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Multi-Criteria GIS Analysis for School Site Selection in Gorno-Badakhshan Autonomous Oblast, Tajikistan

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Master Thesis, 30 Credits, in *Physical Geography and Ecosystem Analysis*

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Abstract

The aim of this study is to determine the locations for school construction in two isolated mountainous communities in Gorno-Badakhshan Autonomous Oblast (GBAO) – Khorog and Porshnev towns. The study will undertake a comparative analysis of two weighting methods employed in *Multi-Criteria Decision Analysis (MCDA)*. The first one is the popular *Analytic Hierarchical Process (AHP)* and the second one is a *Rating* method that rates criteria using a common scale (allocating 100 points among all criteria). The two objectives of the research are: a) the development of a standardized set of criteria for school suitability analysis in GBAO and b) the comparative analysis of the site suitability results obtained using the two approaches (AHP versus Rating). There were six factor datasets used in the study: *distance from emergency facilities, distance from existing schools, distance from roads, distance from rivers, distance from transformers and population density* which were normalized into four scores: 1- Unsuitable, 2- Less Suitable, 3- Suitable and 4 – Most Suitable and two constraint datasets - *slope* and *hazard risk* areas. The distance buffer range was selected to suit the context of the study area. The *Rating* method included seven scenarios as a sensitivity analysis: all factors equally weighted and six scenarios where each factor was weighted five times the weight of the other five factors. In comparing the *AHP* methodology with the *Rating* methodology, the *AHP* method resulted in higher *Suitable* category values than the Rating method. Each of the seven scenarios results were influenced by the decision makers weighting allocation. AHP has been applied successfully in previous studies to tackle resource allocation, planning and conflict resolution problems. Applications using AHP have included site suitability analysis for landfill sites to identifying locations to site a windfarm. The criteria selected here are generic and could be used to identify location of medical facilities, place of worship and other facilities in the region.

Keywords: multi-criteria decision analysis, analytical hierarchical process, GIS, school site selection, disaster risk reduction

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List of Acronyms

AHP – Analytic Hierarchy Process

AKDN – Aga Khan Development Network

BEI – Built Environment Initiative

CI – Consistency Index

CR – Consistency Ratio

DEM – Digital Elevation Model

FHI – Flood Hazard Index

GBAO – Gorno-Badakshan Autonomous Oblast

MADM – Multi-Attribute Decision Making

MCDA – Multi-Criteria Decision Analysis

MFI – Modified Fournier Index

MODM – Multi-Objective Decision Making

NAIP – National Agriculture Imagery Program

NDVI – Normalized Difference Vegetation Index

SAW – Simple Additive Weighting

SRTM – Shuttle Radar Topography Mission

UTM – Universal Transverse Mercator

1. Introduction

Gorno-Badakhshan Autonomous Oblast (GBAO), Tajikistan's eastern-most province, occupies roughly half of the country's area and is home to the Pamir mountain range with an altitude ranging between 2000m and 5000m above sea level (See Figure 1). In recent decades, this region has become increasingly vulnerable to natural disasters. A major contributing factor to this vulnerability is the fact that very little land is available for human settlement and agriculture. In 2007, Tajikistan's population density was estimated to be 48.2 people per sq. km, but considering that much of the country's surface area (93%) is mountainous and not arable, the population density per sq. km of arable land amounted to 488 people per sq. km – one of the highest in the world (Khodjamuradov & Rechel, 2010).

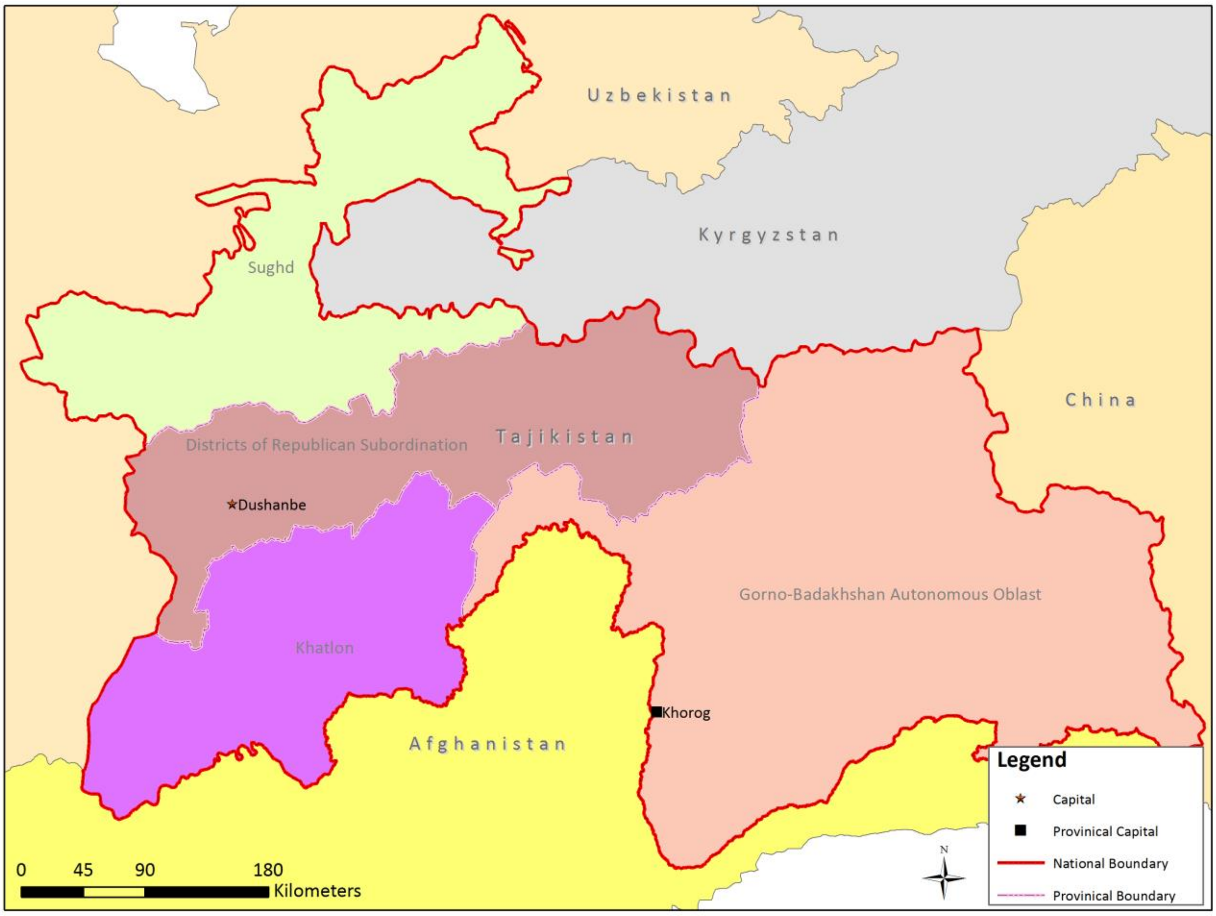


Figure 1: Tajikistan and neighbours

In the Western Pamirs, the area where this research is focused, arable land accounts for only 240 km^2 which is equivalent to 0.4% of the total area of GBAO. Arable land and areas of settlement are concentrated primarily on alluvial fans and river banks (Breu & Hurni, 2003). Consequently, inhabitants cannot avoid living in or adjacent to areas prone to hazards such as floods and debris flows. (FOCUS Humanitarian Assistance USA, 2010). The region is also prone to landslides, avalanches and rockfall.

In responding to the challenge of risk assessment and mitigation of natural disasters in these isolated mountainous communities of GBAO, my research Seeks to answer the question: **Where should schools be located in isolated mountainous communities?** In other words, the aim is to identify suitable areas for school construction that reduces the vulnerability of schools in this highly seismically charged region.

To answer this question, there are several approaches available in the domain of Multi-Criteria Decision Analysis (MCDA), where the basic premise is that a decision maker(s) is presented with a set of conflicting alternatives of varying standards of measurement.

Broadly speaking, multi-criteria decision rules can be divided into two main groups; MADM – Multi-Attribute Decision Making and MODM – Multi-Objective Decision Making (Jankowski, 1995). In MADM, problems and alternatives are defined explicitly rather than implicitly as in MODM. The modelling paradigm is outcome based in MADM whereas in in MODM it is more process oriented. The choice of the method will be largely determined by the problem being solved. For example, in the case of site selection, landuse suitability, vulnerability or environmental impact assessment MADM would be a suitable choice. On the other hand, for location-allocation, transportation and shortest path related problems, MODM would be more appropriate (Malczewski & Rinner, 2015).

In the case of MADM, methods like weighted linear combination, Analytic Hierarchical Process (AHP), outranking methods and ideal point methods are typically employed. MODM on the other hand involves the use of linear/integer programming, goal programming and heuristics (Malczewski & Rinner, 2015).

