
Cliff Hammer
Ernst Basler + Partner Ltd., CH-8702 Zollikon, cliff.hammer@ebp.ch

Abstract

A reliable year-round energy supply is a precondition for economic development. Without such provision, Tajikistan will remain unattractive to investors operating in sectors such as manufacturing, technology, and value-added processing. Considering Tajikistan's ample water resources, the development of small-scale hydropower plants (SSHP) (500 kW – 10 MW) is considered essential for establishing a sustainable local economy in the country. In order for investors to engage in Tajikistan's small-scale hydropower sector, however, several steps have to be undertaken, which include: 1) the creation of an attractive and stable market environment; 2) the establishment of a transparent regulatory and commercial framework; and 3) the development of a readily accessible knowledge-base facilitating planning and construction of small scale hydropower plants (SSHP).

Within this project, a Geographical Information Systems (GIS) was applied for several different purposes. The most basic task was to put the existing and potential hydropower schemes into a geographical context i.e. georeferencing the basic scheme components such as intake, headrace channel, powerhouse etc. For each site, based on a digital ASTER terrain model, the catchment and its characteristic parameters including size, glacier coverage, exposition and altitude distribution was derived. The same geo-analysis was conducted for selected hydrological observation stations for which aggregated historic mean monthly discharge data were available. Comparative catchment analysis allowed indicative run-off estimates at the ungauged potential hydropower sites. GIS was furthermore used to assess the feasibility and resulting construction cost of the potential sites. Relevant factors include potential gradient, distance to access roads and to the closest electrical grid uplink. The visualization of the schemes in GoogleEarth allowed remote initial assessments of the sites regarding natural hazards (landslides, avalanches etc.) and potential water user conflicts.

Keywords: GIS, hydropower, geoprocessing, geodata

1. Approach and Screening Methodology

A transparent evaluation method was developed in order to screen and subsequently rank the sites of small scale hydropower plants (SSHP).

Two databases were developed, 1) a relational database containing characteristics for each SSHP, and 2) a geodata base managed in a GIS. For the overall assessment the two databases were used in combination.

Parameters to be check included data availability, optimal overall potential harnessing, importance for the energy sector, technical risks, environmental and social impact, and statistically derived standard generation cost per kilowatt-hour. The method applied is based on archive data therefore doesn't need preceding visits of possible sites and planning works.

2. Build-up of the SSHP Data Base

The management of SSHP site specific information has to be organized in a way which allows to easily obtain information, conducting further analysis and to establish a connection to the spatial information hosted in a GIS. The implemented data management for the site data was organized and managed in two ways:

- Electronic site library including photos, sketches, previous documentations, etc.
- Microsoft Access database (in English and Russian language)

The Access database was designed in order to break down the broad spectrum of aspects relevant for an initial site assessment in a structured manner. The database contains a total of 70 attributes grouped in the following categories:

- Identification of the sites (name, location, owner, …)
- Hydropower plant data (head height, operation mode, capacity, …)
- Electricity generation cost
- Investment cost
- Tariff (only for sites in operation)
- Site conditions (natural hazards, ground stability, …)
- Site hydrology (mean run-off, run-off characteristics, type of catchment, …)
- Site development/access (road access, nearest distance to electrical grid, …)
- Environmental and social impact (protected areas, user conflicts, fishing, ..)

Each SSHP owns an unique identifier. This identifier is used to connect the data base entries to the GIS.

The data was collected and entered by a group of engineers and environmental specialist and consists of archive data and information provided by different governmental bodies of Tajikistan. For several sites, field visits were conducted to check existing or to collect missing data. Information such as altitude, catchment characteristics and locations were derived or cross-check by using the GIS.

Data shortcomings are critical and affected the quality of the SSHP site assessment. Especially the hydrological data are partly not reliable. The hydrological network covers primarily large rivers, smaller mountainous tributary streams are generally not gauged. The same applies for irrigation systems. The quality of the data is further affected by outdated equipment and lack of trained specialists responsible for data collection, processing and assessment. Data collected during Soviet-times is, if at all only available in analog (printed or handwritten) format. Such data was used for sites without nearby gauging stations, but its reliability is considered doubtable. Crosschecking with a simplified hydrologic model set up in the GIS underline the concerns.

