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A Report on

Identification of Hydropower Potential sites using Geospatial Technology

Submitted by:

Anil Pangeni (BGE/071)

Pramod Devkota (BGE/071)

Pratichhya Sharma (BGE/071)

Rheecha Sharma (BGE/071)

Rupesh Bhandari (BGE/071)

Santosh Subedi (BGE/071)

Submitted to:

Department of Civil

and Geomatics Engineering

Supervisor

Dr. Krishna Prasad Bhandari

Er. Bikash Sherchan

ABSTRACT

Nepal has a huge hydropower potential. In fact, the abiding nature of Nepali rivers and the steep gradient of the country's topography provide ideal conditions for the development of some of the world's largest hydroelectric projects in Nepal. Determining the best possible sites for hydropower is a cardinal task for pursuing hydropower projects. Use of technology for this can help in many ways along with the reduction of manual errors. There is a need for an approach that can be used to access hydropower potential sites using Geospatial technology.

Our project fabricated a model by using geospatial technology that helps in determining the possible sites for hydropower projects based on multi parametric analysis around the Madi watershed. ASTER DEM of 30m resolution was used for carrying out hydrological assessment in GIS from which various factors that affect the site suitability was determined along with calculation of TRI. On the basis of the weightage given to the reclassified data for each parameter different possible site on the basis of their level of suitability was determined. After knowing the best possible sites for Madi water, a Geoprocessing model was prepared that could automate and document our spatial analysis and data management process in an easier manner. Our model assembled together sequences of processes and Geoprocessing tools where output of one process as the input to another process.

This project will aid decision makers in the energy sector to optimize the available resources in selecting the suitable sites for hydropower plant with higher power potential. The proposed approach can be further utilized to assess an overall hydropower potential of the country.

Keywords: Hydropower, Hydropower sites, Hydrological assessment, Geoprocessing, ASTER, TRI, model, Madi watershed

LIST OF ABBREVIATION

MT=	*mount*
MW=	*mega watt*
GPS=	*Global Positioning System*
RS=	*Remote Sensing*
GIS=	*Geographic Information System*
ASTER=	*Advanced Space borne Thermal Emission and Reflection Radiometer*
DEM=	*Digital Elevation Model*
EIA=	*Environmental Impact Analysis*
RHAM=	*Rapid Hydropower Assessment Model*
SHP=	*Small Hydro Power*
GSIS=	*Geo-spatial Information System*
Landsat=	*Land Satellite*
NDVI=	*Normalized Difference Vegetation Index*
AOI=	*Area of Interest*
TRI=	*Terrain Roughness Index*
SWAT=	*Soil and Water Assessment Tool*

GLOSSARY

untapped: not yet exploited or used

dismantle: take to pieces

exacerbate: make (a problem, bad situation, or negative feeling) worse.

aesthetic: concerned with beauty or the appreciation of beauty

delineate: indicate the exact position of (a border or boundary).

vigilant: keeping careful watch for possible danger or difficulties

tributaries: a river or stream flowing into a larger river or lake

morphometric: the quantitative analysis of form, a concept that encompasses size and shape

stagnant: showing no activity; dull and sluggish

INTRODUCTION

General Background

Hydroelectric power is environmentally friendly and completely free of emissions and waste products. Water is a renewable resource in its eternal cycle through precipitation, reservoir, power plant and evaporation and runoff. Hydropower is one of the oldest and purest forms of renewable energy we have, and a climate-friendly way to produce energy. This is because hydropower makes it possible to create electricity without fossil fuels such as coal or gas. The relatively long construction times of large stations are balanced by low long-term costs and a long lifespan, even up to 100 years. With proper planning and design, hydropower stations can also help to conserve water, irrigate and provide flood control. The major issue with hydroelectric power is the location of the reservoir; decisions must be backed by thorough and impartial Environmental Impact Assessments. Biodiversity must be considered since inappropriate placing and design can flood irreplaceable habitats and historical sites. Hydro is potentially the cheapest form of power available. Payback times, the most important measure of energy saving schemes, are good, and hydro is ideal for base load operation. The major negative effects of hydroelectric power are environmental (destruction of habitats) and social (forced displacement). Large dams raise underground water levels near the lake, which has large effect on the surrounding flora and fauna. Even for projects with reservoirs, there can be supply problems in summer when flow drops. There can be other problems with reservoirs themselves, not just with hydroelectric stations. The latter have been found to emit methane, which is a stronger and more dangerous greenhouse gas than carbon dioxide. This problem can be virtually eliminated at the design stage, since the gas can be trapped and used for power generation with suitable dam designs. One of the most complicated aspects of power sources, even renewable ones, is how to weigh up their environmental effects Hydro already generates around a fifth of the world's electricity, but this represents only a quarter of the world's hydro potential. China, Brazil, Russia, Canada and the US have the largest resources. Not all water sources are suitable, however, and developed countries such as the US, Japan, France and Germany have already exploited around three quarters of the available sources. Similarly, Norway, Iceland and Canada are already using hydro as a major power source.

More recently Nepal has preferred transmitting the electricity itself, small hydropower plants. Such a network is also handy for transmitting hydroelectric power. Nepal is therefore developing small hydropower plant power transmission lines. A Hydro is generally thought to be one of the most effective and lowest-cost renewable resources. Water is free, fairly dense and, left to its own devices, tends to flow downhill. The energy in water is proportional to the flow rate and the 'head' of falling water. Hydroelectric stations are either run-of-the-river, or have a dam and reservoir. Run-of-the-river types are easiest to build and have least environmental effect. They can be built on small diversion weirs, but mainly depend on constant and fast-flowing water flow. Large projects use a dam and reservoir to smooth out the effects of water level fluctuations throughout the year. Water flows through a channel called a penstock to the turbine (normally a Frances turbine), which spins to drive the generator. Water can be pumped up to the reservoir again during periods of low demand and be reused when needed.

Nepal has a huge hydropower potential. Although, Nepal is small landlocked country, it has got a tremendous geographical diversity as it rises from as low as 194ft (59 meters) elevation in Terai, to the perpetual snow line with 90peaks above 7000meters including the top of the world Mt. Everest located at the height of 8848m. In fact, the continuing nature of rivers in Nepal and topographical status provide ideal conditions for the development of some of the world's largest hydropower in Nepal. Current estimates are that Nepal has approximately 40,000 MW of economically feasible hydropower potential. However, the present situation is that Nepal has developed only approximately 600 MW of hydropower. More recently Nepal has preferred transmitting the electricity itself, small hydropower plants. Such a network is also handy for transmitting hydroelectric power. Nepal is therefore developing small hydropower plant power transmission lines. Therefore, bulk of the economically feasible generation has not been realized yet.

Geographic information system is a computer based information used to digitally represent and analyze the feature present on the earth's surface and the events taken place in it. Similarly, remote sensing is science and art of acquiring information about material objects area or phenomenon without coming into physical contact with the objects, area or phenomenon under investigation. The integrated approach of GPS and RS is being recognized universally as unique and highly effective and extremely versatile technology. Similarly, timely updated information about landscapes and water resource is key component for hydropower development. In conventional system the geospatial data are poorly maintained, maps and statists are not updated, accurate information may not be available, data sharing and removal are not easy.

Hydropower from large dams is estimated to contribute to 19% of world's total electricity supply (as opposed to total energy supply). Approximately one-third of the world depends on hydropower for over half of their electricity, and 24 of those countries rely on hydropower to supply nearly 90% of their total electricity supply (www.dams.org). The percentage of electricity from hydroelectricity is expects to fall to 16% by 2030, however, as coal and natural gas consumption grows at a much faster rate than hydropower and renewables (U.S. Government, 2007).

The reason why such little growth is projected for hydropower as a proportion of the earth's energy resources is due to the exhaustion of such of the developed world's hydroelectric resources. There are over 45,000 large dams, and 10s of 1000s of smaller dams built across the world. The few remaining untapped hydroelectric resources are primarily located in the tundra of Alaska, Canada, Russia, and in some of Latin American and Africa (Withgott & Brennan, p.446, 2007). Consider the United States in comparison, which has exhausted 98% of potential large hydropower plants in the country, while its remaining 2% go untouched due to the fact that they fall within wildlife protected areas. Other developed nations, such as Sweden and Norway, do not have much more they can or need to develop (Withgott & Brennan, p.615, 2007). For some regions, there is even a growing movement for the dismantling of hydropower plants due to their expiration, or the unwillingness of locals to bear the social and environmental cost for any longer. In the United States alone, 500 total dams have been removed, of which 200 of them were retired in the past decade (Withgott & Brennan, p.449, 2007).

The basic costs to consider in hydropower plant development are the costs to construct the dam, the costs to operate and maintain the facilities, and adverse impact to the economy (localized or beyond), including fishery and agriculture. Dam construction can be enormously capital intensive, such as Three Gorges Dam being constructed on the Yangtze

River in China, which is estimated to cost between $26 billion (Chinese estimate) to $50 billion ("Western" estimate) (Etzweiler et al., 2007). Further, unexpected costs must be considered. China, for instance, just recently had an additional, unexpected waste management cost of $5 billion (20% of the estimated cost of the project!). Costs such as these must be considered, because they may make or break the economic value of the project (Withgott & Brennan, p.447, 2007).

The economic benefits of a successfully managed hydropower project are plentiful. Besides the heavy capital needed to build a hydroelectric plant in the beginning, the facility runs almost independent of human or energy inputs, and thus enjoys a very low operating and production cost per kWh. Further, a hydroelectric facility has a lifespan of 50-100 years - which is beyond any fossil-fuel fired plant. This allows the project to a) be depreciated across a longer time period to boost accounting returns (in the case of a privately run hydropower plant), and b) the plant has a longer life to produce revenue (Etzweiler et al., 2007).

From an economic and strategic aspect, by harnessing natural hydropower, a country increases the degree of energy independence and diversifies away from the risk of increasing fossil fuel prices. Moreover, the storage ability of the dam allows energy production to be controlled on an at-need basis, and may also allow a country to manage water reserves for irrigation purposes or in a time of water scarcity (Etzweiler et al., 2007). Lastly, the increase in water levels behind the dam system may allow an expansion of shipping lanes, encouraging trade and the development of wealth (Withgott & Brennan, p.447, 2007).

Damming flows of water may lead to slow, or even stagnant water bodies, which decreases an ecosystem's ability to wash away waste (especially human waste). A dammed water flow may also prevent fertile silt from reaching downstream, and impact wildlife and agriculture downstream. Further, fish that swim upstream to spawn may be prevented from doing so, unless proper technology is in place for them to pass without the turbines turning them into sushi (a water "staircase" can be implemented around the sides of the dam). However, negative environmental impact is not limited to downstream; the vegetation engulfed by the dam's water reservoir decomposes and subsequently emits CO_2 and methane (CH_4) into the atmosphere, especially in warmer climates (Etzweiler et al., 2007).

When the waters subside, land that was previously underwater is now exposed to locals, who may wish to plant crops by the water; however, if a river is contaminated, these areas surrounding the river may become disease-infested and threaten the health of local populations. Another threat to local populations is in an instance of a natural disaster, such as an earthquake or landslide, that causes a large dam to crack and wash away human lives and infrastructure (Etzweiler et al., 2007).

While the social costs and benefits of hydropower significantly vary depending on the project's circumstances, all should be outlined and considered. In many circumstances, entire communities are forced to relocate due to flooding from a dam; it is estimated that between 40 - 80 million people have been displaced by damming (www.dams.org). For instance, the Three Gorges Dam project in China has led to the washing away of 22 cities and many smaller settlements, forcing a mass exodus of up to two million people (Withgott & Brennan, p.449, 2007). Due to displacement, or instead, a decrease in land resources due to flooding, unemployment or even social conflict might be the result (www.dams.org).

Flooding may also lead to the loss of an area's aesthetic appeal and part of its fauna diversity. In the case where communities are submerged, the consequence may also be a loss of cultural heritage (Etzweiler et al., 2007). The construction of the Three Gorges Dam, for instance, will lead to the loss of some towns and villages that have over 10,000 years of valuable, national history (Withgott & Brennan, p.447, 2007)

Even with such a negative social cost to damming for hydropower, in many instances, the social benefits may outweigh the costs. For instance, a dam for hydropower can also be used to contain spontaneous flooding that might otherwise have killed countless people, which had been an especially important consideration in the building of the Three Gorges Dam in China. It could also be used for reserves in case of drought, or controlled irrigation of crops so to help safeguard a community's or country's food supply like Egypt's Aswan dam (Etzweiler et al., 2007). Finally, new recreational opportunities abound in the reservoir system created by the dam; although this comes at the cost of recreational activities downstream) (Withgott & Brennan, p.447, 2007).

New, hydropower technologies in development may yield significant benefits over traditional hydropower technologies, namely, by mitigating the costs of traditional hydropower. Three new hydro technologies, run-of-river, free-standing turbines, and vortex turbines shine hope on the future of low-costs, high-benefit hydropower. However, run-of-river systems are not currently a significant hydropower resource, and both free-standing and vortex turbines are still in their infancy.

Run-of-river systems redirect part of a river's water through pipelines or other means to generate electricity via a turbine in a land-based powerhouse. This approach avoids the adverse effects of damming in the pursuit of electricity generation, however, it sacrifices the reliability of hydropower generation due to the lack of storage control that dams possess. Run-of-river dams may also be useful in areas beyond the main electrical grid, or for those without the means to build and maintain a dam (Withgott & Brennan, p.614, 2007).

Freestanding turbines are similar to run-of-river systems in the sense that they do not require damming either. Rather, as the name implies, the concept employees freestanding turbines in the middle of a stream, and can currently achieve around a 35% efficiency. Pilot studies are currently being tested around South Korea and North America (End of a dammed nuisance, 2008)

The conventional techniques of determining hydropower potential sites could be more difficult and costly and also might not directly adopt in the inaccessible areas where the water resources potential could be high. Similarly, consideration of other factors such as geology, precipitation, slope, land use, structural configuration is essential to study and to understand the strength and weakness of the area so that the project will be implemented in suitable terrain. Study of effects of all the factors and ranking of then in order to make optimal decision requires a lot of time in coordination of data from various departments and preparation of map of those updated information. Manually caring out the process is tedious and thus, geospatial technology can prove to be as backbone for carrying out the work in an effective manner. While concerning geographical information system (GIS) and the tools it incorporates, GIS could prove as a best attempt to select suitable sites for hydropower potential via GIS tools, hydrological investigation and multi parametric analysis for their potentialities. Hydrological investigation is done through Hydrological analysis in GIS.

The hydrologic modeling tools in the GIS Spatial Analyst extension toolbox provide methods for describing the physical components of a surface. The hydrologic tools allow you to identify sinks, determine flow direction, calculate flow accumulation, delineate watersheds, and create stream networks using ASTER DEM from Earth Explorer (here). It is possible to automatically delineate a drainage system and quantify the characteristics of the system and the direction in which water would flow out of each cell is determined.