In this paper, the *Analytic Hierarchical Process* (AHP) weighting method along with the Rating weighting method (allocating 100 points among all criteria) as a comparison were selected to demonstrate how a decision maker's choice of weights and selection of criteria can influence the final results. Moreover, the choice of the *Rating* weighting method served as a sensitivity analysis test in that each of the factors was weighted three times greater than the remaining five factors. This is used to demonstrate the decision maker's perception of one factor over the other.

In addition, the selection of the criteria in this paper may be applicable to the suitability of other facilities such as hospital or a place of worship and therefore generic in nature.

The *AHP* method was selected for this research as it lends itself well to the hierarchical nature of the project. The breaking down of the goal into criteria and sub-criteria is best tackled through the use of this methodology.

The analysis will include both compensatory methods (Weighted Linear Combination, also known as simple additive weighting) where criteria scores are normalized and then multiplied by their weights versus non-compensatory techniques that completely exclude areas that don't meet a certain criterion, via the classification of data sets to 0 or 1 Boolean values. In a compensatory MCDA approach, a high score of an alternative achieved in one criterion is traded off for the low score received on another criterion. On the other hand, in a non-compensatory approach, a low criterion score for an alternative cannot be offset by another criterion's high score.

There are four main themes that have been selected for this analysis;

1. ***Hazard/Risk*** – 1. *Hazard zone areas*- specifically (landslide, avalanche, rock fall, flood-zone and debris flow). 2. Digital Elevation Model – used to derive a slope gradient raster. Slope gradient was chosen to eliminate areas that had steep slopes. The selected hazards are the most common hazards in the area. Between 1996 and 2010, 29% of the deaths in the country were related to avalanches and 6% to landslides (Disaster Risk Management Initiative, 2013). The topography of the study area - a valley with a river and steep slopes on either side makes it particularly vulnerable to these hazards.

2. ***Environment*** – *rivers* – debris flow chutes laden with soil and fragmented rock roll down steep slopes and deposit their load into rivers causing rivers to overflow their banks, furthermore rapid glacier meltwater into rivers may also contribute to flood hazard risk. The further away the river the better the location suitability.

3. ***Economic*** – 1. *Emergency Facilities* - distance buffer from facilities such as hospitals, clinics, emergency communication centres and safe havens were created. The closer the facility, the better suited the location. 2. *Roads* – distance buffer from roads, the closer the road the higher the location suitability. 3. *Transformer* - The transformer stations convert hydro- electric power to electricity for transmission across households in Khorog and Porshnev. The further away from transformers, the more desirable the location.

4. **Social** – Includes the following datasets: 1. *Activity zones* are used to provide the study area extent for the analysis. 2. *Population density* - A denser population signifies demand for the service, thus the more desirable the suitability of the location. 3. *School* – the further away from existing schools, the higher the suitability ranking.

   The following objectives need to be realised in order to meet the goal of the research project i.e. the *identification of suitable areas for school siting*;

- The development of a standardized set of criteria for school suitability analysis in GBAO.
- The comparative analysis of the site suitability results obtained using the two approaches (AHP versus Rating).

1.1 Literature Review

In order to proceed further with the methodology used in this paper, the following is a brief overview of some of the studies that have adopted a similar strategy in site selection suitability analysis.

The first study - ***A New Approach to School Site Suitability Assessment: A Case Study in Durham, North Carolina*** (Liddle, 2013) describes the work of a GIS graduate student at the University of Minnesota, who undertook a study to determine suitable locations to build a public high school in Durham County, North Carolina which had Seen an influx of over 50,000 permanent residents between 2000 and 2010 and consequently put a strain on the county's infrastructure.

To address this problem, a geographic information system (GIS) was integrated with a multiple criteria decision making (MCDM) method to identify suitable locations for a public high school. Through the use of GIS and MCDM, suitability assessment took into account not only spatially relevant data but also analytical planning. The selected criteria were divided into three main themes; environmental impacts, safety concerns and accessibility.
This study used an established GIS-based MCDM method known as the analytic hierarchy process (AHP). The basic AHP approach, developed by Saaty (1980), used a structured hierarchy to determine the relative importance of each criterion.

The three selected themes and their associated criteria were:

1. *Environment* – Slope, land cover, distance from managed areas (private and public lands and easements of conservation interest, distance from natural heritage areas, and distance from hazardous wastes.

2. *Safety* – Distance from flood zones, distance from fire stations, distance from police stations and distance from emergency medical services

3. *Accessibility* - Distance from libraries, distance from public high schools, distance from major roads and number of people under the age of 15.

Due to inadequacies associated with the use of National Land Cover Data for county level analysis, image classification was performed using 1-metre colour infrared aerial imagery obtained from the National Agriculture Imagery Program (NAIP). A normalized difference vegetation index (NDVI) was calculated via the NDVI function which generated a new raster with pixel values between 0 and 200 depending on the green vegetation intensity. Pixel values that were under 102 were considered as constraints as they represented water bodies, buildings and parking lots. The raster was classified as suitable = 1 and unsuitable = 0. The three rasters (1 for each of the three themes) were normalized to a common scale of 1-5 where higher values represented most suitable sub criteria. The normalization was performed because of the differing nature of the criteria and thus a common scale was needed to combine the factors together. Finally, each of the suitability rasters was multiplied by a constraints raster to arrive at a suitability map for school locations.

The second study - ***Spatial multi-criteria decision analysis for safe school site selection*** (Bukhari & Noordin, 2010)examined the use of GIS with multi-criteria evaluation and the Analytical Hierarchy Process (AHP) in primary school site selection planning in Malaysia.

School site selection in Malaysia has traditionally been undertaken by multiple departments each working independently to define a set of criteria for school selection planning. Consequently, this led to a non-transparent and redundant use of resources with some school sites even falling into contaminated areas.

The criteria for the analysis were divided into three categories:

1. I*nfrastructure* - distance from industrial area, distance from commercial area, distance from the main road and distance from electrical transmission line.

2. *Environmental* - broken down into the Air Pollution Index (API) reading, noise level reading and distance from stream.

3. *Physical* theme - comprised of slope, height and flood plain. In addition to the above 10 sub-criteria, the location of existing schools was also included in the analysis.

Each criterion was normalized to a common scale ranging from 1- not suitable, 2-less suitable, 3-suitable, 4-most suitable. A pairwise comparison was performed for each of the sub-criteria in the categories above and a weight assigned to each sub-criteria. The factors and constraints rasters were combined to arrive at a suitability map. In this study, the constraints were identified as reserve areas for transportation, electricity, stream, park and land greater than sixty meters in height.

The third paper - ***A study on school location suitability using AHP in GIS approach*** (Samad et al., 2012)demonstrated the use of GIS and the Analytical Hierarchy Process (AHP) in the identification of suitable locations for school construction in Northern Malaysia. The goal of the study was to evaluate and revise existing criteria for school construction using the AHP methodology to arrive at three suitability categories; most suitable, suitable and less suitable.

In the modeling process four factors were chosen:

1. Population density below 19 years of age.
2. Topography – to evaluate slope risk.
3. River network – to minimize flood risk.
4. Road network – to maximize accessibility.

The four layers from above and two additional layers (a cadastral layer consisting of household locations and an existing school locations layer) were used in the analysis. Each of the four factors was normalized to five scores: Score 1 – less suitable, Score 3 – suitable, Score 5 – moderate suitable, Score 7 – highly suitable, Score 9 – extremely suitable. After the scoring process, weighting was allocated using the AHP pairwise comparison. The weights were multiplied to each of the four layers and then summed together. The final layer was overlaid on the existing school layer and cadastral layer. The minimum area requirement for a school in this study was five hectares.

The fourth paper - ***Multi-Criteria Decision Analysis integrated with GIS and remote sensing for astronomical observatory site selection in Antalya province, Turkey*** (Koc-San et al., 2013), while not directly related to school location optimization, the methodology was nonetheless relevant to the analysis employed in my thesis. The study described a methodology that used multi-criteria decision analysis with the Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW) and remote sensing to identify the most suitable sites for constructing a new astronomical observatory in Antalya province, Turkey.

The rationale for this construction was that rapid population growth and the subsequent massive construction had given rise to bright lighting at night, impeding observations from the existing observatory. In addition to light pollution, mining activities had increased near the observatory leading to suspended dust particles in the atmosphere thereby decreasing atmospheric transparency.

The study involved the use of eleven criteria divided into three categories; meteorological, physical and anthropogenic.

The *meteorological* sub-criteria included precipitable water and cloud cover. Both these data sets were extracted from the Moderate Resolution Imaging Spectrometer (MODIS) imagery between January 2009 and December 2011.

The *geographical* data sets consisted of digital elevation model (DEM), geology, landslides, active fault lines and earthquake zones. The DEM was developed from the Shuttle Radar Topography Mission data set, the remainder of the information was made available by the ministry of mineral research and exploration.

The *anthropogenic* data sets comprised of city lights, distance to villages, distance to roads and point density maps of mining sites.