3. Build-up of the Hydropower GIS System

The elaboration and use of a comprehensive GIS system in the hydropower sector for data visualization, information exchange, quality control and analysis has never been done in Tajikistan. The build-up and maintenance of such as hydropower data management system will be in future an important aspect for sustainable development of the hydropower sector, especially when considering attracting different investors including private ones. The GIS system in this project was established with the following primary aims:

- Visualization of spatial data relevant for decision making
- Common knowledge base for local and international experts and decision makers
- Spatial data analysis
- Third party data verification
- Development of scenarios for water availability and impact of climate change

3.1 Data sets implemented in the GIS

In Tajikistan, the use of GIS and accordingly spatial data availability is currently still very limited. The international donor community (in particular UNDP, European Commission, Swiss Development Cooperation and recently World Bank and Asian Development Bank) has undertaken efforts in preparing GIS-data and in defining data standards. Further, data was and is prepared by NGO's and international academia programs. Overall coordination is however lacking. Different activities on the part of UNDP were undertaken, but until today no common database or data gateway has been established.

The here presented project thus had to undertake a significant effort to collect GIS base data suitable for hydropower assessments covering all of Tajikistan. . Additional geodata sets were established focusing on the SSHP catchments only. Thus, the geodata sets can be divided into two groups:

- Base Data Set (all of Tajikistan): Collection of general topographical and physical data.
- Thematic Data Sets (SSHP catchments): Collection of data specifically used in the field of hydropower.

Base Data Set: The collection of topographical and physical base information was building the fundament for all further assessments regarding the location and specification of possible sites for SSHP's. All data were assembled into a file-based system. Main use of these data was the cartographical background information, input data for geoprocessing such as catchment calculation or population density nearby SSHP sites and cross-check / validation of third parties data.

Table 1: Short description of layers of the Base Data Set

Layer	Description
Topographical maps	Full coverage of Tajikistan by georeferenced and seamless Russian topographical maps at scales of 1:50 000, 1:100 000, 1:200 000 and 1:500 000. Full coverage of Tajikistan by maps of Orell Füessli Kartographie AG[1] at the scales of 1:500 000 and 1:800 000.
Digital terrain model	Digital elevation model (DEM) based on the imagery of the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER). It reflects approximately the level of detail of the topographical maps 1:200 000. Additionally the derived data such as slope and aspect were used for characterizing individual catchment areas of SSHP's or hydrological observation stations.
Glacier coverage	Vector layer based on Russian topographical maps and updated using up-to-date satellite imagery compiled by Orell Füessli Kartographie AG.
Topographic vector base data	Full coverage of Tajikistan digitized base layers from Russian topographical maps at 1:200 000 such as roads, rivers, lakes, contours, settlements.
Population	Full coverage of Tajikistan of the LandScan[TM2] 2008 dataset. This data set provides a pixel-based estimation of the population density.

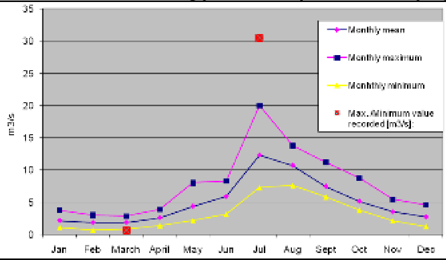
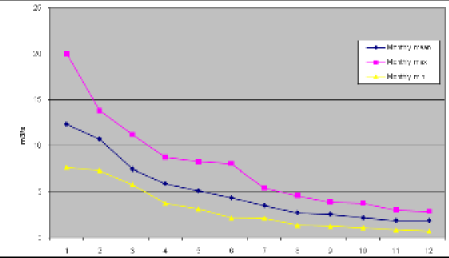
Additionally full coverage of Tajikistan by geological maps, protected areas and administrative boundaries are included in the Base Data Set.