Making decision in real world sometimes can complex because of the complexity of reality. One of the possible solution is Multi-Criteria Decision Making which refers to making decision in the presence of multi criteria that usually conflicting each other (Zavadskas et al.2014). The GIS tools also allows for working on satellite imagery to determine the land type and to work with precipitation data by based on its average precipitation value obtained from the Department of Meteorology and Hydrology.

Statement of Problem

Energy crisis has become a serious issue throughout the world in recent years. Nepal is facing a similar crisis which has resulted in frequent power facilities and loadshedding throughout the country for past few years. So this shows the requirement of hydropower plant that can provide with high power capacity. This could be possible when best site is selected. In the way to use technology to assist in suitable site determination a number of problems were encountered. Some are as listed below:

- Lack of availability of high resolution satellite images for data abstraction.
- Problems regarding location of project sites, project implementation and selection of beneficiaries' process.
- The project location is not so appropriated due to extension of rural electrification which is being run in the neighboring village so question may arise with its sustainability.

Rationale

A number of advantages can be listed that the community can be benefited from water power. Hydropower being clean and domestic source of energy is preferred in uplifting the standard of people in country. Especially, in the context of Nepal which is the second richest country in water resources in the world hydropower is of great importance.

Determination of potential sites for hydropower is the crucial task in hydropower establishment and need vigilant decisions. Human made decision are more prone to delusion so automation process is more preferred. Estimation of hydropower potential sites using geospatial technology has greater advantage than the conventional method.

This project in the context of Nepal can evince to be of great usefulness as it uses geospatial technology which is up-to-date and versatile technology. Our project provides a model that provides better understanding of the multi-parameters responsible for selection of sites and performs various hydrological assessment in an easy manner. Along with being more economical method, this method is elementary in achieving described objective.

Objective

This project has set some standard objectives. we have worked to obtain those objectives using different methods and procedure.

Major:

- To prepare a model that identifies potential sites for hydropower in the proposed area.
- To prepare a thematic map showing hydropower sites of hydropower on the basis of degree of suitability.

Minor:

- To perform hydrological analysis.
- To perform comparative analysis of potential sites on the and selection of the most suitable area.

Study Area

The study area lies in between latitudes 28°32´- 27°57´ and longitudes 84°00´-84°22´. Area of the study area is 1,111.470 km² covering few watersheds in the parts of Kaski, Lamjung, Tanahun Districts. The climate of the study area is characterized by a hot summer and heavy rain in the north-west during monsoon. October and November forms the post monsoon or transition period. The climatic condition ranges from subtropical in the south to alpine and artic in the north. Madi, Seti and Modi are three major glacier-fed river systems flowing in the district and they have several tributaries.

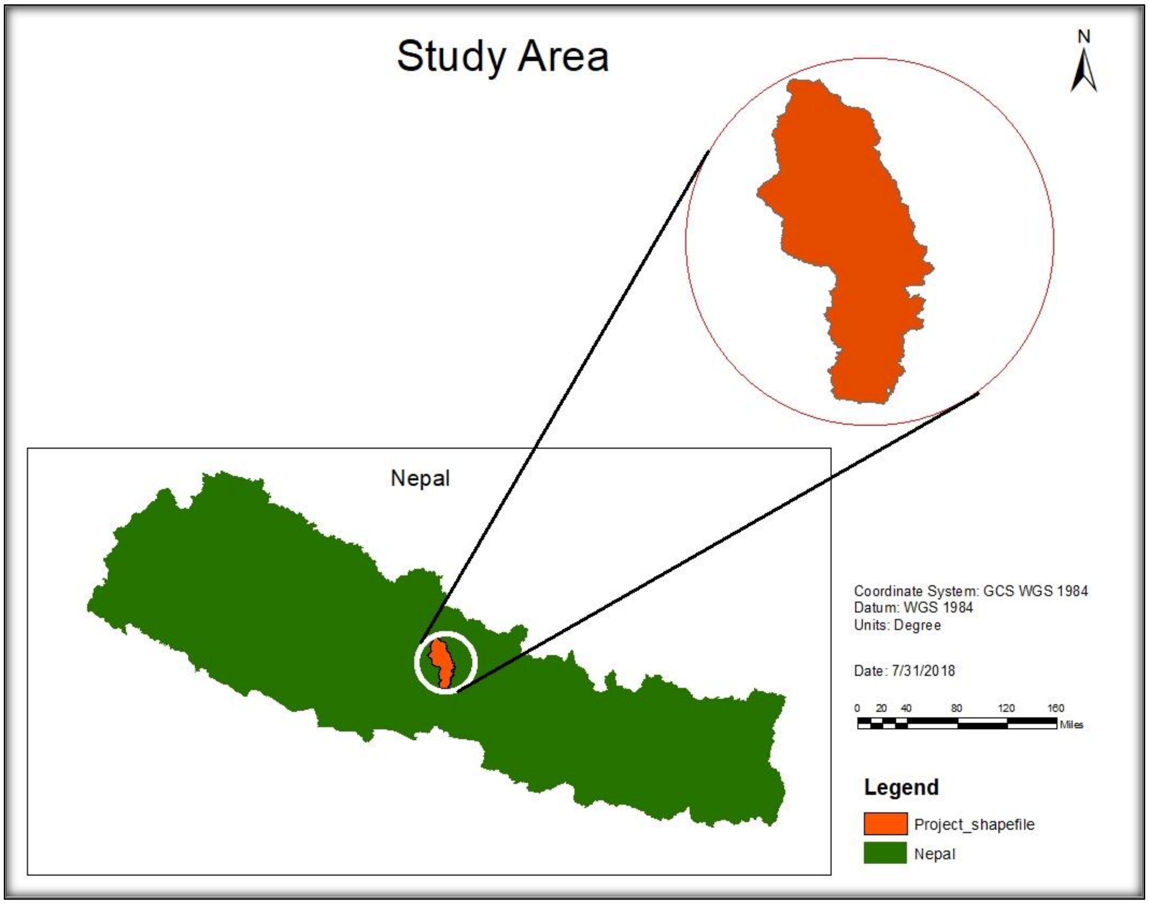

Figure 1: Study Area of Project

All these rivers make a river network. Landslide and floods are mostly confined along the channels of these river networks. The altitude of Madi watershed ranges from 307 m. in the south at the point of confluence with Seti River at Damauli to 7937 m. Annapurna II in the north with north south 64 km aerial distance. Nearly,38 percent of the total land lies in basin area, below 1000 m. altitude. 56.5 percent of the total area falls above 26-degree slope of land. The geographical representation of the area is mainly hilly in the northern part and flat areas in the southern east.

Scope of Project

1. Department of Electricity Development (DOED) can carry out further research related to the selection of sites of hydropower.
2. EIA is high in the context of hydropower.
3. For independent generation of power for each state.
4. Gives new dimension in hydropower development.
5. In NGO’s and INGO’s assisting in flood risk assessment.
6. Further for research purpose.

LITERATURE REVIEW

For the successful completion of project and analysis we have done the literature study from different sources and different authors. All things that are backbone to the project are listed here whereas some fundamental concepts are not included though.

Hydropower

Hydropower is considered to be the best source of energy due to its environmentally friendly nature. Although power shortage can be satisfied by many other non-renewable energies, they have many environmental problems and are too costly to install and to maintain and manage. For these few reasons a similar project was done concentrated on SHP using RS and GIS techniques in Odisha using DEM and discharge data, so that a large rural population can be benefited who were earlier being deprived of electricity. It also made the study easier as data were efficiently and effectively utilized to get the desired result. [Sanoj Sahu. (2014)]. Many rivers across Nepal have hydropower potential varying across a large magnitude. Before harnessing the hydropower from river, we should know the feasible locations and the hydropower potential available in the respective location. Generally, many of these sites are located in remote places. Visiting each and every site location for feasibility study is expensive, time-taking, tedious and labor intensive. Geospatial technique provides many advantages over the conventional methods of site locations. As it uses Remote Sensing and Geographical Information System.

Hydropower technologies in development may yield significant benefits over traditional hydropower technologies, namely, by mitigating the costs of traditional hydropower. Three new hydro technologies, run-of-river, free-standing turbines, and vortex turbines shine hope on the future of low-costs, high-benefit hydropower. However, run-of-river systems are not currently a significant hydropower resource, and both free-standing and vortex turbines are still in their infancy.

Geospatial Technology

Monk et al. (2009) developed a model named RHAM (Rapid hydropower assessment model) which takes input as DEM and regional hydrologic data and gives output as total hydropower available on all streams in the study area. It can also estimate the project costs, environmental and social factors etc. Jha (2010) used the hydro-meteorological data and incorporated GIS and a hydropower model to estimate the total run of river hydropower potential of Nepal.

GIS based procedure was used by Larentis et al. (2011) for hydropower potential spotting. They developed a GIS based computational program named 'Hydro spot' which can locate potential locations in the study area by using the RS and hydrologic data. Bose et al. (2013) identified suitable locations of micro hydropower stations using geo-spatial techniques in the state of Andhra Pradesh. His study area was Kakataya main canal, a major distributary to river Godavari.

Hydrological module of ArcGIS software was utilized for calculation and delineation of the watershed and morphometric analysis of the watershed using SRTM DEM. Digital elevation models (DEMs), such as from the Shuttle Radar Topography Mission (SRTM), or the ASTER GDEM product (USGS, Denver, Colorado, USA), have been used to extract different geomorphological parameters of drainage basins, including drainage networks, catchment divides, slope gradient and aspect, and upstream flow contributing areas (Farr and Kobrick, 2000; Grohmann et al., 2007; Panhalkar, 2014). Land use map of the watershed was generated from latest available multispectral satellite data and whole watershed covers under agricultural land, settlement, fallow land, forest, mining areas and water body. The study revealed that SRTM DEM based hydrological evaluation at watershed scale was more applied and precise compared to other available techniques. The study also revealed that the recent development in geospatial technology, the assessment of drainage basin has been more accurate and precise for morphometric parameter evaluation with better accuracy. Satellite data and GIS have been successfully utilized to generate data on the spatial deviations in drainage characteristics thus providing an insight into hydrologic conditions necessary for developing watershed management strategies.

Satellite imageries in Hydrology

Construction of Small Hydro Power (SHP) dams is very important to fulfill energy requirements. In whole world, 70% potential sites still exist 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. 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 dam 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.

Watershed analysis

In a research paper entitled “Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques” highlighted the importance of Digital Elevation Model (DEM) and satellite images for assessment of drainage and extraction of their relative parameters for the Orr watershed Ashok Nagar district, M.P., India. Hydrological parameters such as drainage analysis, topographic parameters and land use pattern were evaluated and interpreted for watershed management of the area. Surface hydrological indications are one of the promising scientific tools for assessment and management of water resources. Drainage morphometric analyses are a prerequisite for selection of water recharge site, watershed modeling, runoff modeling, watershed delineation, groundwater prospect mapping and geotechnical investigation (Magesh et al., 2011; Thomas et al., 2012). In this paper an integrated use of multispectral satellite data, digital elevation model (DEM) and survey of India topographical sheets were utilized for generation of database and extraction of various drainage parameters.

Journal of Geography, Environment and Earth Science International published an article on "Application of Geospatial Technology in Watershed Delineation and Extraction of Hydrologic Characteristics in Opa Catchment, Southwestern Nigeria" that explored the opportunity offered by geospatial technology to delineate the watershed draining surface water into Opa River, Southwest Nigeria and its tributaries using a selected outlet downstream of Opa reservoir and then carried out extraction of hydrologic characteristics of the watershed. This study aimed at delineating the micro watershed of Opa River, extracting its hydrologic characteristics as well as soil characteristics using digital elevation data, soil map with minimal cost and Geospatial technology for effective water resources planning. The automated delineation procedure of ArcHydro extension of ArcGIS software was used. The watershed boundary was delineated to determine the contributing areas to a selected outlet or pour point downstream. The Arc Hydro tool of ArcGIS 10.0 was used to process the DEM. DEM reconditioning in order to resolve the problem of undesirable competing flow paths within watersheds. Fill Sinks tool was selected to obtain a depressionless DEM. Flow direction tool was selected to obtain the flow direction grid. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell. The Flow Accumulation tool was selected to obtain the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid. Other automated steps were stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, drainage line processing, adjoint catchment processing and drainage point processing. After these preprocessing steps was the final stage of watershed processing. Hydrologic Engineering Centre-Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) was used to extract the hydrologic characteristic of the sub-watershed such as area, basin slope, river slope, centroid elevation and longest flow length. The division of the catchment into sub-watersheds enables matching the characteristics of each unit with soil and land use characteristics thereby making watershed management at micro scale easier.

Hydropower potential using Geospatial Technology

Assessment of hydropower potential using spatial technology and SWAT modelling in the Mat River, southern Mizoram, India was done as a research work under Department of Water Resources Development and Management, Indian Institute of Technology (IIT). In this study, a hydrological model and spatial technologies have been employed to assess water availability in the Mat River basin, southern Mizoram, India. Correct assessment of hydropower potential at a site requires realistic information on topography (particularly elevation) and flows followed by careful analysis of these data. Recent advances in remote sensing (RS), geographic information system (GIS) and hydrological modelling provide realistic, upto-date and useful information for the assessment of hydropower potential. Furthermore, the results obtained from the SWAT (Soil and Water Assessment Tool) model, satellite data and GIS tools were utilized to identify the hydropower potential in the basin. The assessment of head, site selection and simulation of flow at each selected site was carried out using the Arc-SWAT model. The SWAT model generates stream network characteristics, the length of the river, and elevation difference for each stream within the watershed boundary. The model has provision for addition or deletion of outlets and inlets by user intervention, which affects the delineation and number of sub-watersheds created by the model, and this facility was utilized in assessing the head variation along the river, by placing sub-basin outlets at different locations. Thirty-three sites with hydropower potential were identified within 147 km2 of the Mat River basin. A methodology has been proposed for the identification of potential hydropower sites using a distributed hydrological model (SWAT). Calibration and validation of the SWAT model for the Mat River basin have shown that the model is able to give realistic output for assessment of hydropower potential by generating flow at selected potential sites. The results of the sensitivity analysis reveal that the important parameters of the SWAT model in respect of their sensitivity for the Mat watershed. The study revealed that the hydropower potential of a river basin can be correctly assessed by employing a digital elevation model, stream network data and a hydrological model, such as the SWAT model, within a GIS framework.

Hydropower in Economic Development

Hydropower from large dams is estimated to contribute to 19% of world's total electricity supply (as opposed to total energy supply). Approximately one-third of the world depends on hydropower for over half of their electricity, and 24 of those countries rely on hydropower to supply nearly 90% of their total electricity supply (www.dams.org). The percentage of electricity from hydroelectricity is expects to fall to 16% by 2030, however, as coal and natural gas consumption grows at a much faster rate than hydropower and renewables (U.S. Government, 2007).