The main steps in the suitability assessment process were as follows:

1. Identification of the criteria to be used in the analysis; in this case the 11 vector layers were used.
2. Generation of distance rasters and project to WGS84 datum and Lambert conformal conic projection.
3. Normalization of all layers to a range between 0-0.25, 0.25-0.50, 0.50-0.75 and 0.75-1.0. Lower values were an indication of less desirable areas whereas higher values a reflection of higher desirability.
4. A pairwise comparison for all the eleven criteria using the AHP methodology.
5. Multiplication of each raster by its weight and aggregation to arrive at a final suitable raster.

It is important to note that the determination of ranking in the pairwise comparison matrix was conducted by decision makers who were experts in in astronomical observations, geosciences, meteorology and urban planning.

A fifth study - ***A site planning approach for rural buildings into a landscape using spatial multi-criteria decision analysis methodology*** (Su Jeong et al., 2013) examined the use of GIS, multi-criteria decision analysis, AHP and SAW to identify suitable locations to site a new single dispersed tourism-related commercial building in the northern Spain. The rapid tourism influx in the region coupled with massive urban to rural settlement gave rise to immense clustering placing immense pressure on environmental resources. The aim of this paper was to solve the rural building integration problem with the surrounding landscape through the use of a flexible methodology from which decision makers could evaluate from multiple criteria (fifteen in total). Three main themes were selected; physical, environmental and economic.

The *physical* theme consisted of; elevation (elevation greater than 1725m was excluded), slope, aspect (south and west orientation less suitable), vegetation type and visibility.

The *environmental* theme was based on the following sub-criteria; presence of sensitive ecosystem, presence of water source (springs or ground water wells), presence of surface water (lakes, rivers and continuous water flows), land use type and proximity to urban area.

Finally the *economic* theme was broken down into; site access, population density, proximity to residential area, proximity to tourist area and proximity to agricultural area. The method used for this analysis was the following:

1. The vector layers were converted to raster and Euclidean distance was calculated for proximity to residential, tourist and agricultural area.
2. Pairwise comparison was done for each of the categories, for example the five sub-criteria in the physical category were compared with one another and assigned weights, this was repeated for the environmental and economic categories.
3. All sub-criteria in the three categories were then quantified to a common scale between 0 (least suitable) and 10 (most suitable).
4. The pairwise comparison was carried using a panel of experts consisting of professors, regional policy makers, planners and local authorities.
5. Consistency Ratio (CR) was calculated by dividing Consistency Index (CI) by Random Inconsistency (RI). The consistency ratio calculated for each of the three categories was less than 0.1 (the threshold specified by Saaty).

The study resulted in the illustration of four scenarios;

a) The three categories (physical, environment and economic) were each equally weighted at 0.33.

b) The physical category was allocated a weighting of 0.50 and the remaining two 0.25 each.

c) The environmental category was assigned a value of 0.50 and the remaining two 0.25 each.

d) The economic category was assigned a value of 0.50 and the remaining two 0.25 each.

Sites with suitability rating between 0 and 4 were considered unsuitable; sites between 9 and 10 were considered the best sites for the proposed study.

A sixth study - **Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece** (Kazakis, Kougias, & Patsialis, 2015). Flooding in February 2015 in North Eastern Greece resulted in 20,000 to 30,000 hectares of farm land being flooded and consequently a huge impact on the local economy. This paper describes the development of a Flood Hazard Index (FHI) using multi-criteria analysis.

The seven criteria that were selected for the FHI were:

1. Flow accumulation – It was the most important parameter in defining flood hazard. Accumulated flow sums water flowing down-slope into cells of the output raster. Pixel values (15, 125-50, 250) were assigned a score of 10 (worst) and pixel values (0-731) were assigned a value of 2 (best).

2. Distance from drainage network – Areas near the river network (< 200m) have a high flood risk whereas the effect of the parameter decreases in distance (> 2000m). The scores assigned are 10 and 2 respectively.

3. Elevation and slope – water flows from higher to lower elevations and therefore slope influences the amount of surface run-off and infiltration. Flat areas in low elevation may flood quicker than areas in higher elevation and steeper slope. The chosen values for elevation were (0-124) assigned a value of 10 and (699-1440) assigned a value of 2. For slope (%), the values in the range of (0-2) were assigned a score of 10 and (35-60) were assigned a score of 2.

4. Landuse – This has an influence on infiltration rate. Forest and lush vegetation favor infiltration whereas urban and pasture areas support overland flow of water. Urban-wetlands were assigned a score of 10 and mixed forest a score of 2.

5. Rainfall Intensity – Rainfall intensity is expressed using the Modified Fournier Index (MFI) which measures the sum of average monthly rainfall intensity at each gauge station. The range (159-193) was assigned a score of 10 and range (59-88) was assigned a value of 2.

6. Geology – This influences amplification/extenuation of the magnitude of flood events. Impermeable rocks such as crystalline favour surface runoff and karst formations significantly affect the triggering of flash floods. On the other hand, alluvial and continental deposits contribute to high infiltration capacity. Crystalline rocks were assigned a score of 10 and alluvial rocks a value of 2.

The methodology used for the analysis was the following:

1. A 7 x 7 matrix was created using pairwise comparison and AHP

2. All the 7 criteria were then normalized to a common scale between 2 (most suitable) and 10 (least suitable).

3. The consistency index was calculated as 0.08 which is less than 0.1 and therefore acceptable.

4. Multiplication of each raster by its weight and aggregation to arrive at a final suitable raster.

The last study - **Integration of GIS and Multicriteria Evaluation for School Site Selection - A Case Study of Belgut Constituency** (Talam & Ngigi, 2015) examined the use of GIS with multi-criteria evaluation and the Analytical Hierarchical Process in primary school site selection in Kenya.

The study area in Belgut constituency in Kericho County, Kenya had schools with less than minimum land size, over enrolment and close to flood prone areas.

The twelve criteria chosen for this study were:

1. Proximity to major road ways – closer to major road ways was associated with high noise levels and site related traffic. A 0m -150m buffer was assigned a value of 1 – not suitable and buffer distances greater than 450m were assigned a value of 4 – most suitable.

2. Noise – daytime sound level measured in decibels. Decibels between 0-50 are assigned a value of 4 and decibels greater than 70 are not suitable or 1.

3. Air pollution index - values between 0-50 are most suitable and values greater than 150 are not suitable.

4. Proximity to high voltage power lines – distance buffer between 0m – 150 m are unsuitable whereas buffer distance greater than 450m were most suitable.

5. Proximity to flood areas – buffer distances of between 0m – 500m are not unsuitable and distance greater than 1500m are most suitable.

6. Distance from streams – distances between 0m – 500m are unsuitable and distances greater than 450m are most suitable.

7. Proximity to factories – fumes and noise are associated with proximity to factories hence distances between 0m – 500m are unsuitable and distances greater than 500m are most suitable.

8. Proximity to other schools – distances between 0m – 1000m were unsuitable and distances greater than 2000m most suitable.

9. Slope – gradient greater than 30 degrees is unsuitable and slopes less than 15 degrees most suitable.

10. Proximity to schools with expansion space - certain schools have the potential of being expanded due to ample expansion room. Distances between 0m – 2000m were unsuitable and distances greater than 4000m were deemed most suitable.

11. Population density per square km – values between 0m and 200m were unsuitable and distances greater than 400m most suitable.

12. Distance from towns – distances between 0m – 300 m were unsuitable and distances greater than 900m were most suitable.

The methodology used for the analysis was the following:

1. A matrix was created using pairwise comparison and AHP

2. All the 7 criteria were then normalized to a common scale between 1 (unsuitable) and 4 (most suitable).

3. Multiplication of each raster by its weight and aggregation to arrive at a final suitable raster.

Based on the relevant literature review, few studies on school suitability analysis have incorporated risk and hazard information as criteria for decision making. Furthermore, those that have done so have fallen short of being exhaustive in the inclusion of factors such as the location of earth quake zones, active fault lines and hazard layers such as landslides, avalanches and debris flows.

2. Materials and Methods

The software used for this analysis was Esri ArcGIS 10.2.2 with the Spatial Analyst extension.

Table 1 describes the datasets and their respective sources used in the analysis.

Dataset Name	Description	Category	Source	Year
Activity Zone	Polygon feature class defined as all areas the community visits on a daily basis. See section 7.2 for more details.	Social	Focus Humanitarian Assistance Hazard Vulnerability and Risk Assessment Database	March 2012
Digital Elevation Model	SRTM 90m Digital Elevation Model	Physical	DEM from the Consortium for Spatial Information (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1#download)	February 2000
Hazard Zone	Polygon feature class of Avalanche, Bank Erosion, Debris Flow, Flooding, Landslide and Rock fall	Hazard/Risk	Focus Humanitarian Assistance Hazard Vulnerability and Risk Assessment Database	March 2012
Emergency Facility	Point feature class of hospitals, safe havens and Radio Communication Stations	Economic	Focus Humanitarian Assistance Hazard Vulnerability and Risk Assessment Database	March 2012
Transformer	Point feature class for Hydro Power Conversion station	Economic	Focus Humanitarian Assistance Hazard Vulnerability and Risk Assessment Database	March 2012
School	Point feature class of school	Social	Focus Humanitarian Assistance Hazard Vulnerability and Risk Assessment Database	March 2012
River	Polyline feature class of the river network	Environment	Aga Khan Development Network – Disaster Risk Management Initiative Spatial Data Infrastructure Database	June 2012
Road	Polyline feature class of the road network	Economic	Aga Khan Development Network – Disaster Risk Management Initiative Spatial Data Infrastructure Database	June 2012
Population	Population Density 100m Resolution Tajik Population Statistical Data	Social	World Pop Datasets www.worldpop.org.uk/ Agency on Statistics under the President of the Republic of Tajikistan www.stat.tj/en/	2015 Projected 2012,2013 and 2014

Table 1: Datasets used in the analysis

Table 2 describes values used to generate the distance buffers and their associated scores.