[1] Orell Füessli Kartographie AG, Switzerland, www.orellkarto.ch
[2] LandScanTM, www.ornl.gov/sci/landscan/

Thematic Data Set: Thematic data sets were compiled based on the assessments for the individual SSHP sites and based on the availability of hydrological and meteorological data. These data sets and the derived information per site were used as input into the ranking system of the sites.

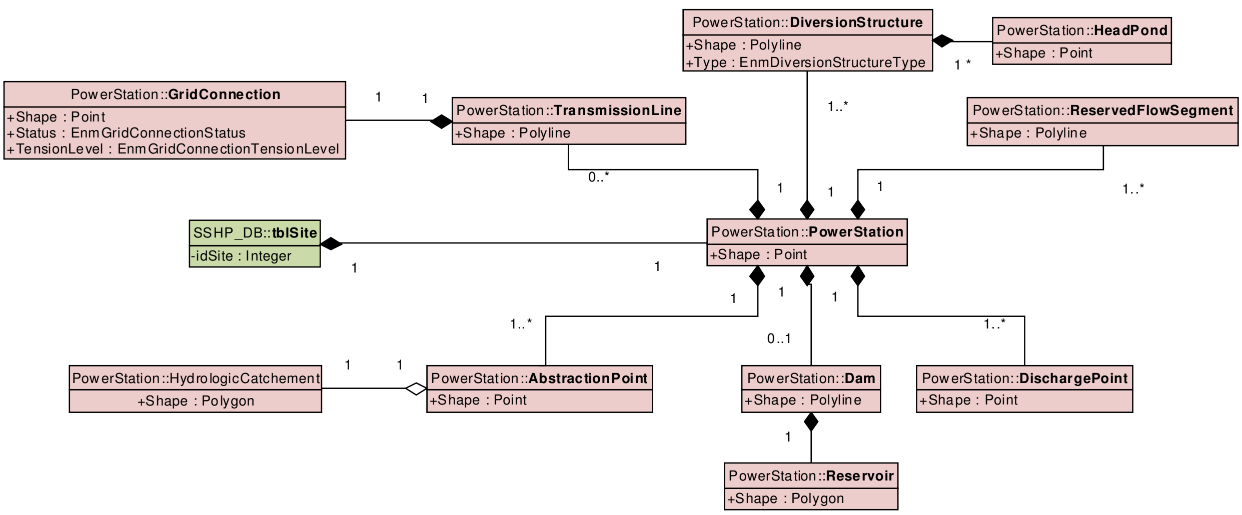
Table 2: Short description of layers of the Thematic Data Set

Layer	Description
SSHP scheme data	Scheme data of 46 potential SSHP sites including location of proposed intake structure, dam, headrace, power house, trail race, discharge point, depleted reach, transmission lines and link to existing grid. The individual sites are linked by using unique identifier to the site data base. All attributes of the sites (about 70 attributes organized in 9 groups) are kept and maintained in the site data base. The detailed structure of the scheme data will be shown in Figure 1.
Transmission grid	High, medium and low voltage transmission grid in the vicinity of potential SSHP sites. The grid was digitized based on large format scans. The vector data of grid contains line features with the attributes of the capacity, voltage and transmission quality. Additionally the most important switch-yards are captured as point layer containing attributes about the capacity of the switch-yard.
Hydrologic catchments	Hydrologic catchments were calculated using the ASTER digital elevation model and derived topographic parameters of the catchments (minimal, maximal and mean elevation, range of elevation and standard deviation). Additionally the percentage of glacier cover and a classification of the altitude was derived from the ASTER DEM. Based on the glacier cover and the altitude classification the catchments can be divided into the three classes Rain, Rain / Snow, Snow / Glacier feed. The individual catchments were calculated for: • Each SSHP site • Hydrological observation stations
Meteorological network	Meteorological network of Tajikistan: All the stations were linked with long term precipitation measurements.