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The basic costs to consider in hydropower plant development are the costs to construct the dam, the costs to operate and maintain the facilities, and adverse impact to the economy (localized or beyond), including fishery and agriculture. Dam construction can be enormously capital intensive, such as Three Gorges Dam being constructed on the Yangtze River in China, which is estimated to cost between $26 billion (Chinese estimate) to $50 billion ("Western" estimate) (Etzweiler et al., 2007). Further, unexpected costs must be considered. China, for instance, just recently had an additional, unexpected waste management cost of $5 billion (20% of the estimated cost of the project!). Costs such as these must be considered, because they may make or break the economic value of the project (Withgott & Brennan, p.447, 2007).

The economic benefits of a successfully managed hydropower project are plentiful. Besides the heavy capital needed to build a hydroelectric plant in the beginning, the facility runs almost independent of human or energy inputs, and thus enjoys a very low operating and production cost per kWh. Further, a hydroelectric facility has a lifespan of 50-100 years - which is beyond any fossil-fuel fired plant. This allows the project to a) be depreciated across a longer time period to boost accounting returns (in the case of a privately run hydropower plant), and b) the plant has a longer life to produce revenue (Etzweiler et al., 2007).

From an economic and strategic aspect, by harnessing natural hydropower, a country increases the degree of energy independence and diversifies away from the risk of increasing fossil fuel prices. Moreover, the storage ability of the dam allows energy production to be controlled on an at-need basis, and may also allow a country to manage water reserves for irrigation purposes or in a time of water scarcity (Etzweiler et al., 2007). Lastly, the increase in water levels behind the dam system may allow an expansion of shipping lanes, encouraging trade and the development of wealth (Withgott & Brennan, p.447, 2007).

Sites for damming flow of water

Damming flows of water may lead to slow, or even stagnant water bodies, which decreases an ecosystem's ability to wash away waste (especially human waste). A dammed water flow may also prevent fertile silt from reaching downstream, and impact wildlife and agriculture downstream. Further, fish that swim upstream to spawn may be prevented from doing so, unless proper technology is in place for them to pass without the turbines turning them into sushi (a water "staircase" can be implemented around the sides of the dam). However, negative environmental impact is not limited to downstream; the vegetation engulfed by the dam's water reservoir decomposes and subsequently emits CO2 and methane (CH4) into the atmosphere, especially in warmer climates (Etzweiler et al., 2007).

The consequences of dammed water may be exacerbated in cases where a dam seasonally releases water from the reservoir behind it so to compensate for dry summers. Why? When the waters subside, land that was previously underwater is now exposed to locals, who may wish to plant crops by the water; however, if a river is contaminated, these areas surrounding the river may become disease-infested and threaten the health of local populations. Another threat to local populations is in an instance of a natural disaster, such as an earthquake or landslide, that causes a large dam to crack and wash away human lives and infrastructure (Etzweiler et al., 2007).

While the social costs and benefits of hydropower significantly vary depending on the project's circumstances, all should be outlined and considered. In many circumstances, entire communities are forced to relocate due to flooding from a dam; it is estimated that between 40 - 80 million people have been displaced by damming (www.dams.org). For instance, the Three Gorges Dam project in China has led to the washing away of 22 cities and many smaller settlements, forcing a mass exodus of up to two million people (Withgott & Brennan, p.449, 2007). Due to displacement, or instead, a decrease in land resources due to flooding, unemployment or even social conflict might be the result (www.dams.org).

Flooding may also lead to the loss of an area's aesthetic appeal and part of its fauna diversity. In the case where communities are submerged, the consequence may also be a loss of cultural heritage (Etzweiler et al., 2007). The construction of the Three Gorges Dam, for instance, will lead to the loss of some towns and villages that have over 10,000 years of valuable, national history (Withgott & Brennan, p.447, 2007)

Even with such a negative social cost to damming for hydropower, in many instances, the social benefits may outweigh the costs. For instance, a dam for hydropower can also be used to contain spontaneous flooding that might otherwise have killed countless people, which had been an especially important consideration in the building of the Three Gorges Dam in China. It could also be used for reserves in case of drought, or controlled irrigation of crops so to help safeguard a community's or country's food supply like Egypt's Aswan dam (Etzweiler et al., 2007). Finally, new recreational opportunities abound in the reservoir system created by the dam; although this comes at the cost of recreational activities downstream) (Withgott & Brennan, p.447, 2007).

Run-of-river systems redirect part of a river's water through pipelines or other means to generate electricity via a turbine in a land-based powerhouse. This approach avoids the adverse effects of damming in the pursuit of electricity generation, however, it sacrifices the reliability of hydropower generation due to the lack of storage control that dams possess. Run-of-river dams may also be useful in areas beyond the main electrical grid, or for those without the means to build and maintain a dam (Withgott & Brennan, p.614, 2007).

Freestanding turbines are similar to run-of-river systems in the sense that they do not require damming either. Rather, as the name implies, the concept employees freestanding turbines in the middle of a stream, and can currently achieve around a 35% efficiency. Pilot studies are currently being tested around South Korea and North America (End of a dammed nuisance, 2008)

In the context of SHP development, the GIS based approach is increasingly being used to determine optimal site location. However, these applications generally exclude environmental attributes (Lurentis et al. 2010; Kusre al.2010; Balance et al.2000) and donot implement multicriteria analysis (Yiet al.) or explicitly provide a formal methof to justify the weighting of each attribute needed to perform a site selection (Rojanamon et al. 2009).

Multicriteria analysis

In Minas Gerais State, Brazil, a group of researcher proposed a GIS multicriteria analysis framework for site selection of SHPs. To the authors' knowledge, this was the first work that integrates GIS processing with multicriteria analysis using the AHP method to provide the weighted contribution of relevant attributes to inform SHP optimal site selection in Brazil. Overall, the goal was to provide a framework to improve decision making at the early stages of SHP development (Fig. 1). Specifically, the objectives of this work were to:

- select, classify and integrate relevant attributes for SHP site selection freely available in the web-GIS database Ecological Economic Zoning of Minas Gerais State (EEZ-MG 2015);
- spatially identify areas with socio-environmental restrictions for SHP development; and
- classify planned locations for SHP development in Minas Gerais based on the restriction mapping and, therefore, prioritize those projects accordingly.

METHODOLOGY

Data and software used

Data:

We have used data from different sources for the analysis and development of the project. Although data were from different sources and at large extent we have used those all data in only our required region of Nepal Extent.

- Digital Elevation Model (DEM)

  The DEM used in this project is Advanced Space borne Thermal Emission and reflection Radiometer (ASTER) Global Dem, a product of The Ministry of Economy, Trade, and Industry (METI) of Japan and the United State National Aeronautics and Space Administration (NASA). ASTER DEM was acquired via usgs.org. The resolution of the acquired DEM was of 30m.

- Predicting Precipitation Data in response to climate change

  The data for the precipitation was acquired from Department of Meteorology located in Ratnachowk, Pokhara. The data was collected from Bhujung, Bhorletar Syamghat, Damauli, Sikles and Begnas guage station from 2006-2018 on monthly basis. Thus the data was interpolated in order to determine the precipitation along our project area.
- Satellite image (Sentinel 2)
- Soil Data

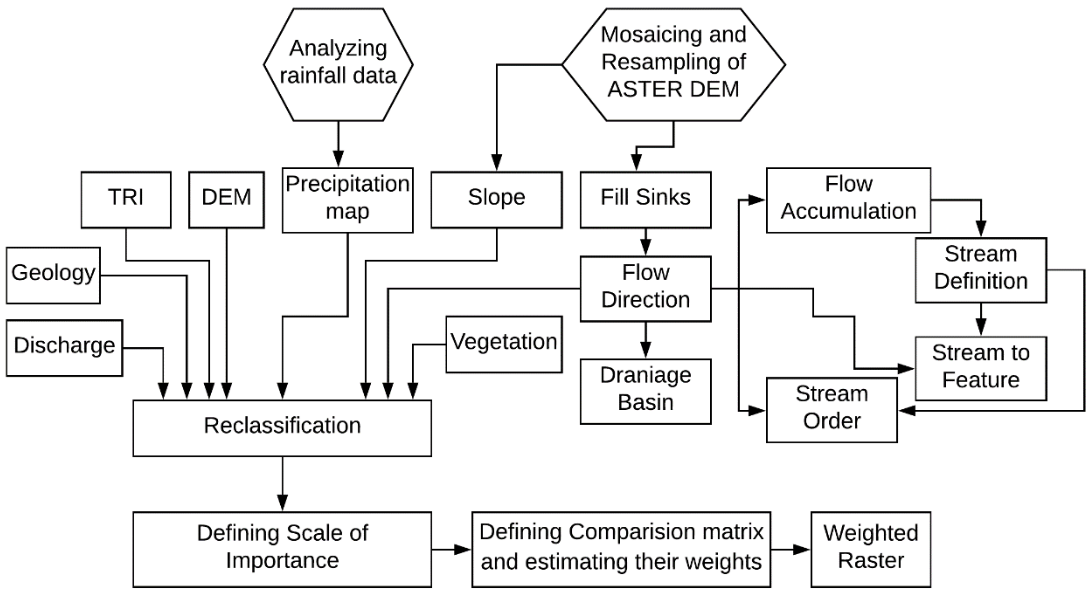
Software

1. Open Source GIS
2. ERDAS Imagine 2014

   Erdas Imagine 2014 was used as image processing software package that allows users to process both geospatial and other imagery as well as vector data. Imagine is tightly woven into the GIS fabric more than other image processing software packages and that is the advantage of this package. We used Erdas Imagine software package to layerstack the satellite images like landsat-8 downloaded from usgs earth explorers. Then, we created the subset of image of our area of interest and performed classification in order to prepare land use land cover map.
3. Lucid Chart

Lucid chart is a web-based commercial service which allows users to collaborate and work together in real time to create flowcharts, organizational charts, website wireframes, UML designs, mind maps, software prototypes, and many other diagram types.

Proposed Methodology



The whole methodology can be subdivided into four different steps which includes:

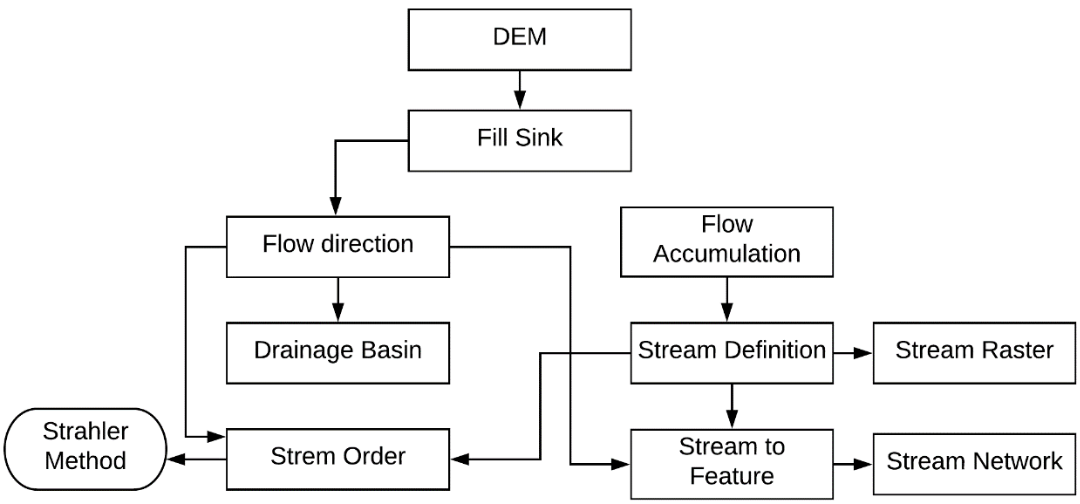
1. Initial Data Processing
2. Hydrological Assessment
3. Identification of several factors and weight assignment
4. Identification of several feasible sites and development of a model.

<u>Initial Data processing</u>

The downloaded ASTER DEM was of Resolution 30m. The initially downloaded Dem was in four tiles covering N27 E83, N27 E84, N28 E83 and N28 E84. They were mosaic to cover the Maadi watershed which contained in the three districts and then projected to WGS84_DTM ZONE 44-N. The resampled DEM is entracted using Madi a watershed AOI. The Discharge data at the Gauge Station at Sisaghat and Namarjung was obtained from the Department of Hydrology and Meterology. Annual Discharge ranges from 62.7m^3/s to 96.4m^3/s with an average discharge of 78.7m^3/s. Monthly discharge peaks in August. The maximum instantaneous ranges from 329m^3/s to 250m^3/s. The rainfall data were collected from the rain gauge station at Siklesh, Shyamgha, Bhorletar, Damauli. These data were analyzed for determining different hydrological relationship.

Initial Hydrological Assessments

For the initial hydrological assessment ArcGIS hydrology and Arc Hydro Tools were used. During the assessment, in the resampled DEM. FILL sink tool was used in order to remove any sinks present in the DEM to make it depression less. The flow direction is obtained from the filled sink as input. From the flow direction we obtained the flow accumulation as well as the Drainage Basin of the watershed. Similarly, we classify the order of the stream as primary, secondary and tertiary using Strahler method.



DEM of study area:

DEM basically provides the elevation data. It is used as the input in ArcGIS software to generate various maps based on different basin characteristics. DEM is a remote sensing data. It is a raster whose grid values signifies the height of the surface.

Flow direction map of study area:

The flow direction map represents the direction of flow out of each cell. The input required is the DEM of the study area in the form of raster. The flow direction is based upon eight direction (D-8) flow model. In this model, there are eight valid output directions relating to the eight neighbouring cells into which flow could travel.

Flow accumulation map of study area:

The Flow Accumulation tool in ArcGIS software calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster.

Identifying several Factors, Definition of criterion map and estimation of weights.

In multicriteria analysis for potential hydropower sites, people has proposed several factors such as flow characteristics, indices of flow, peak average and annual discharge but, nowadays there is requirement of multivariate approaches. Apart from that different terrain parameters likes elevation, slope, geology, rainfall is also important.

- Flow and discharge
- Slopes
- Geology and soil
- Terrain smoothness
- Elevation
- Precipitation

Flow and Discharge:

Flow and discharge are one of the main parameters that affect the potentiality of hydropower generation. Higher the value of flow and discharge helps to generate more power. Hence the flow accumulator as well as the stream order can be used as some important criteria. However, we have a problem with stream order as it gives only a linear series of selected pixel of flow and effects the weighted overlay tool for computing the possible site selection. Hence, we used flow accumulation map instead of stream order. The Strahler method is effective as it takes the small tributes and makes them as order 1 i.e. primary and increase their order and resulting stream is numbered as 2 and so on.