Distance from Emergency Facilities (in metres)	Score	Classification
0 - 300	4	Most suitable
300 - 600	3	Suitable
600 - 900	2	Less Suitable
Greater than 900	1	Unsuitable
Distance from Transformer (in metres)		
0 - 500	1	Unsuitable
500 - 1000	2	Less Suitable
1000 - 1500	3	Suitable
Greater than 1500	4	Most Suitable
Distance from School (in metres)		
0 – 1000	1	Unsuitable
1000 – 1500	2	Less Suitable
1500 - 2000	3	Suitable
Greater than 2000	4	Most Suitable
Distance from River (in metres)		
0 - 200	1	Unsuitable
200 - 400	2	Less Suitable
400 - 600	3	Suitable
Greater than 600	4	Most Suitable
Distance from Road (in metres)		
0 - 150	4	Most Suitable
150 - 300	3	Suitable
301 - 450	2	Less Suitable
Greater than 450	1	Unsuitable
Population Density (per pixel)		
0	1	Unsuitable
0.01 – 0.02	2	Less Suitable
0.03 – 0.17	3	Suitable
Greater than 0.17	4	Most Suitable
Slope (in percentage)		
0 – 20	1	Suitable
Greater than 20	0	Unsuitable
Natural Hazards		
Outside hazard polygon	1	Suitable
Inside hazard polygon	0	Unsuitable

Table 2: Factors and Constraint Criterion Scores

2.1 Preparation of the data for analysis.

The choice of study area for this analysis was based on the availability of the datasets from the AKDN Built Environment Initiative. The AKDN Built Environment Initiative (BEI) currently includes about a dozen urban and rural pilot projects, which will be used to test scalable strategies that promote more disaster-resilient and intelligent planning at the municipal scale. Four Built Environment pilot projects were chosen for Tajikistan, two of which have been selected for this analysis. The first one is Khorog – the capital of Gorno-Badakhshan Autonomous Oblast. It has a population of 25,475. The second is Porshnev consisting of 9 villages Vozm, Barchid, Kushk, Buwed, Midenshor, Khosa, Tishor, Jirodj and Pashor. It has a population of 1,559 (Disaster Risk Management Initiative, 2013).

The two main areas for the analysis - Khorog and Porshnev towns (See Figure 2) were extracted from the Focus Humanitarian Assistance Risk Assessment ***activity zone*** feature dataset.

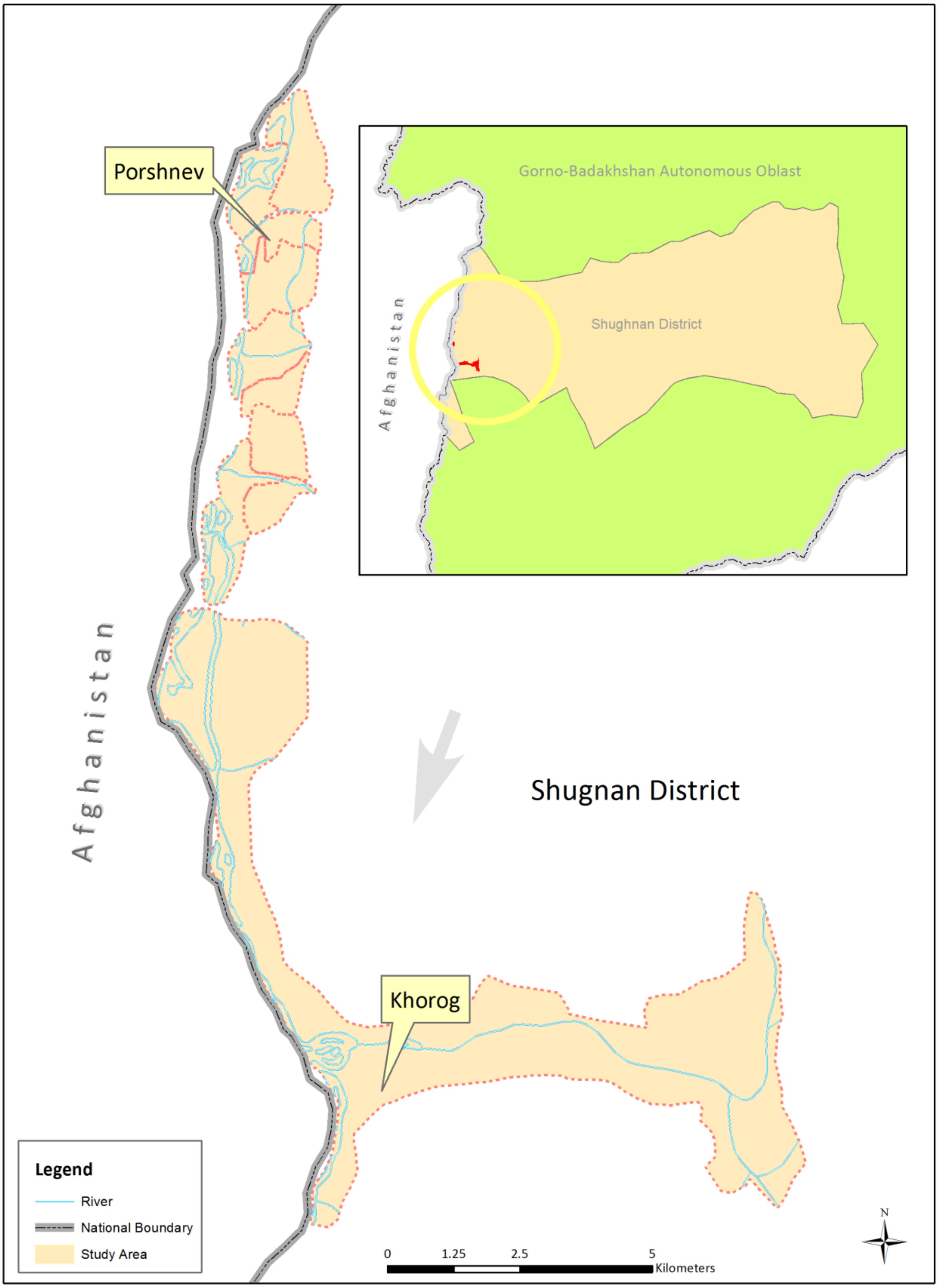


Figure 2: Study Area - Khorog and Porshnev Town

An *activity zone* is defined as all areas the community visits on a daily basis. In a rural area, it is mainly comprised of the households, the irrigated areas, the exploited forests and the low pastures located close to the village. In many cases, the activity zone will encompass all the relatively flat areas around the village. To evaluate the extent of the activity zone, assess whether a new house can be built in this area or if future development could occur in this area, where applicable, the official boundaries of the village can be used to define the activity zone. In any case, the activity zone will never extend beyond the official boundaries of the village. Each activity zone might include one or more ***living zones***. This implies that the general shape of an activity zone is a filled polygon, not a doughnut-like polygon (Henriot & Merchant, 2012).

A *living zone* is defined as a continuous plot of land where households are located. It is accepted that the density of houses is relatively even within a living zone. If a village is clearly split in two or more spatially distinct communities, different living zones must be digitized. A living zone must always be completely included in an activity zone. In extreme cases, the living zone can exactly cover the full extent of its activity zone, but it cannot extend beyond. If a single house is located out of the main residential areas, it must be considered as a separate living zone. If a single non-housing infrastructure (education, health, utility etc.) is located out of the main residential areas, it must not be considered as a separate living zone. If a single non-housing infrastructure (education, health, utility etc.) is located within a residential area, it must be included in the living zone of this residential area (Henriot & Merchant, 2012).
The task of establishing the activity zones was imperative in the creation of the remaining datasets, since activity zone determined the clipping extent and the mask used in creating distance buffers for the subsequent datasets. More importantly, the extent of the activity zones provided the baseline of the population distribution for these two areas. One of the main challenges in conducting this research was the lack of georeferenced demographic data in the region (See Figure 3, next page).

The areas of the Porshnev and Khorog Activity Zones are 7,634,435 sq. m and 19,167,737 sq. m respectively. Khorog is about 2.5 times the size of the Porshnev Activity Zone.