Layer	Description
Hydrometrical network	Hydrometrical network of Tajikistan: The hydrometrical stations which were used to derive run off estimation of the potential sites are linked to long term discharge observations. The long term discharge observations provide the monthly mean, maximum and minimum run-off at the gauging station. This data can be represented as discharge over the year from January to December (figure below left) or as a classified discharge (figure below right) for which the months are sorted based on the amount of discharge. Such a classified discharge allows an estimation of discharge at the gauging station for a certain amount of days per year (e.g. Q_{120} as the minimal discharge during 120 days of the year). The Q_x values are used for estimating the dimensioning of a SSHP and the electrical energy to be potentially generated.
	 
Approximate surface run-off	Approximate surface run-off layer for purposes of cross checking of the hydrometrical data.

The core data of the project is the data set of the individual SSHP sites. A SSHP can exist of an amount of numerous different components. A GIS data structure of 11 different classes, i.e. layers, was developed to reflect the possible setups of SSHP's. This data structure allows to represent the schemes of the SSHP in a level of detail which is sufficient for feasibility studies and preliminary assessments. A simple inheritance structure is used: All classes are inheriting from an abstract base class containing the unique key value as a public attribute. Based on this attribute all classes can be linked to the relational SSHP site data base.

Figure 1: Diagram of SSHP GIS data structure



In the center of the structure, a point layer with the localization of the individual power station represent the individual SSHP. The power house is chosen for geographical localization of the power station.

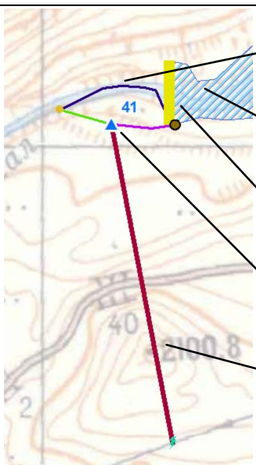
For representation of SSHPs at a scale of 1:50 000 the following information were chosen:

Table 3: Description of geometrical representation of a SSHP

Class / layer	Geometry type	Description
PowerStation	Point	Localization of the power house and turbines.
Abstraction Point	Point	Intake structure along the stream or reservoir which leads into the *DiversionStructure*. This point defines also the start of the *ReservedFlowSegment*.
Hydrological Catchement	Polygon	Each *AbstractionPoint* owns a *HydrologicalCatchement*. Depending of the scheme the *AbstractionPoint* can be far away from the *PowerStation*. For each *HydrologicalCatchement* the physical parameters such as mean altitude, attitude classes, type of hydrological regime are derived. Based on this information the discharge for not gauged catchments can be calculated.
Diversion Structure	Polyline	Linear elements between the *AbstractionPoint*, the *PowerStation* and *DischargePoint*. These elements are describing the technical approach to bring the water from the stream or reservoir to the turbines and back into the stream. The elements can be from different types such as headrace pipe, headrace channel, headrace tunnel, penstock and tailrace.
HeadPond	Point	*HeadPond* is a structures placed in between the *AbstractionPoint*, *DiversionStructure* and the *PowerStation*. It is designed to create a stronger water pressure on the low-head ground. The *HeadPond* is located at a certain altitude above the *PowerHouse* and delivers the water through a relatively short pipe onto the turbines.
DischargePoint	Point	Localization of the structure were the for power generation used water is getting back into the stream. The *DischargePoint* represents the end of the *DiversionStructure* and the *ReservedFlowSegment*.
ReservedFlow Segment	Polyline	Segment of the natural stream which will be affected by the use of water for power generation. This segment has to be well studied regarding the socio-economical and ecological impact of the planned SSHP.
Dam	Polyline	Possible dam construction in the case of a reservoir scheme.
Reservoir	Polygon	Approximated maximal extent of the reservoir caused by a *Dam*.
TransmissionLine	Polyline	Electrical line to transport the generated energy from the SSHP to the main grid.
GridConnection	Point	Connection of the *TransmissionLine* to the main grid.