The value for flow was further reclassified into four categories:

0-70981 (Poor)

70981-251133 (Satisfactory)

251133-740280 (Good)

740280-122500 (Very Good)

Slope

Slope stability is another main concern for stability analysis. Hence slope is also regarded as one of the important factor. For slope stability, the slope greater than 15° is strongly avoided because it is not suitable for building satisfactory wall.

The slope is further reclassified into four categories as:

Stable (0-15 degree)

Medium (15-30 degree)

Satisfactory (30-45 degree)

Poor (>45 degree)

Terrain Roughness/Ruggedness Index (TRI)

The next criteria were 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. As well as the ruggedness index is very vital to manage and analyze the natural resources. TRI was computed using the method proposed by Riley et al. 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. 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

TRI was reclassified as

0-100m→ very good

100-280→ good

280-500→ satisfactory

≥500→ poor

Figure 2 Reclassify tool

Elevation

Elevation along with slope stability is one of the important factor in construction of Dam. Hence, the analysis of DEM, which represent the value of elevation, is also used as the one of the factor. Lower elevation sites are required in order to capture maximum flow from the catchment area. However, it is not always necessary that the dam sites should be present at the lower elevation so it is taken as a lesser important criteria and given lesser weightage. The elevation reclassified in Natural Breaks into 4 Class as:

293-1180 (Very Good)

1180-3400 (Good)

3400-5300 (Satisfactory)

5300-7900 (Poor)

Precipitation and Temperature

The term Precipitation denotes all forms of water that reach the earth from the atmosphere. The usual forms are rainfall, snowfall, hail, frost and dew. Of all these, only the first two contributes significant amounts of water. Rainfall is the predominant form of precipitation causing stream flow. The magnitude of precipitation varies with time and space. Precipitation is expressed in terms of the depth to which rainfall water would stand on area if all the rain were collected on it. 1 cm of rainfall over a catchment area of 1 km2 represents a volume of water equal to 104 m3. In the case of snowfall, an equivalent depth of water is used as the depth of precipitation. The precipitation is collected and measured in a rain-gauge.

In meteorology precipitation is the product of condensation of atmospheric water vapor that falls under the gravity. The main form of precipitation includes drizzle, rain, sleet, snow and hail. The increase of temperature leads to intensification of water circle on the planetary scale because of which dry area remains dryer and wet areas become wet. In areas with reduced precipitation the annual runoff and within connected hydropower production will decrease and increase in precipitation will not automatically result in an increase of energy production in the same scale. Power plants are optimized for designed discharge and an increase can only be used in a limited extent. Hence, we gave lesser weightage to the precipitation. The value of precipitation of several gauzing station were recorded monthly and were interpolated using Inverse Distance Weightage (IDW) method. The value was reclassified into four groups as:

130-190 mm (Poor)

190-235 mm (Satisfactory)

235-287 mm (Good)

287-341 mm (Very Good)

Vegetation

Vegetation also is important for the dam construction especially in terms of normalized Difference Vegetation Index (NDVI) which greatly helps to understand the zones where soil having capacity of strong or carrying water in it.

Land use and Land cover

Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other. Identifying, delineating and mapping land cover is important for global monitoring studies, resource management, and planning activities.

Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify the land use changes from year to year. This knowledge will help develop strategies to balance conservation, conflicting uses, and developmental pressures. Issues driving land use studies include the removal or disturbance of productive land, urban encroachment, and depletion of forests.

For hydropower site selection the criteria based upon the area as well as social economical and socio-economical parameters. The complexity of weight of criterion map were computed using pairwise comparison method proposed by Saaty.

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

The decreasing order of criteria are:

- Flow
- Slope
- TRI

- Elevation
- Precipitation

Reasons for excluding Vegetation Landover and Geology from weighted overlay:
The Geology data was mainly of metamorphic and igneous rocks and are classified as good for hydropower construction. Hence, their inclusion in Multi criteria analysis caused a high suitable zone in the output-weighted map even away from Hydropower site zone as they have high weight in importance. While regarding vegetation and Landover it was also included in the secondary criteria for the suitable site selection for Hydropower.

Multi Criteria Analysis:
Multi-criteria decision method was adopted for identifying and choosing alternatives to find the best solution based on different factors as shown in the table below and their weightage was calculated accordingly. Every decision was made then within decision environment. The table below shows direct weightage calculation for each parameter followed by the consistency ratio table:

Criteria Map	Flow	Slope	TRI	Elevation	Precipitation	Average Weight
Flow	1	4	3	5	6	0.496819
Slope	1\4	1	2	3	4	0.215669
TRI	1\3	1\2	1	2	3	0.146932
Elevation	1\5	1\3	1\2	1	2	0.085519
Precipitation	1\6	1\4	1\3	1\2	1	0.0550599

Criterian Maps	Flow	Slope	TRI	DEM	Precipitation	AVG
Flow	0.496*1	0.215*4	0.146*3	0.0855*5	0.05*6	5.149
Slope	0.496*0.25	0.215*1	0.146*2	0.0855*3	0.05*4	5.149
TRI	0.496*0.333	0.215*0.5	0.146*1	0.0855*2	0.05*5	5.897

DEM	0.496*0.2	0.215*0.333	0.146*0.5	0.0855*1	0.05*2	5.148
Precipitation	0.496*1.667	0.215*0.25	o.146*0.333	0.0855*0.5	0.05*1	5.142

The value of lambda= 5.149+5.149+5.897+5.148+5.142/n=5.297; where n= number of criteria used.

According to this method the value of lambda should be greater

than number of criteria i.e., 5.297.>5

Computation of consistency index:
CI=lambda-n/n-1=5.297-5/5-1=0.07425

Computation of consistency Ratio CR:

CR=CI/RI=0.07425/1.12 where 1.12 is from above table as criteria are 5.

Where RI is random index provided by Saaty.

Saaty stated that if CR<0.1 then there exists the consistency among

the criteria. Hence,

Weight of flow is 0.496 i.e.,49%,

Weight of slope is 0.2156 i.e., 21%,

Weight of TRI is 0.146 i.e., 14%,

Weight of elevation is 0.085 i.e., 8%

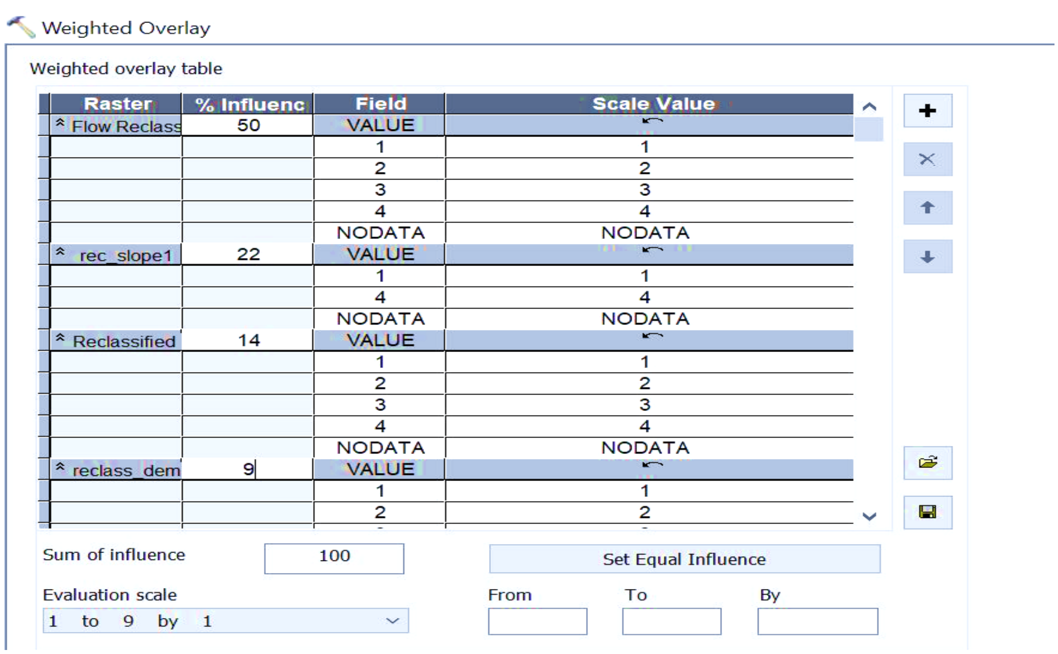
Weight of Precipitation is 0.055 i.e., 5%

S.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

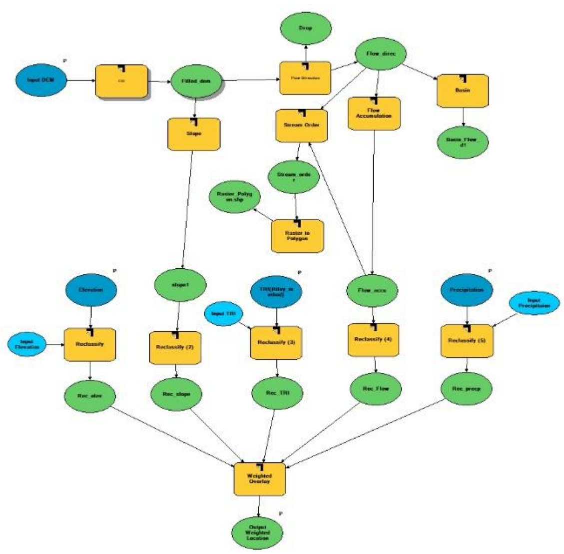
Identification of several feasible sites and development of a model.

After estimating the weights of different criterion maps those weights were assigned to the weighted overlay tool to compute the suitable sites.



Software Extension

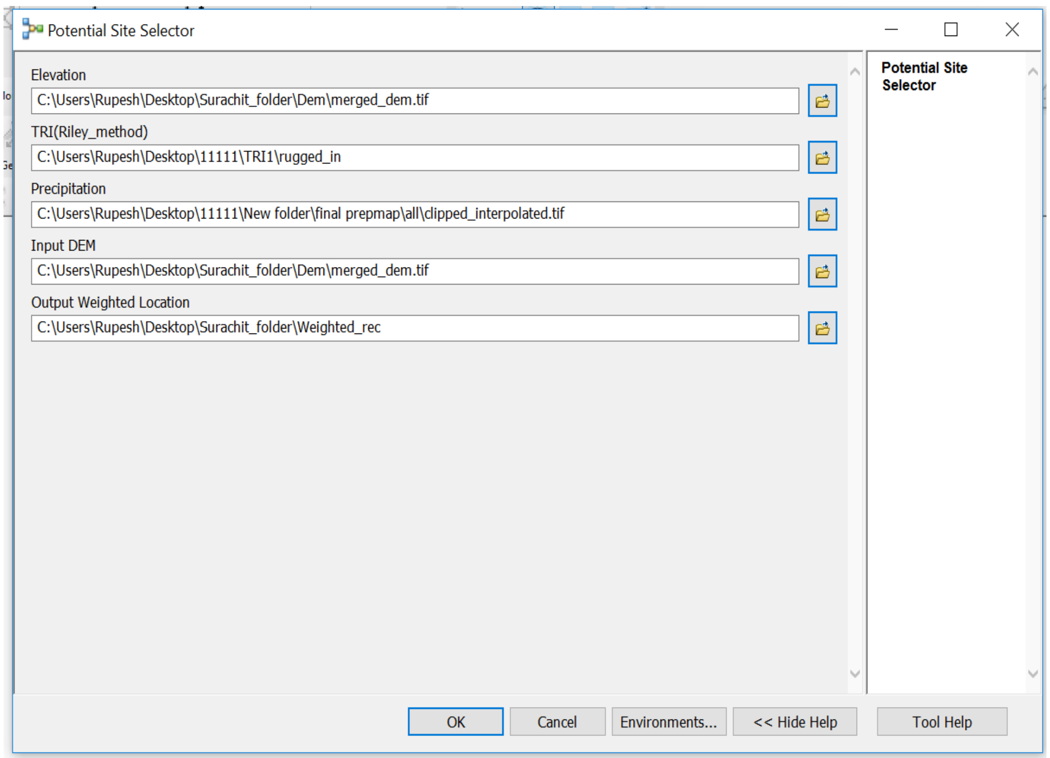
These Extension first reads the data from the user as raster in the form of DEM. ASTER DEM was used as input parameter that was processed using fill sink tool in order to remove any sinks present in the DEM. The next step performed for the model was the output from fill was again used as input for slope and flow direction. Slope tool gave output as a slope map that was reclassified once hydrological assessment was dealt with, where the flow direction map produced as output from flow direction for knowing the direction of flow out of each cell was then processed using stream order, flow accumulation and basin tool for the generation of respective raster output. Once the raster is generated from stream order, it is again converted to polygon for further analysis process. The steps followed till now was summarized as the hydrological assessment method. Reclassification is the major task followed after the completion of hydrological assessment where a number of input parameters are fed such as elevation from DEM, slope previously obtained, flow accumulation map, precipitation map and TRI. The precipitation map is obtained after the interpolation of precipitation data obtained from meteorological department on monthly basis. For TRI input, min and max DEM was computed using Focal statistics toolset that was then fed into raster calculator for obtaining TRI value. Classified output for each input was then collective given weightage using weighted overlay tool in GIS that helps in obtaining the desired output of the model. The following flowchart completely representing the procedure of the extension.



Result and Discussion

A suitability map for the construction of Hydropower in the area of interest was produced on basis of several criterion maps. The suitability map indicates the best possible sites for the Hydropower Construction.

From several research, we identified several factors such as slope, flow DEM discharge, TRI, precipitation etc., which influence the selection of possible hydropower sites. Each of the factors was weighted according to their influence on the site selection. From it, a suitability map was predicted.