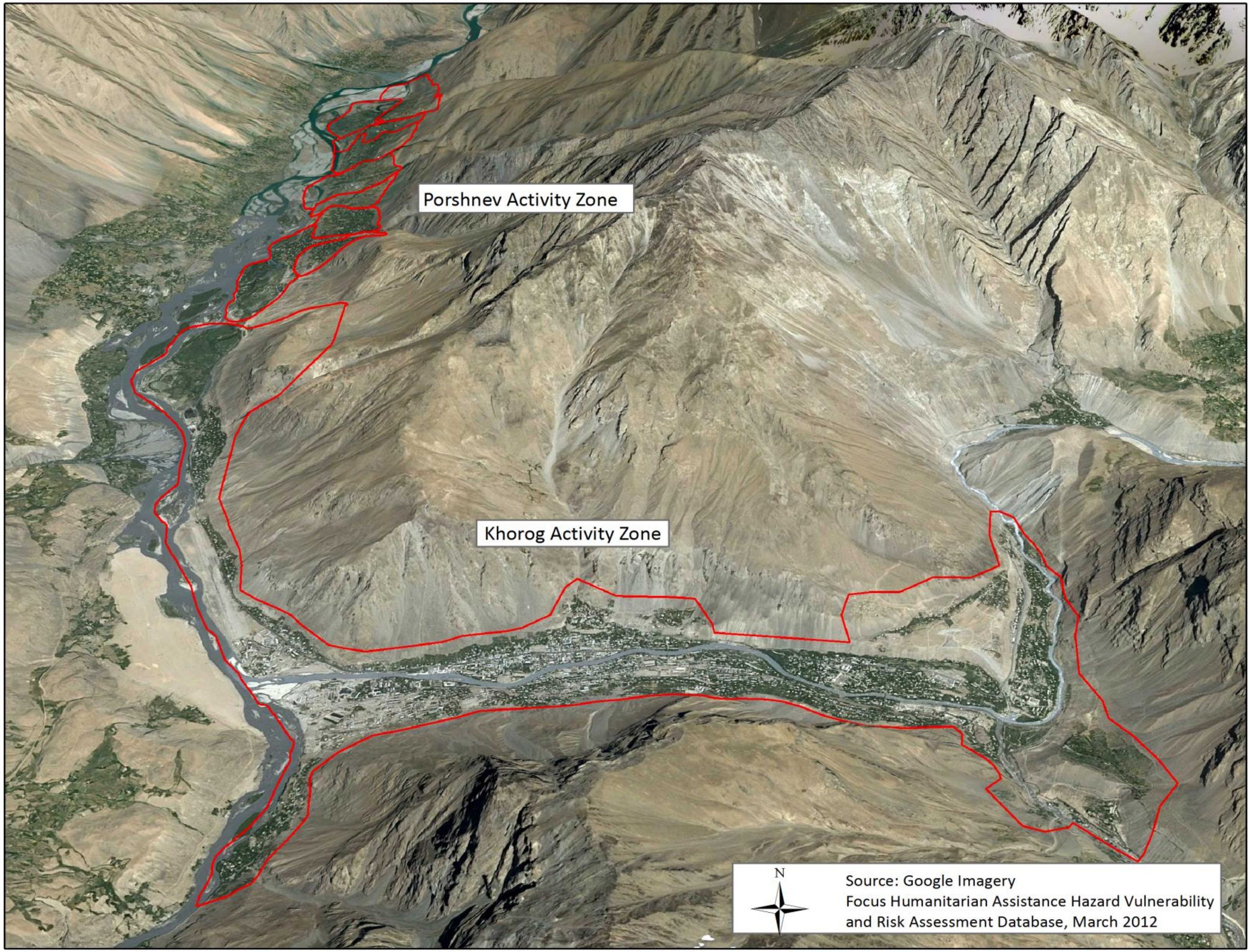


Figure 3: Khorog and Porshnev Activity Zones

2.2 Preparation of the constraints datasets

The two constraint datasets used in the analysis were ***slope*** and ***hazard risk*** areas.

2.2.1 Slope constraint dataset

Since the slope dataset was not readily available as part of the FOCUS Humanitarian Assistance Risk Assessment database, a 90m Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) was downloaded from the Consortium for Spatial Information website (See Table 1, page 16) for data source information).

The activity zones defined in section 2.2 earlier were used as clipping extents for the DEM. The DEM was projected to WGS 84 UTM Zone 43N to correspond to the UTM zone of the study area (See Figure 4)

Figure 4: Khorog and Porshnev, Digital Elevation Model

Slope is an important criterion given the mountainous terrain of this region, consequently natural disasters such as landslides, avalanches and rock-fall are more frequent in areas with steep slopes. Furthermore, areas that are flat along steep slopes are also vulnerable to natural hazards. In addition, sites with steep slopes present immense challenges in school construction.

The DEM was then converted into a ***slope*** raster dataset using the ArcGIS Spatial Analyst Extension. The slope values were expressed as a percentage.

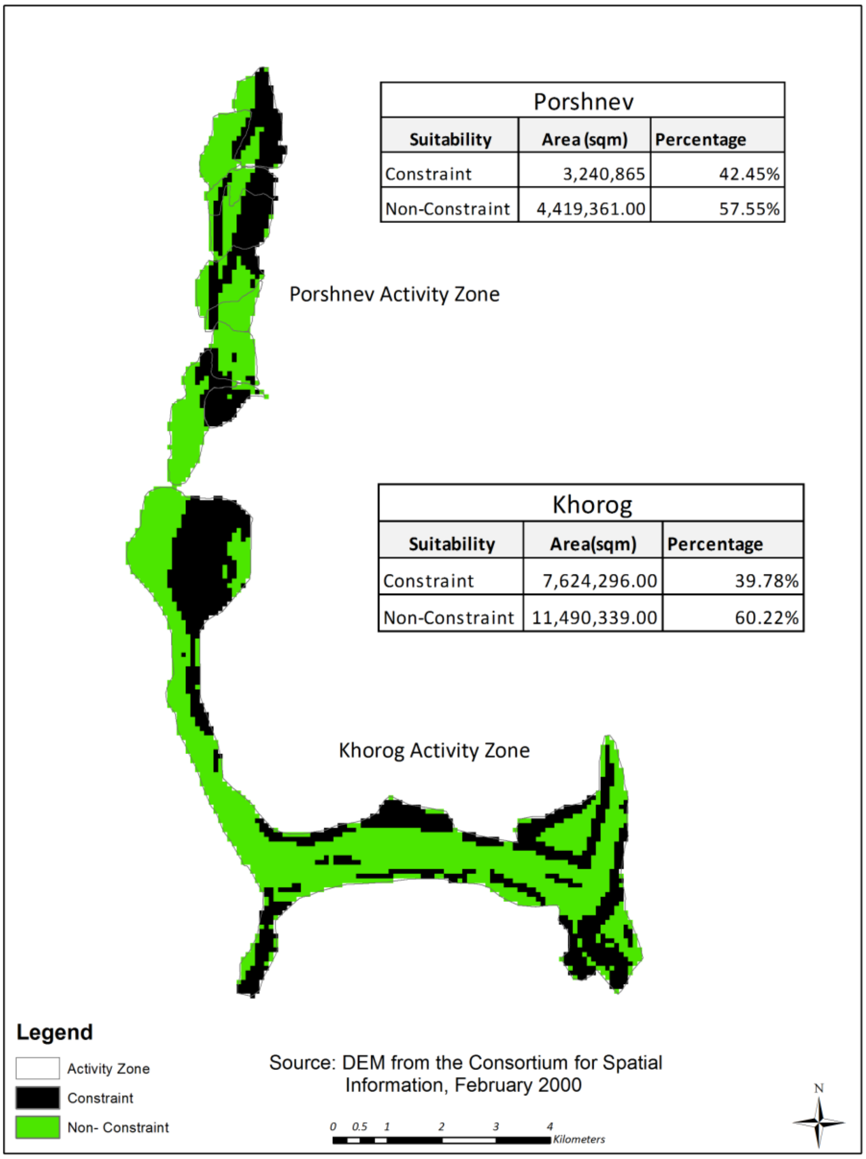
Porshnev activity zone is characterized by steep slopes in the north east whereas Khorog activity zone is characterized by steep slopes in the north, the central part of the zone and to the south east (See Figure 5).

Figure 5: Khorog and Porshnev, Slope

For this analysis, Slope with values between **0% and 20%** were classified as *suitable* and assigned a value of 1 whereas Slope with **greater than 20%** were considered *unsuitable* and assigned a value of 0**.**

The threshold values were adopted and modified based on a similar school site selection paper by (Samad et al., 2012). The slope map (See Figure 5, previous page) was reclassified into Boolean values using the Spatial Analyst *Reclassify* function.

The *constrain*t area in Porshnev town represents **42.45%** of the activity zone whereas the *non-constraint* area represents **57.55%** of the activity zone. In the case of Khorog, the *constrain*t area represents **39.78%** of the activity zone and the *non-constraint* area represents **60.22%** of the activity zone (See Figure 6).