The Figure 2 shows a simple SSHP scheme with a reservoir. In this case, only one stream will be used for power generation. The GIS data structure allows the use of several abstraction points in order of a optimal catchment harnessing. In case of a cascaded scheme design (several SSHP in a row) also several discharge points have to be included. The reserved flow segment covers always the section between the furthest upstream abstraction point and the furthest downstream discharge point.

Figure 2: Example of a simple SSHP site with dam



Reserved flow segment between the dam (or abstraction point) and discharge point. This segment is sensitive to any change in run-off (fishing, use for drinking water, ...) and can cause user-conflicts.
Dam and reservoir with maximum height. The catchment area is calculated from the upstream end of the reservoir during mean height. In river schemes the catchment starts at the abstraction point.
Abstraction point and the following diversion structure to the power house (penstock) and the tailrace leading to the discharge point.
Location of the planned power house and identifier of the SSHP site.
Connection to the main grid using a transmission line and connection point at the existing grid line.

4. Definition and Weighting of Selection Criteria

A ranking of each individual site was conducted based on the information stored in the SSHP relational data base, and the geographical information out of the base and thematic geo databases. Aim of the ranking method was to select most suitable SSHP sites for further investigations and possible investments. The ranking method applied was taking in account numerous criterions as shown in Table 4. To take into account the different needs for different sizes of SSHP's, the evaluation was implemented for 4 categories of projects:

- 10 – 30 MW
- 1 – 10 MW
- < 1 MW
- Rehabilitation and reactivation of existing SSHPs

Table 4: Weighting and selection criterions

Criterion	Explanation and remarks
Gross Head	Main cost driver: Economy of scale (e.g. ten times smaller power causes 50 to 100 % higher specific generation cost)
Gradient of water way (deviation gradient)	Second important cost driver: Economy of density of the energy resource (e.g. 10 time less gross head at same power causes 30 to 60 % higher generation cost)
Natural hazards	This criterion counts the mitigation cost for prevention and cost for insurances. (especially river hazards)
Climate change risks	Diminution of runoff / higher floods
Geology	Additional cost because of difficult geological conditions (all additional cost caused by non standard geol.)
Relative distance to grid	Cost for the feed-in line (distance relative to the installed power)
Relative distance to	Cost for access road and other transport cost

Criterion	Explanation and remarks
transport road	(distance relative to the installed power)
Environmental Impact	Costs for major environment mitigation and/or production losses because of unusual reserved flow beyond standard riparian flow according European state-of-the-art.
Social impact	Social impact can be positive or negative
Conflicts & synergies	Interference with existing in fracture, with projects, with competitive water use etc.
Optimal potential use	Evaluation with the goal of a (very long term) total use of the whole river basin potential
Construction difficulties	All cost drivers due to construction difficulties, which are not contained in the above criteria, especially tunnel cost & steep topography cost

Each criterion has a possible amount of scores (f_i). Several criterions are combined in groups of criterions (technical aspects, hydrological factors, environmental factors, …). Each group has a certain weight (p_j) with which the sum of the individual parameters were multiplied as shown in Equation 1.

Equation 1: Weighting and summarizing of criterions

$$\sum_{j=1}^{m}\left(\sum_{i=1}^{n} f_i\right)_j p_j$$

f	Factor derived from DB and / or GIS
p	Weight per Group of factors
i	Number of Factors
j	Number of Groups of Factors