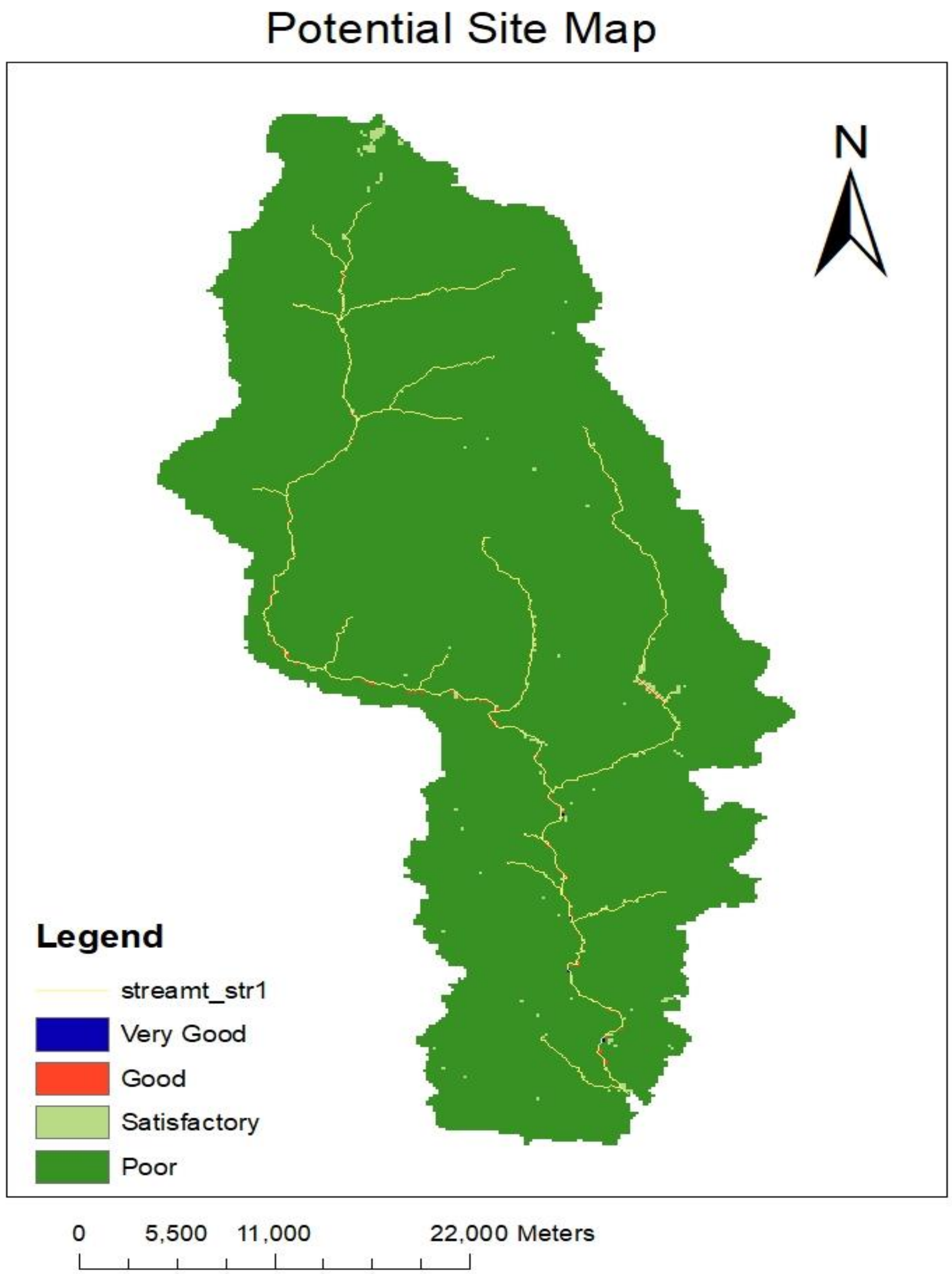


Figure 3 Suitability map

SWOT Analysis

SWOT analysis is a popular and versatile tool, but it involves a lot of subjective decision making at each stage. It should always be used as a guide rather than as a prescription and it is an iterative process. There is no such thing as a definitive SWOT for any particular project because the strengths, weaknesses, opportunities and threats depend to a large extent on the project objectives under consideration. This analysis can be applied in different projects and research with clear thinking about the project. SWOT analysis for this project is tabulated as:

Strength	Weakness
• Easy efficient approximation of potential sites for hydropower. • Economical method. • Easy handling of Geospatial data. • Could be used as preliminary survey for Hydropower • Supports proper environment friendly decision making	• DEM data used was of just 30m resolution. • Unavailability of several data of Secondary parameters. • Accurate power generation capacity cannot be estimated properly • Discharge gauzing station were not sufficient
Opportunity	Threat
• Can play a vital role for initial planning of Hydropower Projects • This project can be extended for flood modelling of that area • Inclusion of other several parameters would enable us for more accurate result • A proper modelling can be carried out for estimating the tentative power that can be generated • This tool can be further extended for estimating potential sites of other places as well	• The output might be effected severely if proper research is not carried during weightage assignment. • Geology and vegetation cannot be included in the multi criteria analysis • Toolbox developed is based on the Arc Gis platform and cannot work without it. • Potential threat of flood and landslides has not been considered properly

Conclusion and Recommendation

Reliability and Validity

From our investigation, we found that several places in Madi River had the potentiality for the generation of Hydropower. Six sites with high potentiality were obtained among which most of the sites were located in the middle and lower Madi. Two of the hydropower that are being constructed also fall within our identified area. These sites had a good amount of flow required for the hydropower generation and the slope, terrain, ruggedness and other factors were suitable. The potential sites which were identified by Hydrological Modelling shows that existing two Hydropower Plants also lies also in this area. It means that our study validates the potential area for Hydropower Plant.

Other four potential hydropower sites can be recommended for the concern authority for development of Hydropower Plant.

Conclusion

Hence, we were finally able to meet the primary and secondary objectives as mentioned in our objectives. This study would enable to identify the potential sites for hydropower generation. To address this, we have used geospatial techniques incorporating ASTER Global DEM, geological map, rainfall data, and discharge data. The sites have been studied via GIS tools hydrological investigation and multi parametric analysis. Similarly, we also created a toolbox based on Arc GIS, which would ask for input of different parameters and hence can determine the possible suitable sites for hydropower generation based on the given parameters. From our investigation on Madi watershed area, we found that several places in Madi River had the potentiality for the generation of Hydropower. Six sites with high potentiality were obtained among which most of the sites were located in the middle and lower Madi. Two of the hydropower that are being constructed also fall within our identified area.

Recommendation

Recommendations include the incorporation of High Resolution DEM to enhance the accuracy of the result. Similarly highly precise Geological Faults as well as formation are required for proper stability of the dams and reservoir. . 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. Soil maps should also be incorporated for the soil stability for dam construction. The proposed approach can be further utilized to access an overall hydropower potential of country.

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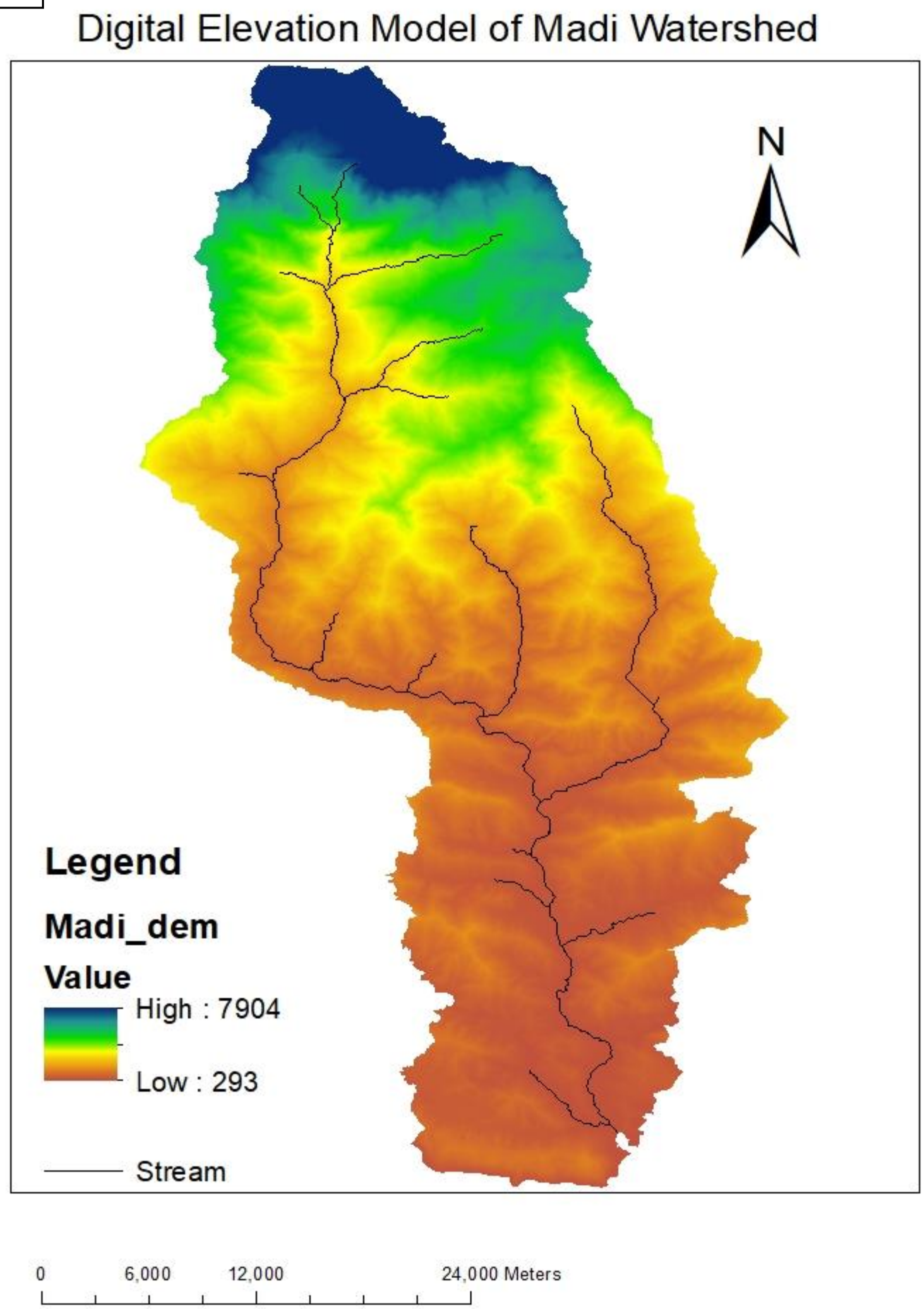
Annexure

1. DEM of Madi watershed
2. Stream order
3. Flow accumulation
4. Flow direction
5. Reclassified flow
6. Drainage basin
7. Slope
8. Reclassified slope
9. precipitation
10. Reclassified precipitation
11. Soil
12. Terrain roughness index
13. Reclassified TRI
14. Reclassified DEM
15. NDVI

Annexure 1


Digital Elevation Model of Madi Watershed
N
Legend
Madi_dem
Value
High : 7904
Low : 293
Stream
0
6,000
12,000
24,000 Meters