Porshnev		
Suitability	**Area (sqm)**	**Percentage**
Constraint	3,240,865	42.45%
Non-Constraint	4,419,361.00	57.55%

Khorog		
Suitability	**Area(sqm)**	**Percentage**
Constraint	7,624,296.00	39.78%
Non-Constraint	11,490,339.00	60.22%

Figure 6: Khorog and Porshnev, Slope Constraint

2.2.2 Hazard risk dataset

The second constraint – Hazard Risk areas was derived using the hazard zone feature class from the FOCUS Humanitarian Assistance Tajikistan database. The hazard zones (See Figure 7) were extracted for the two areas.

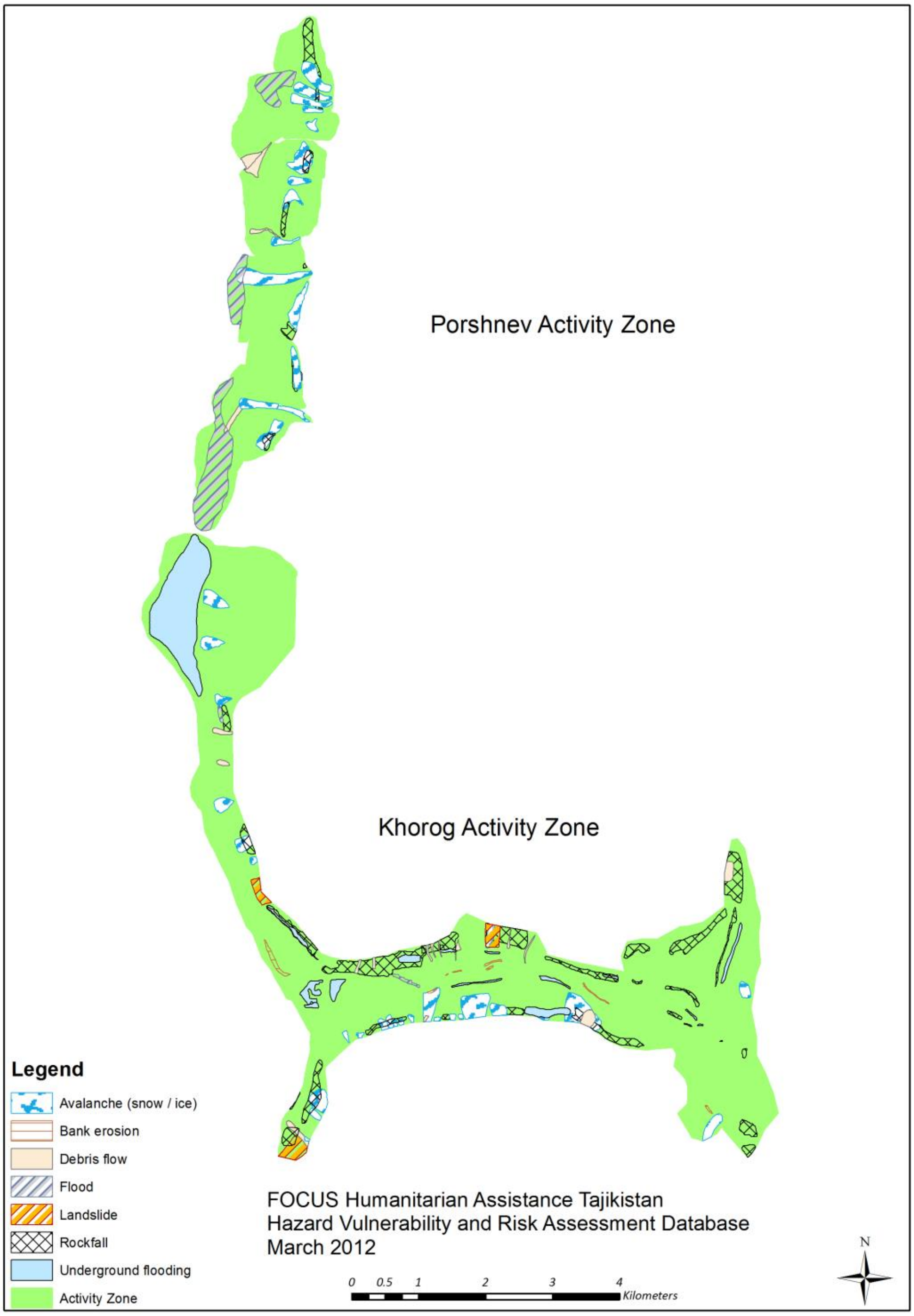


Figure 7: Khorog and Porshnev, Natural Hazards Distribution

A distance buffer (See Figure 8) was created from the natural hazards distribution feature class using the Spatial Analyst Euclidean distance function.

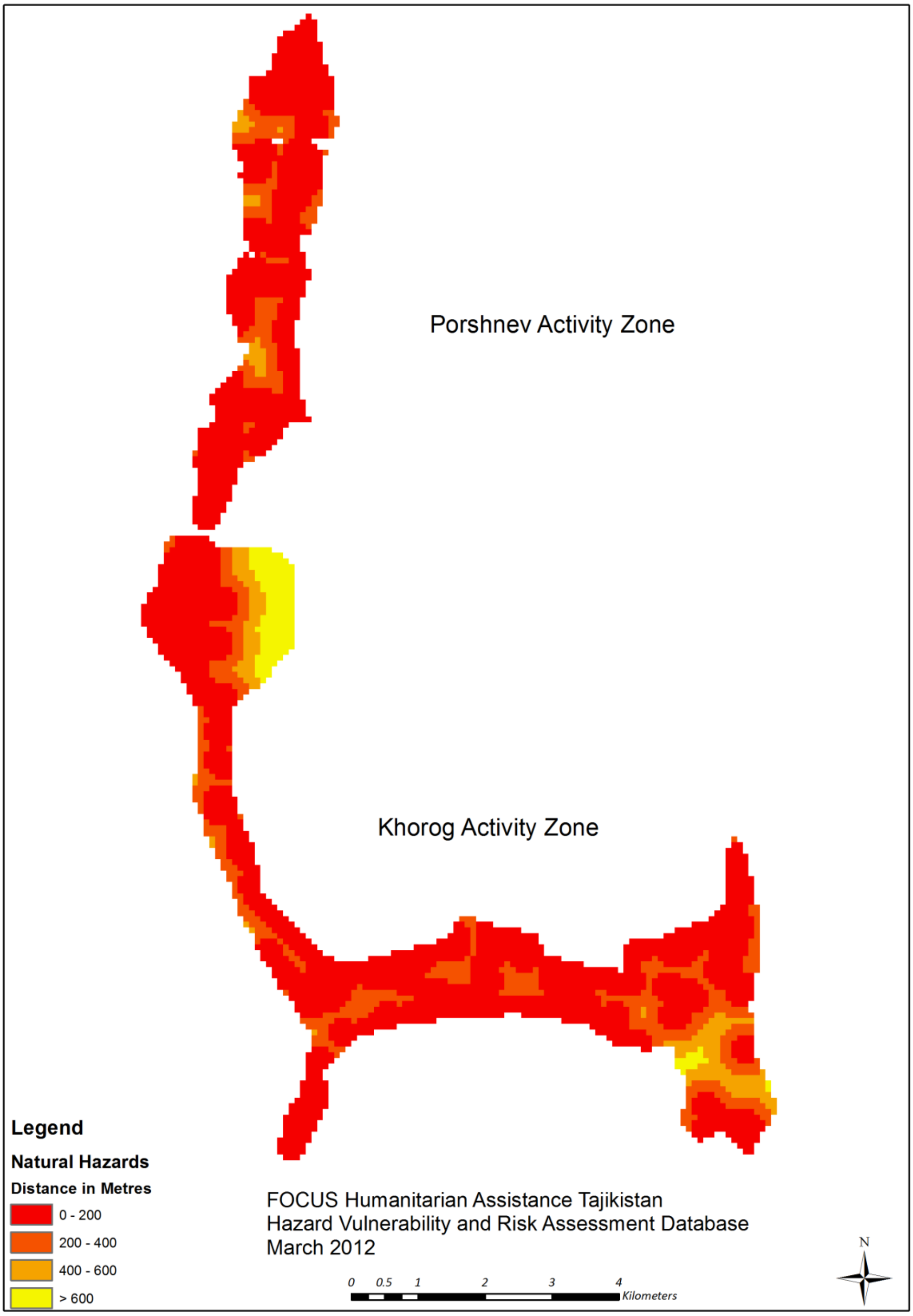


Figure 8: Khorog and Porshnev, Natural Hazards Buffer

The *reclassify function* was used to reclassify the raster into Boolean values (See Figure 9). A small portion in the northern and southern part of the Porshnev zone is classified as *constraint* areas whereas the majority of the area (69%) is classified as *non-constraint*. In contrast, the northern and central parts of Khorog activity zone are classified as constraint zone. Approximately (78%) of the activity zone is classified as *non-constraint.*