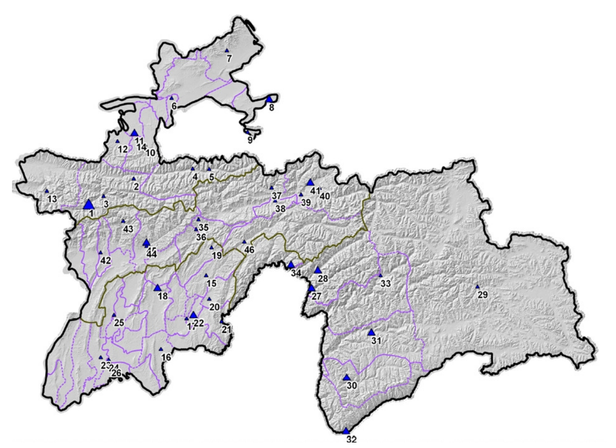
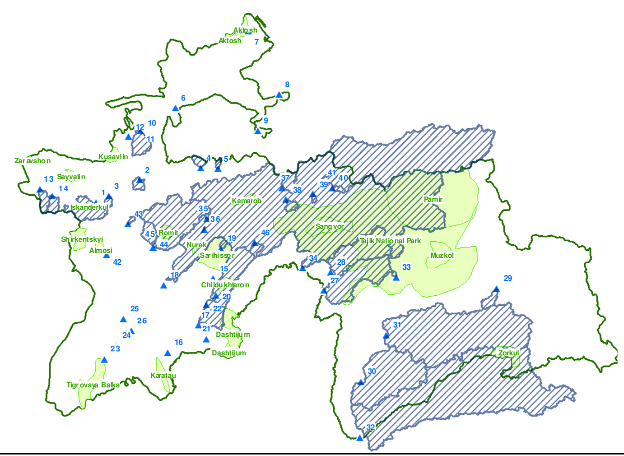
Appling Equation 1 for each individual site a ranking of possible sites for each of the 4 categories was obtained. Based on this ranking the best scoring SSHP sites were chosen for further investigation.

5. Results

The SSHP site database in combination with the collected and derived geodata provides an overall view on the situation of hydropower in Tajikistan. The data resulting out of the geoprocessing and analysis, such as catchments and hydrological regimes, building a solid base for further assessments. The site database can be used to include further projects and using the GIS database a standardized data assessment can be conducted. Such kind of standardized procedure provides a transparent way for judgment of possible SSHP sites.

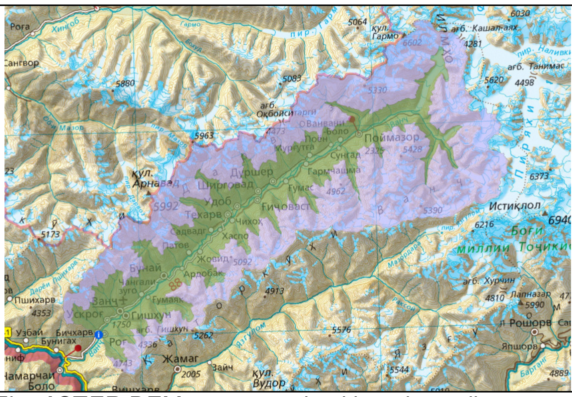
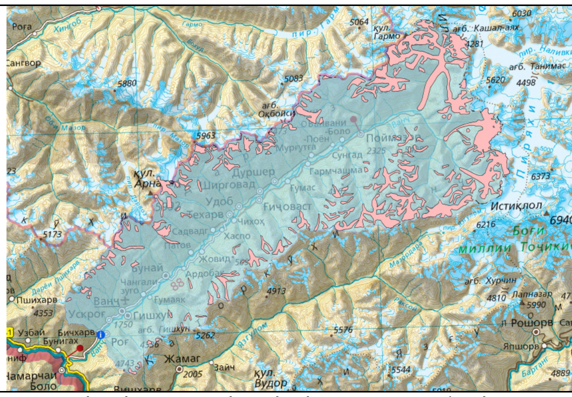
Figure 3 shows an example of a combination an overlay between SSHP schemes with the areas of natural protection. Such kind of qualitative overlays provides a quick assessment regarding possible conflicts with by law protected areas.

Figure 3: Location of possible SSHP sites and intersection with protected areas

	
Location of the proposed SSHP sites within Tajikistan divided into the three classes of electrical power generation < 1 MW (29 sites), 1 – 10 MW (15 sites) and 10 – 30 MW (2 sites).	Overlay of catchments of proposed SSHP sites (blue hatchures) and natural reserves or national parks (green polygons). The intersection between the SSHP schemes indicates possible conflicts with enverinmental protection.