Annexure 2

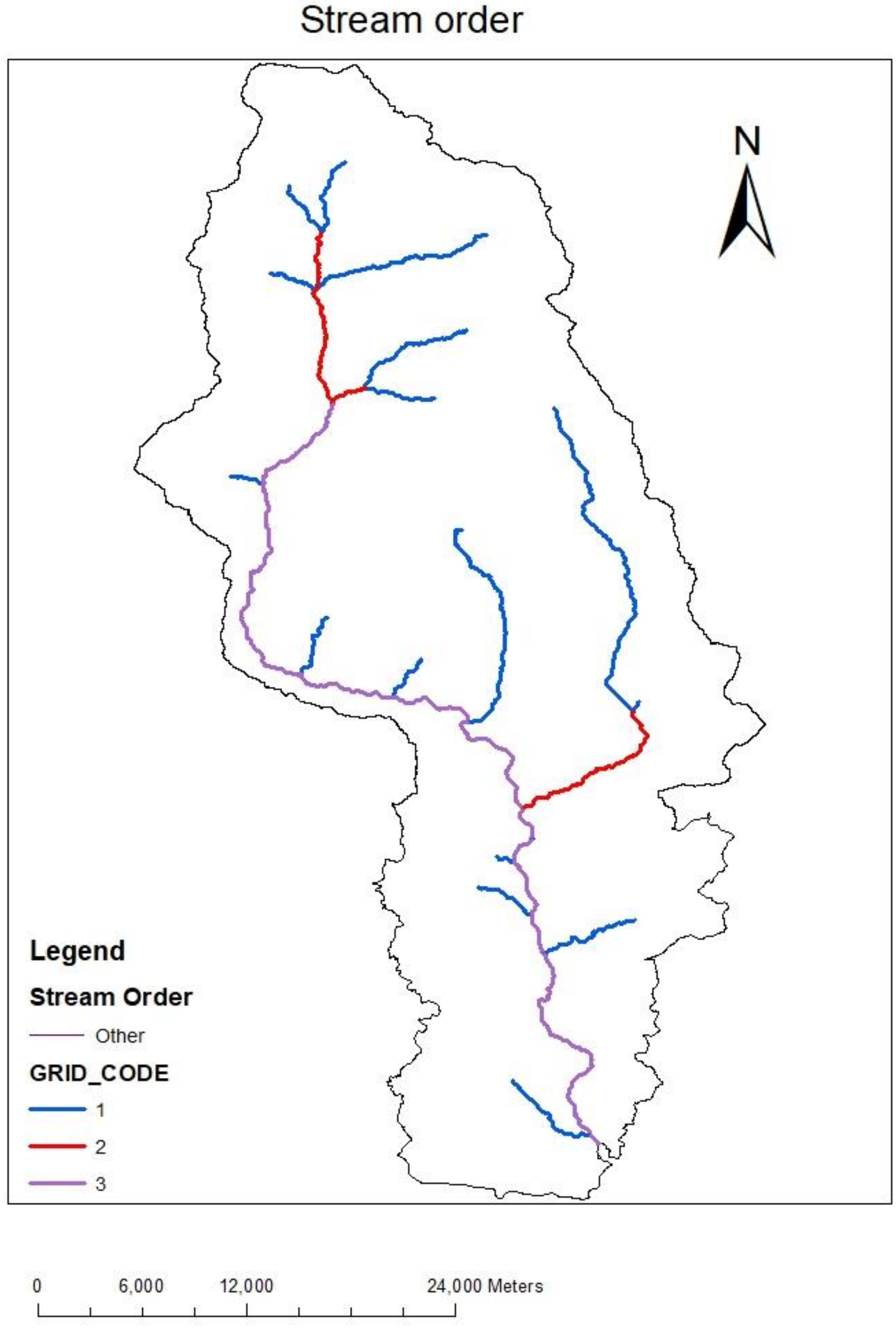


Figure 4 Stream Order

Annexure 3

Flow Accumulation

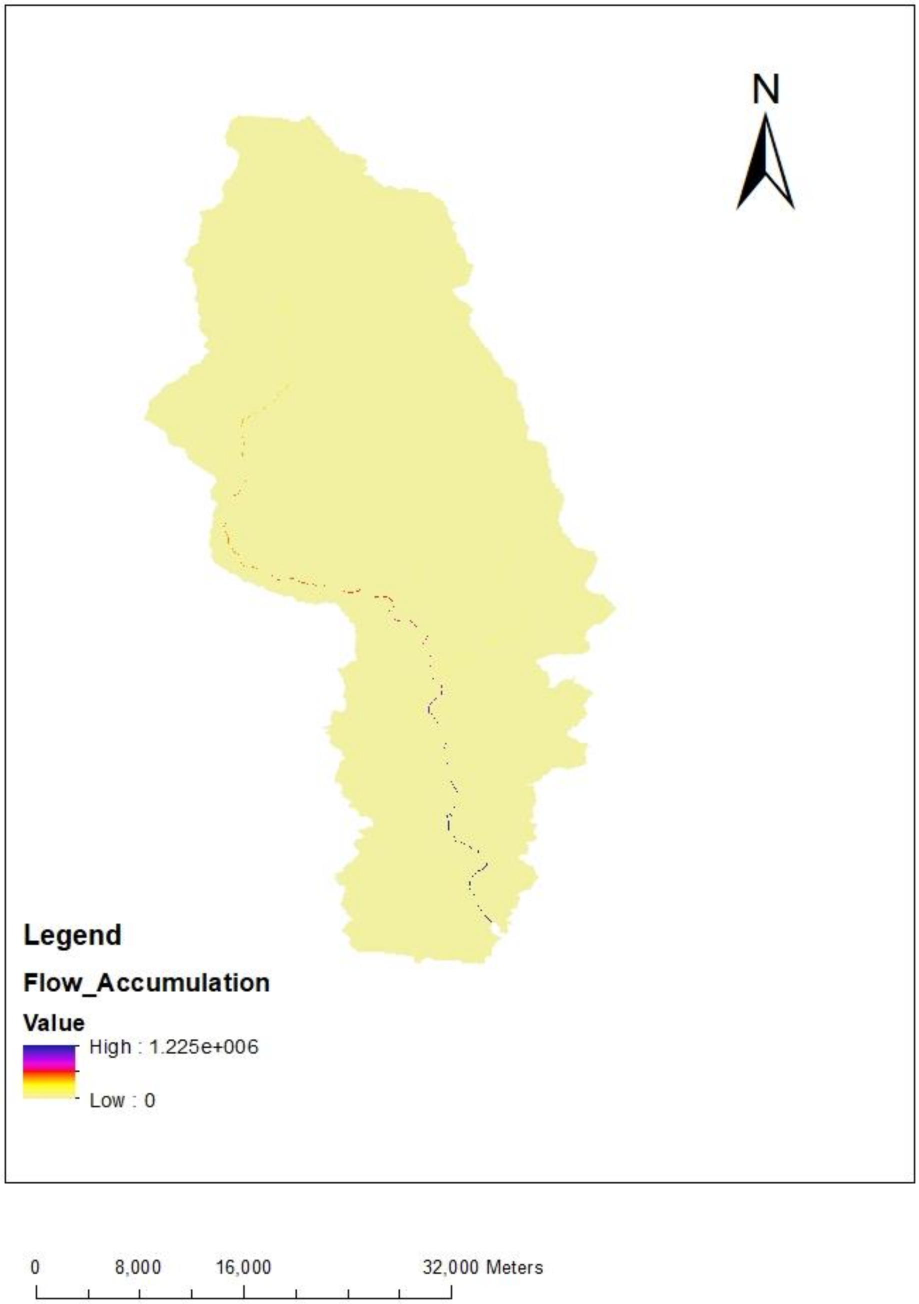


Figure 5 flow accumulation

Annexure 4

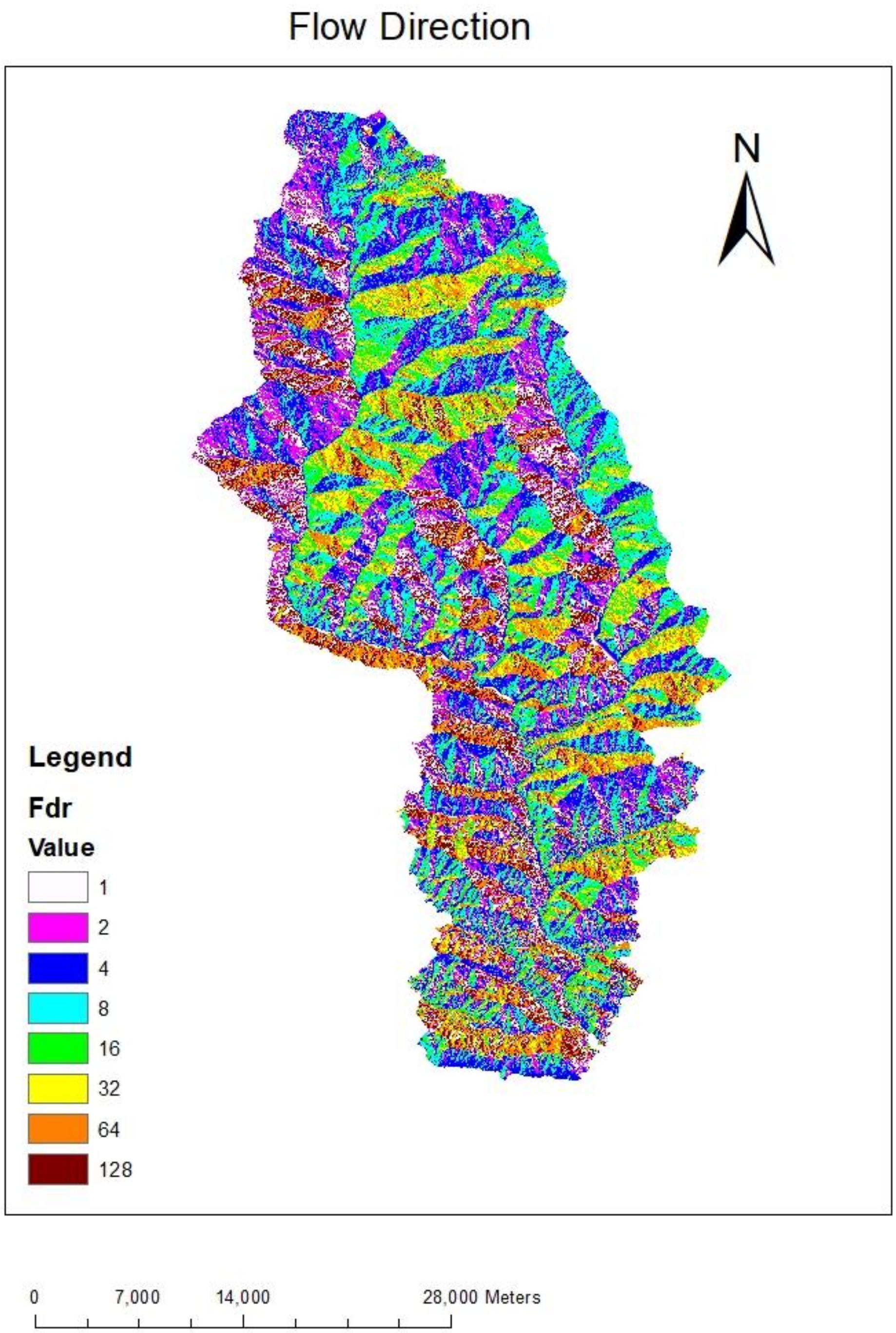


Figure 6 Flow direction

Annexure 5

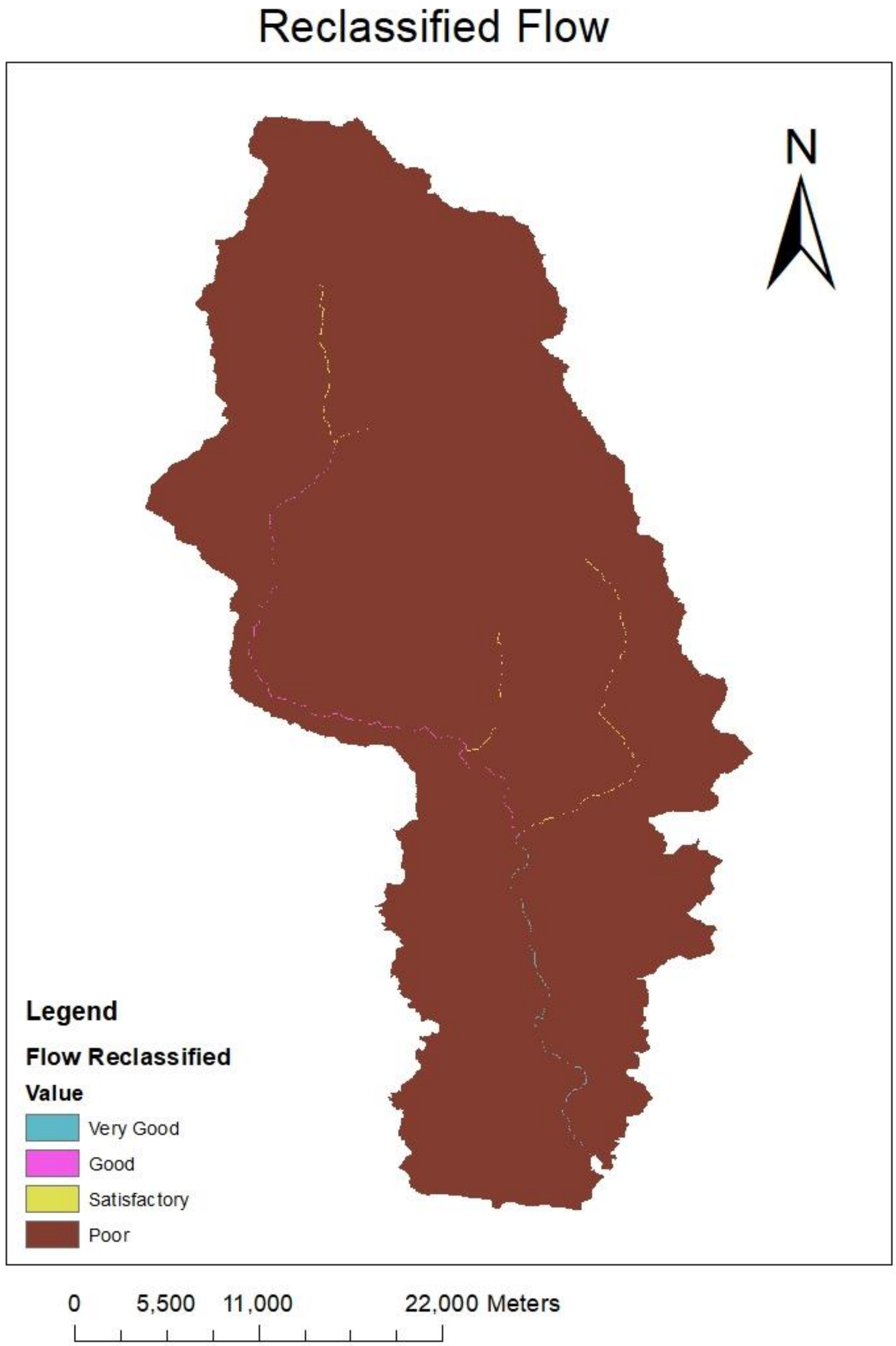


Figure 7 Reclassified Flow

Annexure 6

Figure 8 Drainage Basin

Annexure 7

Figure 9 slope

Annexure 8

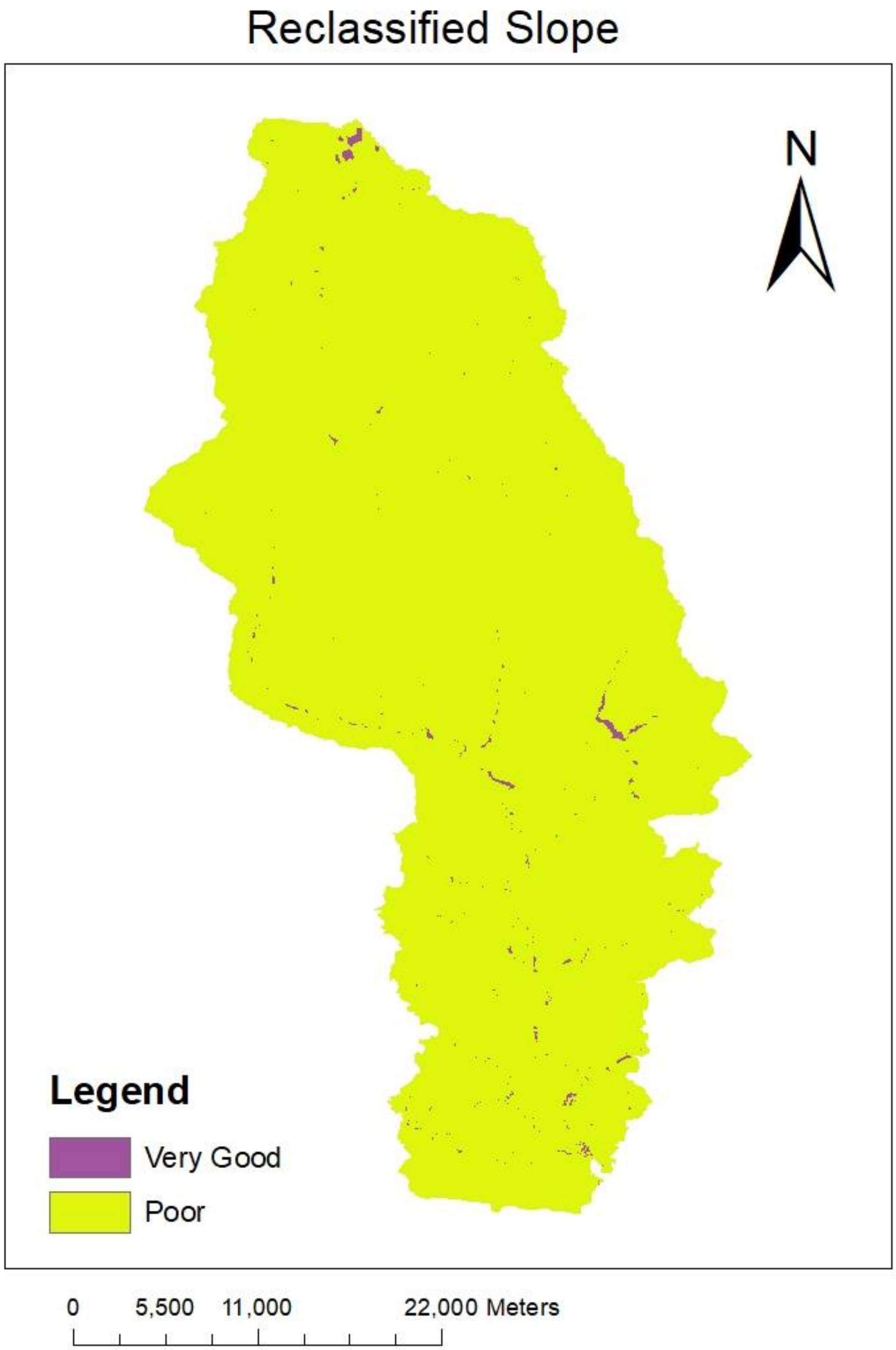
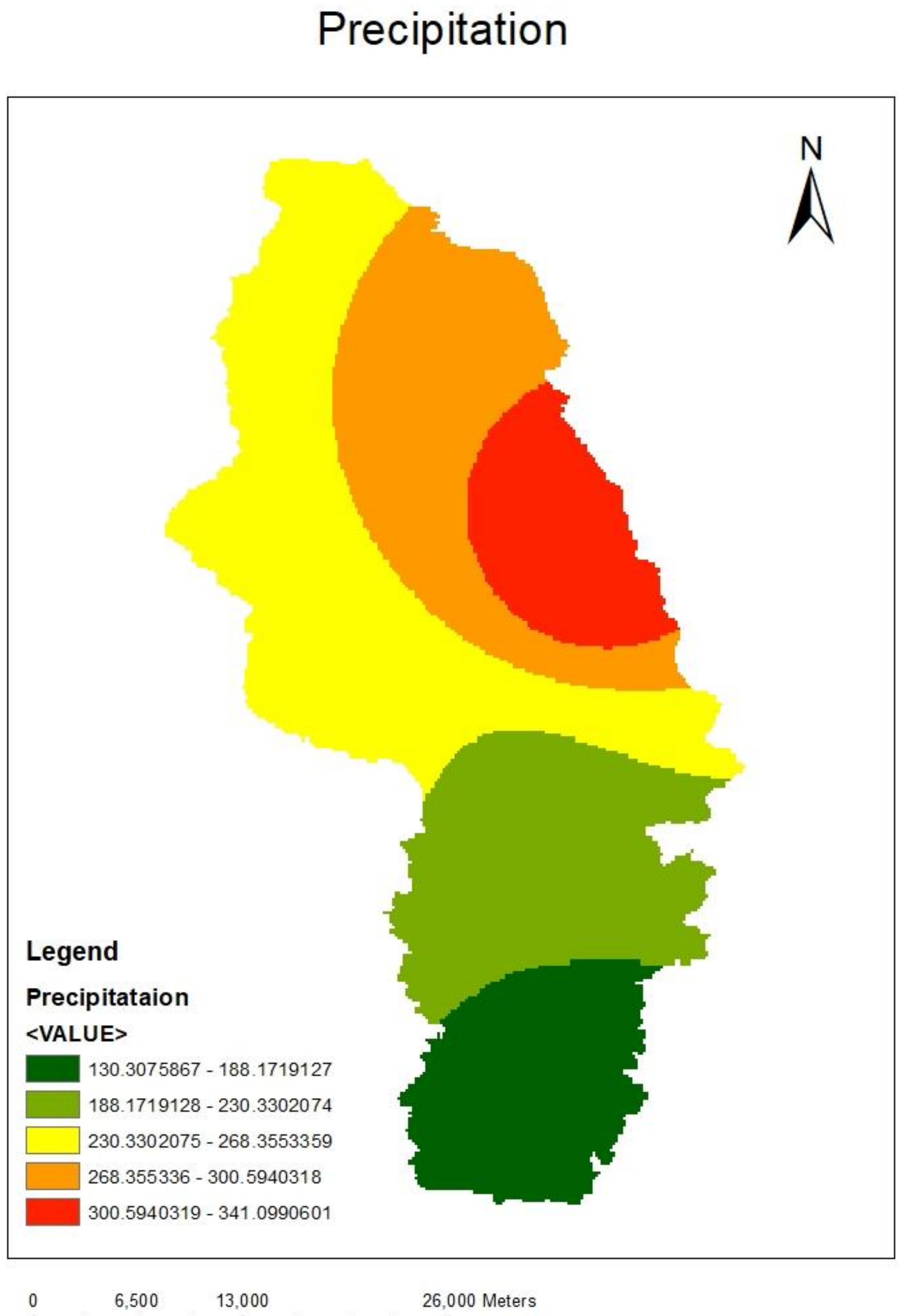