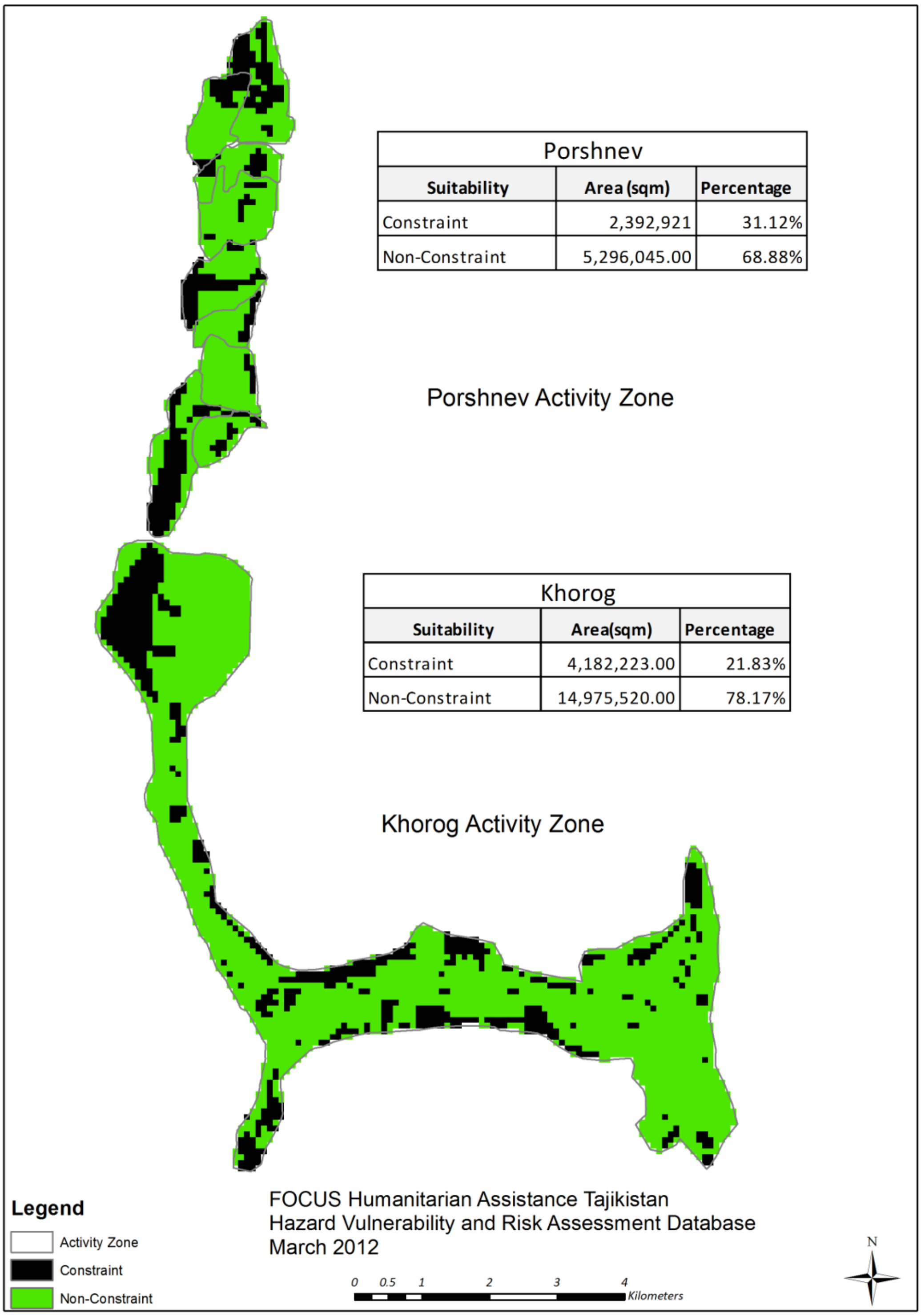


Figure 9: Khorog and Porshnev, Natural Hazards Constraint

The data for this study was provided by the **Aga Khan Development Network – Disaster Risk Management Initiative.** This data was collected by **Focus Humanitarian Assistance's** experienced team of geologists who have been archiving and assessing hazard risk in the region for over two decades. This provided an exciting and unique opportunity for undertaking this study.

2.3 Preparation of the factors datasets

There were six factor datasets used in this analysis (*emergency facilities, roads, rivers, transformers, existing schools and population density*). All the factor datasets were also clipped to the extent of the activity zone and projected to WGS 84 UTM Zone 43N to correspond to the UTM zone of the study area

2.3.1 Emergency facilities

The first factor dataset used in the analysis was **emergency facilities** (See Figure 10, next page). The buffer distance chose was between 0m and 900m. In this study, emergency facilities consisted of three subtypes. 1. *Medical facility* – these facilities can provide rapid assistance during the event of an emergency 2. *Emergency communication* – In the event of a natural disaster, Codan high frequency radios provide the ability to request assistance and are particularly suited for high mountainous communities where cell phone frequencies are often not available. 3. *Safe haven* – Stock piles of non-perishable food and blankets are stocked in containers next to safe haven areas and are therefore easily accessible in the event of a natural disaster. In Porshnev, there are four medical facilities and twelve safe havens. In contrast, in Khorog there are six emergency communication facilities, four medical facilities and twenty one safe havens. The distances were assigned a score based on proximity to an emergency facility i.e. the closer the facility, the higher the score (4), the further the facility the lower the score (1). See Table 2, page 12 for distance and scores.

Figure 10: Khorog and Porshnev, Emergency Facilities

The distances were then reclassified using the Spatial Analyst's reclassification function and assigned a suitability ranking (See Figure 11). The majority of Porshnev activity zone is deemed *suitable* and *most suitable*, except for the northern and southern tip of the activity zone. In contrast, in Khorog, the *suitable* and *most suitable* areas are situated in the central part of the activity zone. The *unsuitable* areas are located in the north and north east.

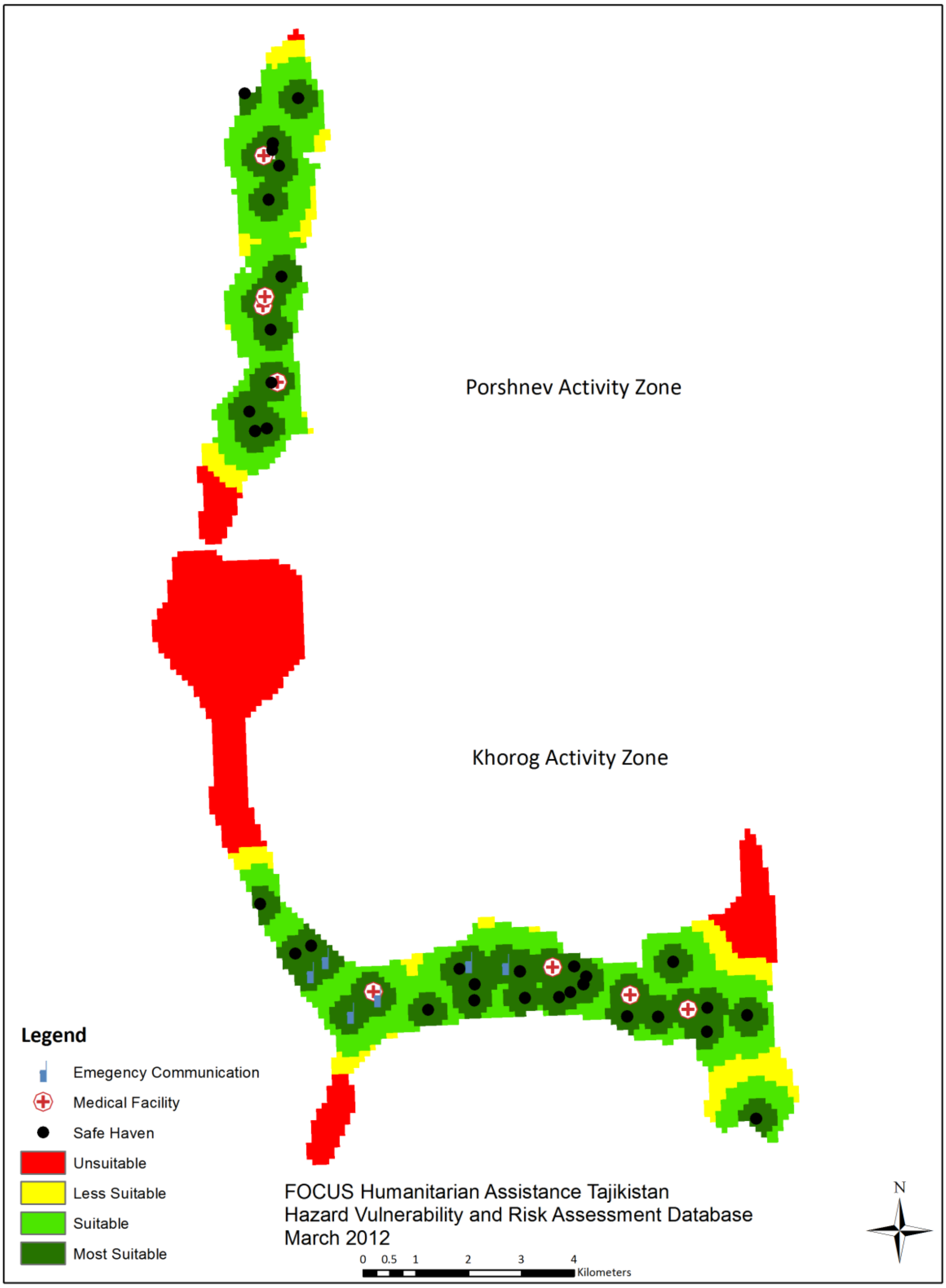


Figure 11: Khorog and Porshnev, Emergency Facilities Suitability

2.3.2 Existing schools

The second factor dataset used in the analysis was **existing schools** (See Figure 12). The buffer distance used was between 0m and 2,000 m. This is based on how far a pupil should walk to school. The buffer distance used for this factor was identical to the research done by (Talam & Ngigi, 2015). In determining optimum buffer distances from schools, the School Siting Guidelines (United States Environmental Protection Agency, 2011) were consulted. The guidelines outlined that the maximum acceptable walking/biking distance for high school children in the US is 1.5 miles or approximately 2,400 m.