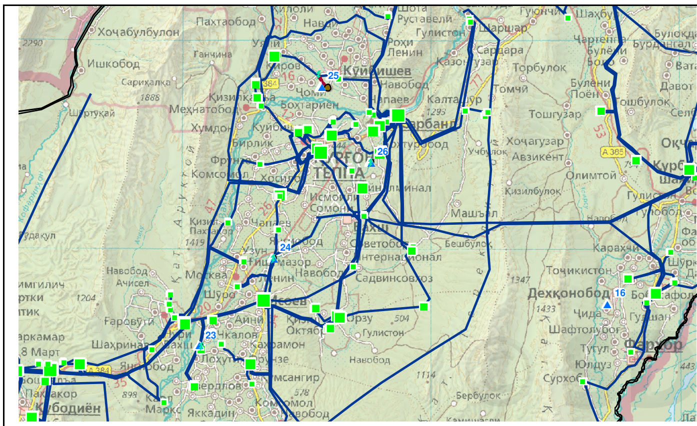
For each possible SSHP site and hydrological observation stations the catchment were calculated and intersected with altitude classes and the glacier coverage. This information influences the estimation of hydrological parameters such as run-off. These information can be used in next steps to optimize the calculation of ungauge catchments and for further tunings of the hydrological models applied. Regarding the effects of global climate change and the influence of these changes to the local climate these information provides a base for scenario calculations. Changes in glacier coverage and precipitation directly affects the hydrological regime and so the layout of SSHP schemes. Taking the long-term investment for a SSHP of > 20 years in account, such kind of scenarios have to be considered.

Figure 4: Determination of hydrological regime type based on altitude and glacier coverage

	
The ASTER DEM was sumarized into three discrete classes of areas < 1500 masl, 1500 – 3500 masl and > 3500 mas. An intersection between the catchment and the discrete altitude classes gives the percentage of altitude classes per catchment which is used for deriving the hydrological regime type.	Intersection between the glacier coverage (red polygons) and the catchment of a SSHP site (blue polygon). The intersection provides the procentual amount of glacier coverage within the catchment. The characteristics of run-off is highly influenced by the amount of glacier coverage.

Digitizing the main grid of Tajikistan was an important step for the estimation of the grid quality. The grid quality, stability, tension and the location of switch yards influences directly the construction of SSHP. Building connection infrastructure or support measures on the main grid providing an effective transportation of the energy from a SSHP increases the investment costs.

Figure 5: Determination of hydrological regime type based on altitude and glacier coverage

	High tension grid in the South-West of Tajikistan. The line width reflects the voltage (low, medium and high tension). The substations and switch yards are symbolised using green squares depending on the voltage handled. Additional information in kept in the database such as overall condition of the line. Using the spatial distance between a SSHP and a possible uplink to the main grid allows a more precisely cost estimation.

The GIS database focused on the need of SSHP engineering provides an integrated assessment tool for the estimation of investment costs and investment risks. The GIS has to be seen as a risk management tool for the private sector.

6. Conclusion

Despite the very weak baseline data, the application of a data base system for collecting information in combination with an extensive GIS for cross-checking and visualization of the data was successfully applied.

Applying a transparent and simple ranking methodology allowed an unbiased selection of possible SSHP sites. SSHP projects scoring high in the 4 different categories are highly recommended to be further developed. The established ranking method can be easily applied for further projects proposed by governmental or private organizations and companies. The ranking methodology using the groups of criterions allows further to conduct a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. This analysis can be used as an input in an iterative process of site development and optimal catchment harnessing.

Maintaining, further development and updating of the SSHP site database and the geodata will provide a very important source of information for any further investigation regarding hydropower in Tajikistan. Including information, such as overall investment costs or detailed hydrological and geological expertise, of SSHP construction accomplished will increase the value of the data collection.