Figure 10 Reclassified Slope

Annexure 9


Precipitation
N
Legend
Precipitataion
<VALUE>
130.3075867 - 188.1719127
188.1719128 - 230.3302074
230.3302075 - 268.3553359
268.355336 - 300.5940318
300.5940319 - 341.0990601
0
6,500
13,000
26,000 Meters

Annexure 10

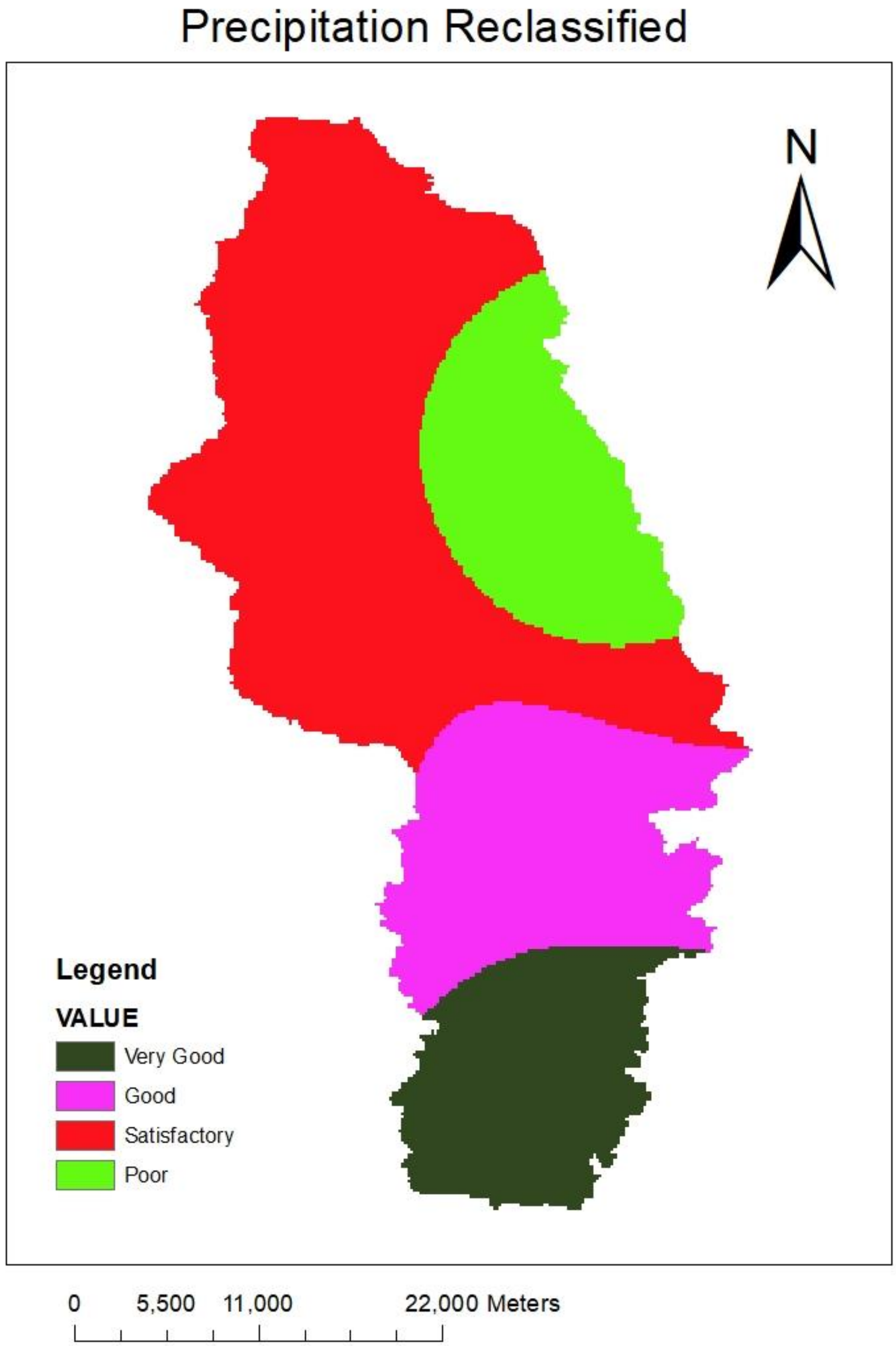


Figure 11 Precipitation Reclassified

Annexure 11

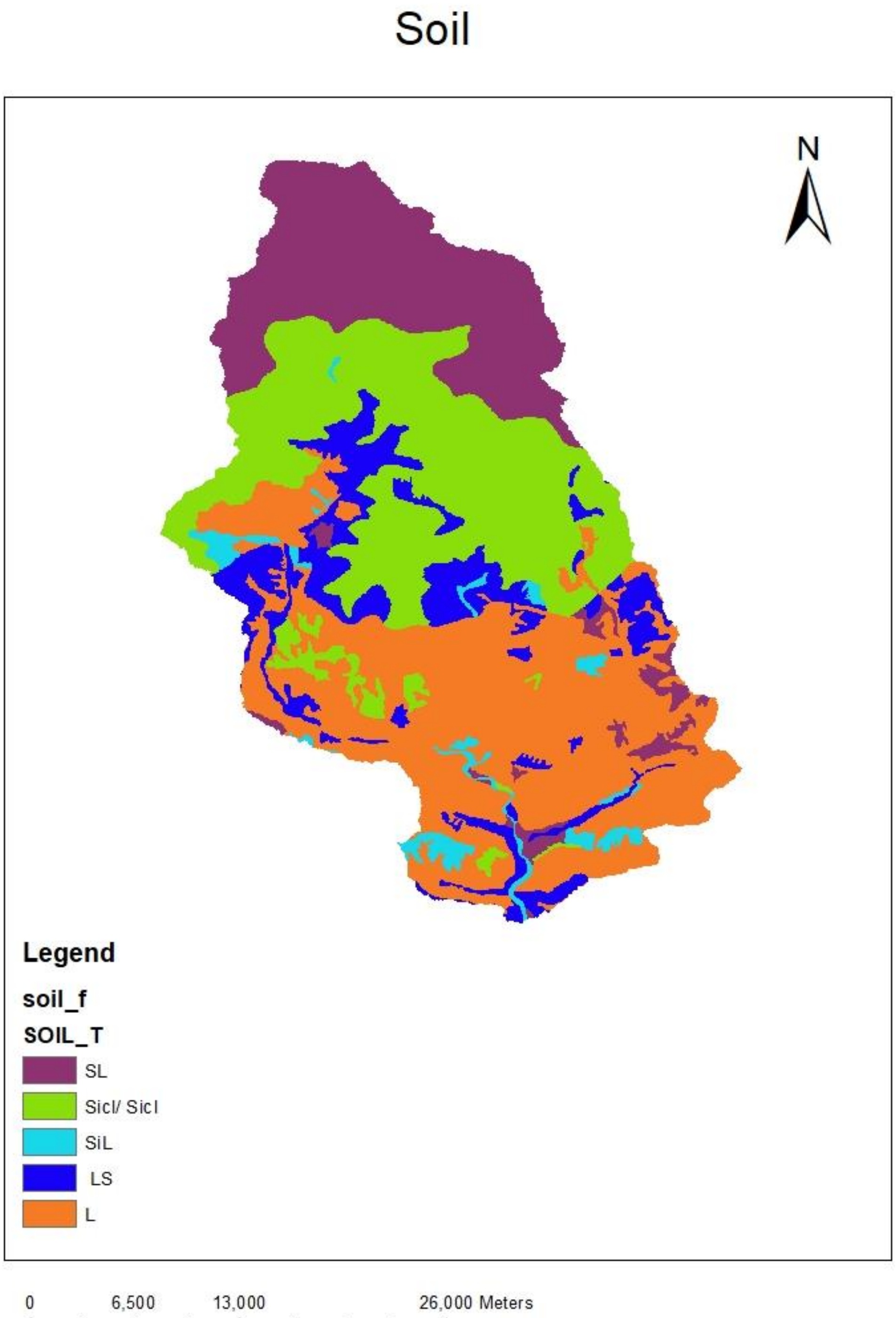


Figure 12 Soil map

Annexure 12

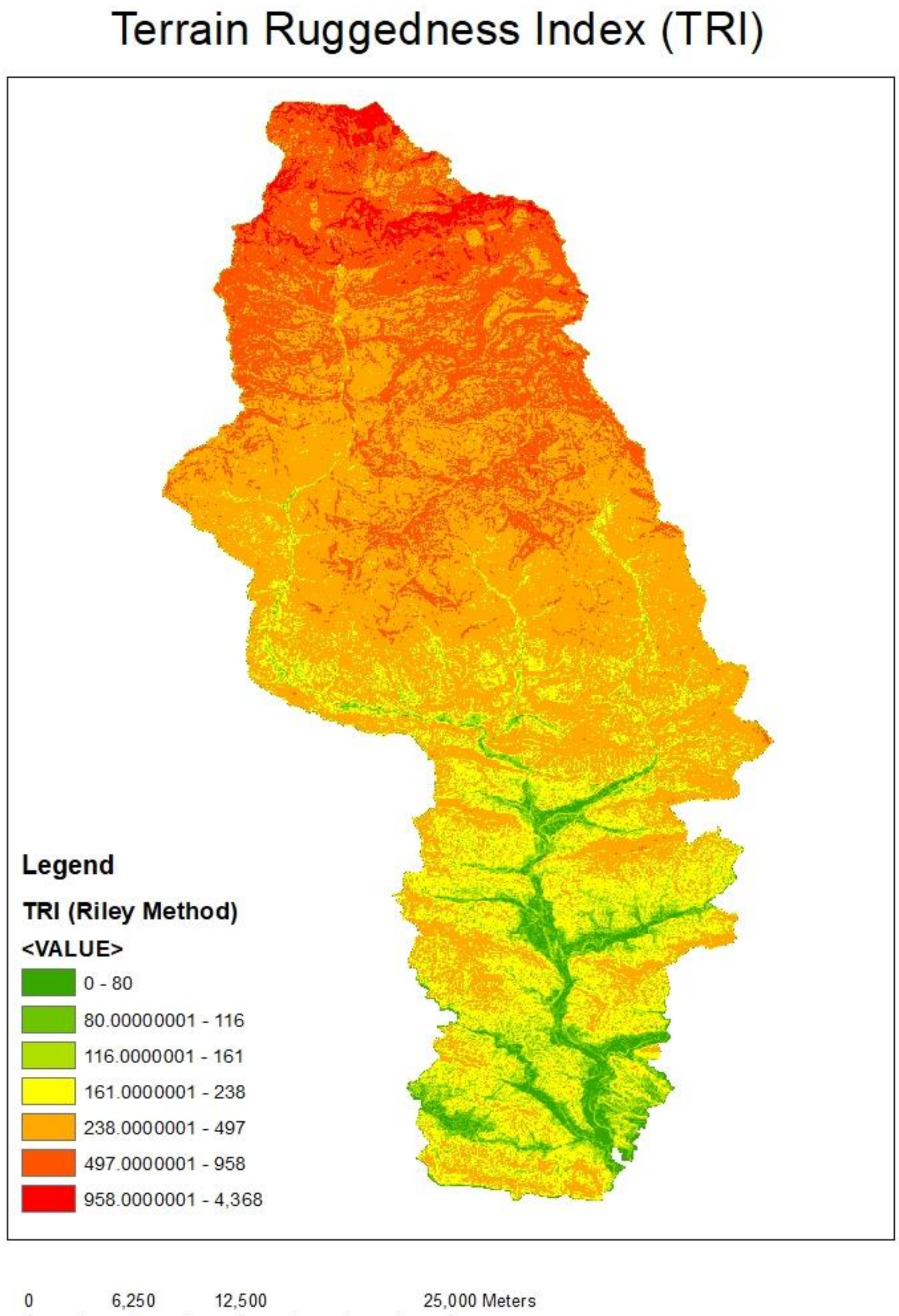


Figure 13 TRI

Annexure 13

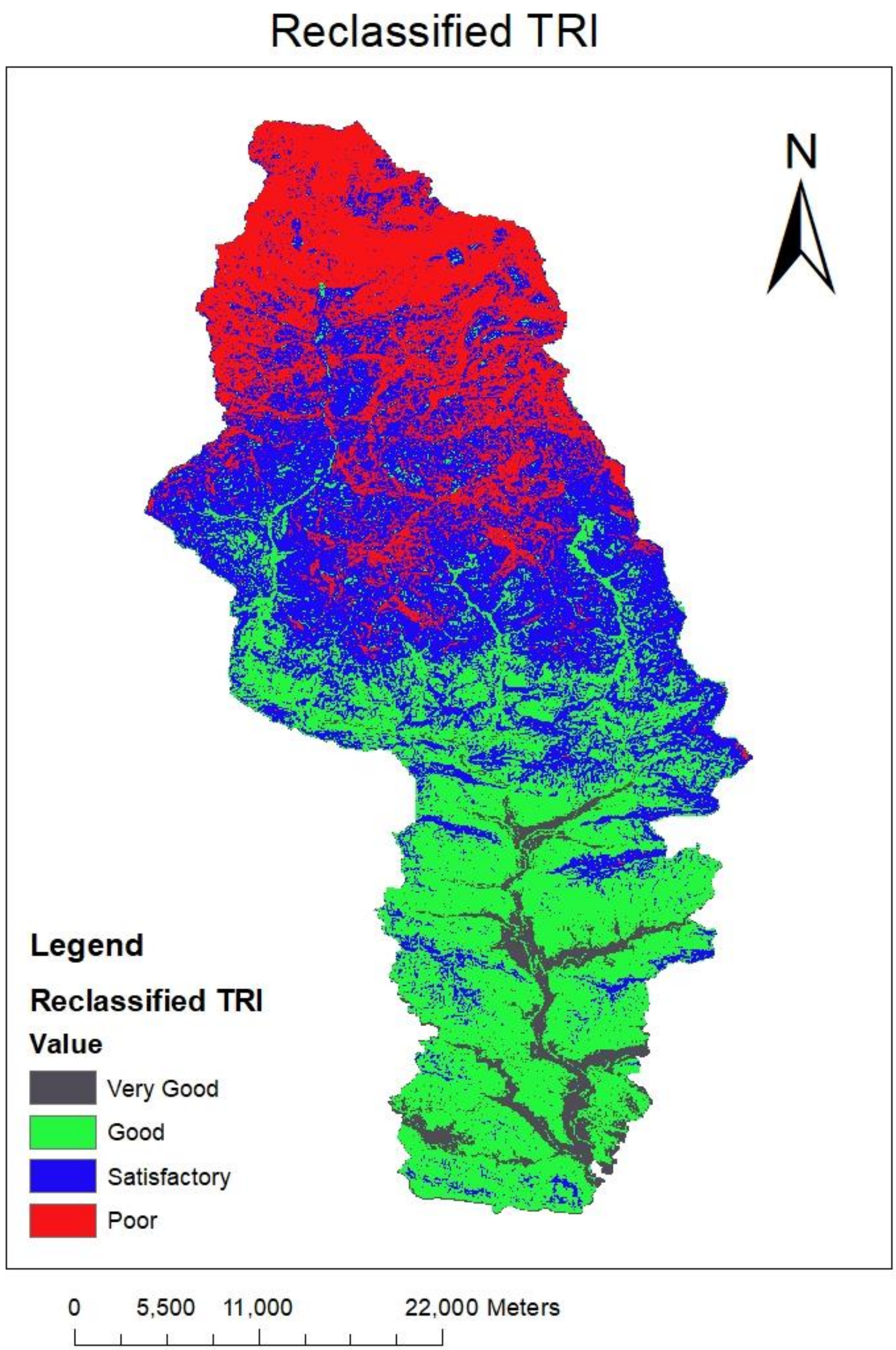


Figure 14 Reclassified TRI

Annexure 14

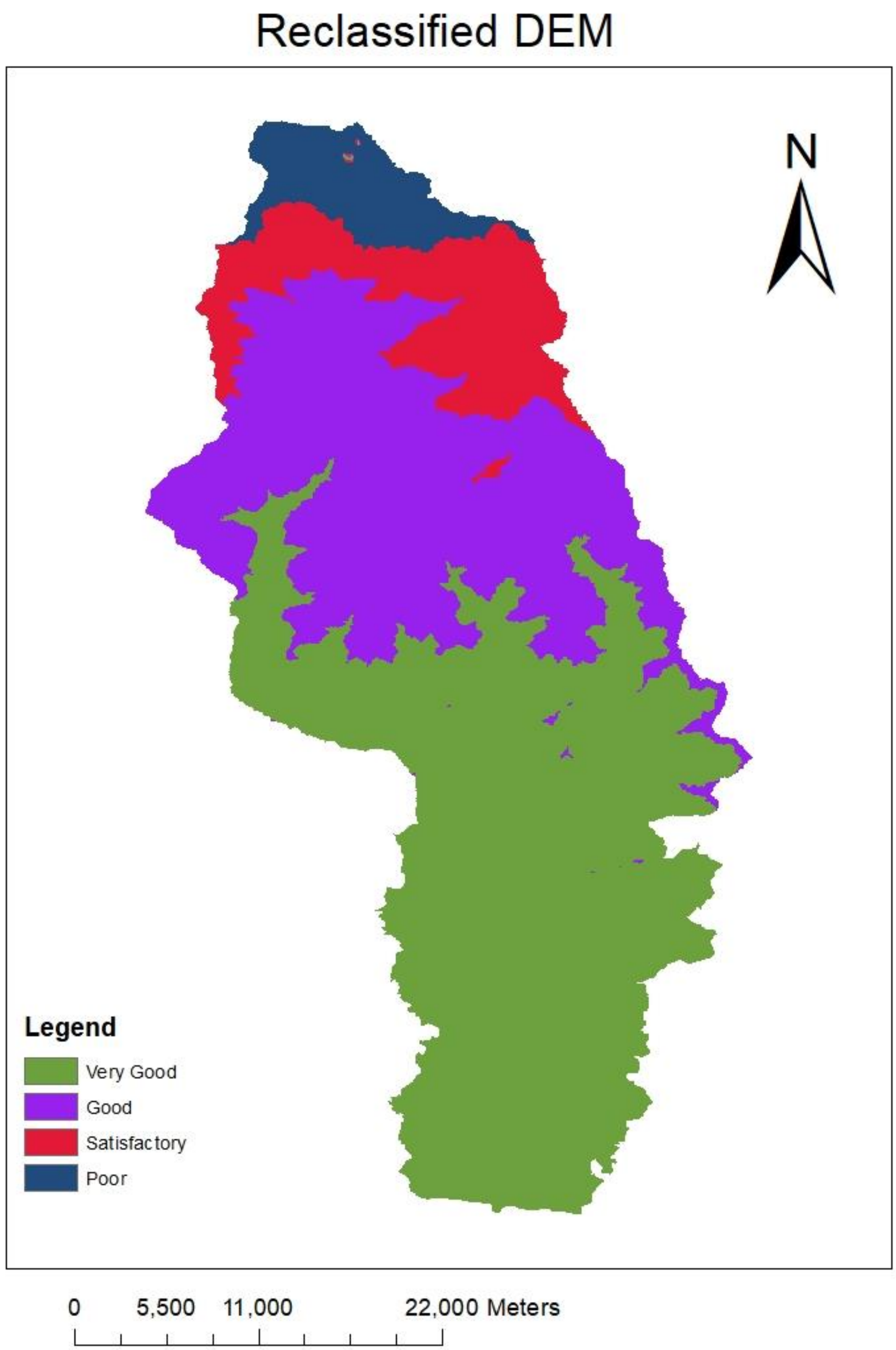


Figure 15 Reclassified DEM

Appendix

1. Precipitation monthly graph

a. January precipitation data

b. February precipitation data

c. March precipitation data

d. April precipitation data

e. May precipitation data

f. June precipitation data

g. July precipitation data

h. August precipitation data

i. September precipitation data

j. November precipitation data

k. December precipitation data

2. Python Script

```
# python script
Import arcpy module
import arcpy

# Script arguments
Elevation = arcpy.GetParameterAsText(0)
if Elevation == '#' or not Elevation:
    Elevation =
"C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Dem\\merged_dem.tif" # provide a
default value if unspecified

TRI_Riley_method_ = arcpy.GetParameterAsText(1)
if TRI_Riley_method_ == '#' or not TRI_Riley_method_:
    TRI_Riley_method_ = "C:\\Users\\Rupesh\\Desktop\\11111\\TRI1\\rugged_in"
# provide a default value if unspecified

Precipitation = arcpy.GetParameterAsText(2)
if Precipitation == '#' or not Precipitation:
    Precipitation = "C:\\Users\\Rupesh\\Desktop\\11111\\New folder\\final
prepmap\\all\\clipped_interpolated.tif" # provide a default value if unspecified

Input_DEM = arcpy.GetParameterAsText(3)
if Input_DEM == '#' or not Input_DEM:
    Input_DEM =
"C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Dem\\merged_dem.tif" # provide a
default value if unspecified

Output_Weighted_Location = arcpy.GetParameterAsText(4)
if Output_Weighted_Location == '#' or not Output_Weighted_Location:
```

```
Output_Weighted_Location = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Weighted_rec" # provide a default value if unspecified

# Local variables:
Filled_dem = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Filled_dem"
Drop = "C:\\Users\\Rupesh\\Documents\\ArcGIS\\Default.gdb\\Drop"
Flow_direc = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Flow_direc"
Basin_Flow_d1 = "C:\\Users\\Rupesh\\Documents\\ArcGIS\\Default.gdb\\Basin_Flow_d1"
Flow_accu = "C:\\Users\\Rupesh\\Desktop\\11111\\mmmm\\fac"
Stream_order = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Stream_order"
Raster_Polygon_shp = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Raster_Polygon.shp"
slope1 = "C:\\Users\\Rupesh\\Desktop\\11111\\mmmm\\slope1"
Rec_slope = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_slope"
Input_Elevation = "Value"
Rec_elev = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_elev"
Input_TRI = "Value"
Rec_TRI = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_TRI"
Input_Precipitaion = "Value"
Rec_precp = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_precp"
Rec_Flow = "C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_Flow"

# Process: Fill
tempEnvironment0 = arcpy.env.outputZFlag
arcpy.env.outputZFlag = "Same As Input"
tempEnvironment1 = arcpy.env.outputZValue
arcpy.env.outputZValue = ""
tempEnvironment2 = arcpy.env.ZResolution
arcpy.env.ZResolution = ""
```

```
tempEnvironment3 = arcpy.env.ZTolerance
arcpy.env.ZTolerance = ""
arcpy.gp.Fill_sa(Input_DEM, Filled_dem, "")
arcpy.env.outputZFlag = tempEnvironment0
arcpy.env.outputZValue = tempEnvironment1
arcpy.env.ZResolution = tempEnvironment2
arcpy.env.ZTolerance = tempEnvironment3

# Process: Flow Direction
arcpy.gp.FlowDirection_sa(Filled_dem, Flow_direc, "NORMAL", Drop)

# Process: Basin
arcpy.gp.Basin_sa(Flow_direc, Basin_Flow_d1)

# Process: Flow Accumulation
arcpy.gp.FlowAccumulation_sa(Flow_direc, Flow_accu, "", "FLOAT")

# Process: Stream Order
arcpy.gp.StreamOrder_sa(Flow_accu, Flow_direc, Stream_order, "STRAHLER")

# Process: Raster to Polygon
arcpy.RasterToPolygon_conversion(Stream_order, Raster_Polygon_shp,
"SIMPLIFY", "VALUE")

# Process: Slope
arcpy.gp.Slope_sa(Filled_dem, slope1, "DEGREE", "1")

# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(slope1, "Value", "0 1;0 89.959739685058594
2;89.959739685058594 89.992103576660156 3;89.992103576660156
89.99961853027344 4", Rec_slope, "DATA")
```

```
# Process: Reclassify
arcpy.gp.Reclassify_sa(Elevation, Input_Elevation, "51 1131 1;1131 1766 2;1766
2466 3;2466 3208 4;3208 3942 5;3942 4633 6;4633 5255 7;5255 5936 8;5936
8147 9", Rec_elev, "DATA")

# Process: Reclassify (3)
arcpy.gp.Reclassify_sa(TRI_Riley_method_, Input_TRI, "0 100 1;100 116 2;116
161 3;161 238 4", Rec_TRI, "DATA")

# Process: Reclassify (5)
arcpy.gp.Reclassify_sa(Precipitation, Input_Precipitaion, "133.55091857910156
197.20762634277344 1;197.20762634277344 244.23368835449219
2;244.23368835449219 296.82424926757812 3;296.82424926757812
353.41033935546875 4", Rec_precp, "DATA")

# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(Flow_accu, "Value", "0 70981 1;70981 251133 2;251133
740280 3;740280 1225000 4", Rec_Flow, "DATA")

# Process: Weighted Overlay
arcpy.gp.WeightedOverlay_sa("('C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\R
ec_slope' 22 'VALUE' (1 1; 2 2; 3 3; 4 4;NODATA NODATA);
'C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_elev' 9 'VALUE' (1 1; 2 2; 3
3; 4 4;NODATA NODATA);
'C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_TRI' 14 'VALUE' (1 1; 2 2; 3
3; 4 4;NODATA NODATA);
'C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_precp' 5 'VALUE' (1 1; 2 2; 3
3; 4 4;NODATA NODATA);
'C:\\Users\\Rupesh\\Desktop\\Surachit_folder\\Rec_Flow' 50 'VALUE' (1 1; 2 2; 3
3; 4 4;NODATA NODATA));1 9 1", Output_Weighted_Location)
```