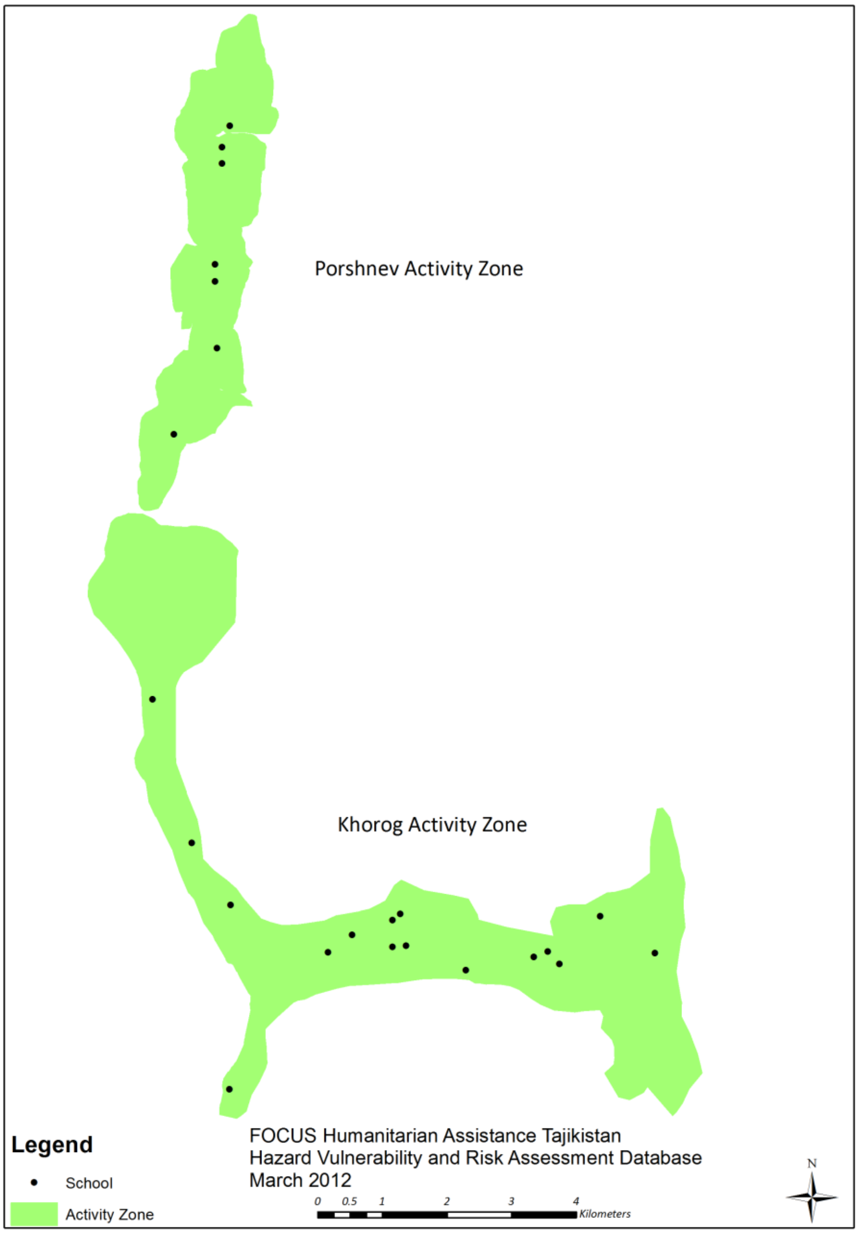


Figure 12: Khorog and Porshnev, Existing Schools

The suitability map based on distance from existing schools is illustrated in Figure 13. In evaluating suitability based on the location of existing schools, the northern tip of Porshnev activity zone is classified as *less suitable* and *suitable* whereas in Khorog, the northern tip and the north east and south east sections are deemed *suitable* and *most suitable*.

There are seven schools in Porshnev and sixteen schools in Khorog.

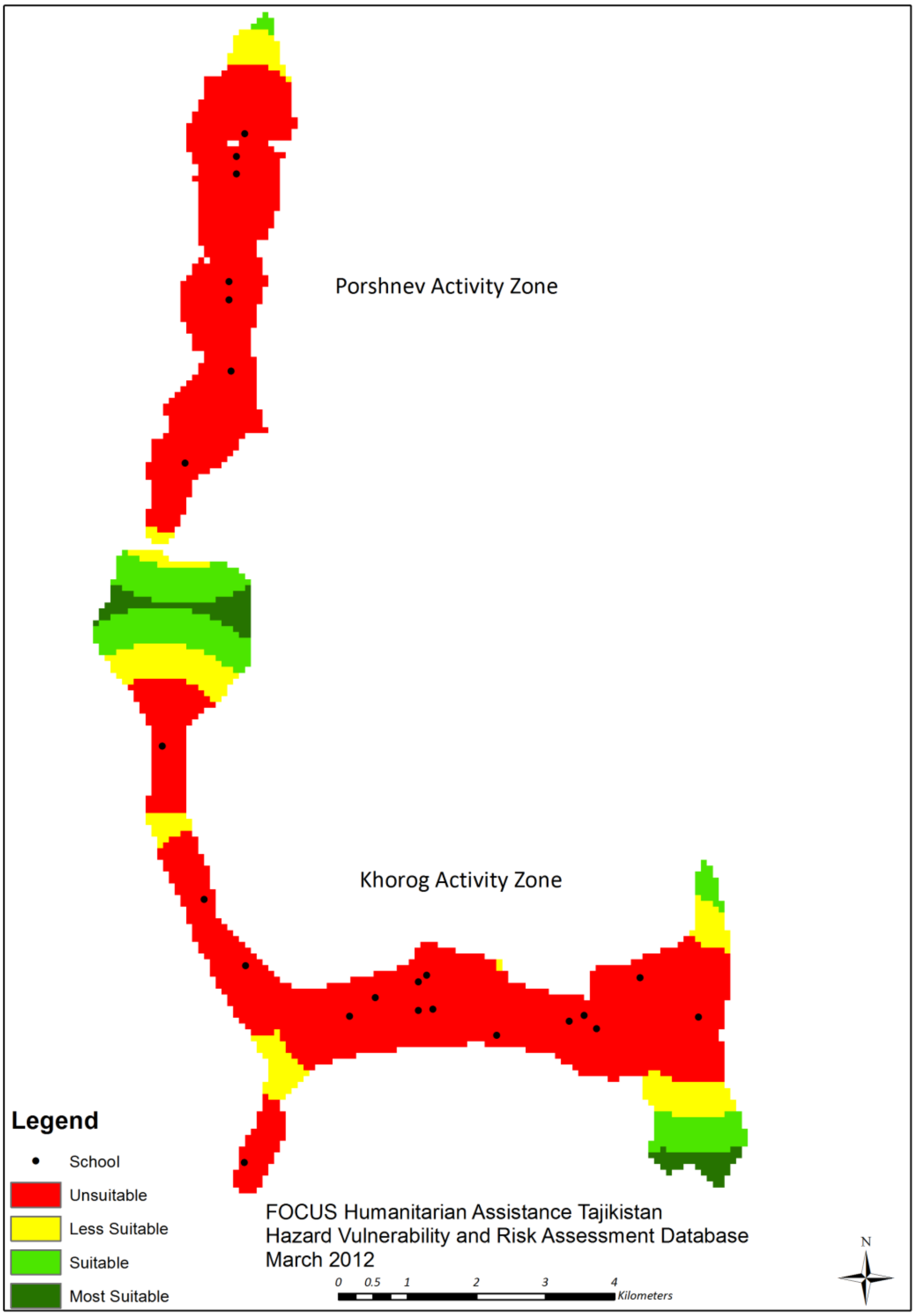


Figure 13: Khorog and Porshnev, Existing Schools Suitability

2.3.3 Transformers

The third factor dataset is **transformers**. In this study, from a safety perspective, the further away from a transformer station, the more suitable the site.

The chosen buffer range for this criterion was between 0m and 1500m. There are a total of fourteen transformer stations in Porshnev and fifty four in Khorog (See Figure 14).

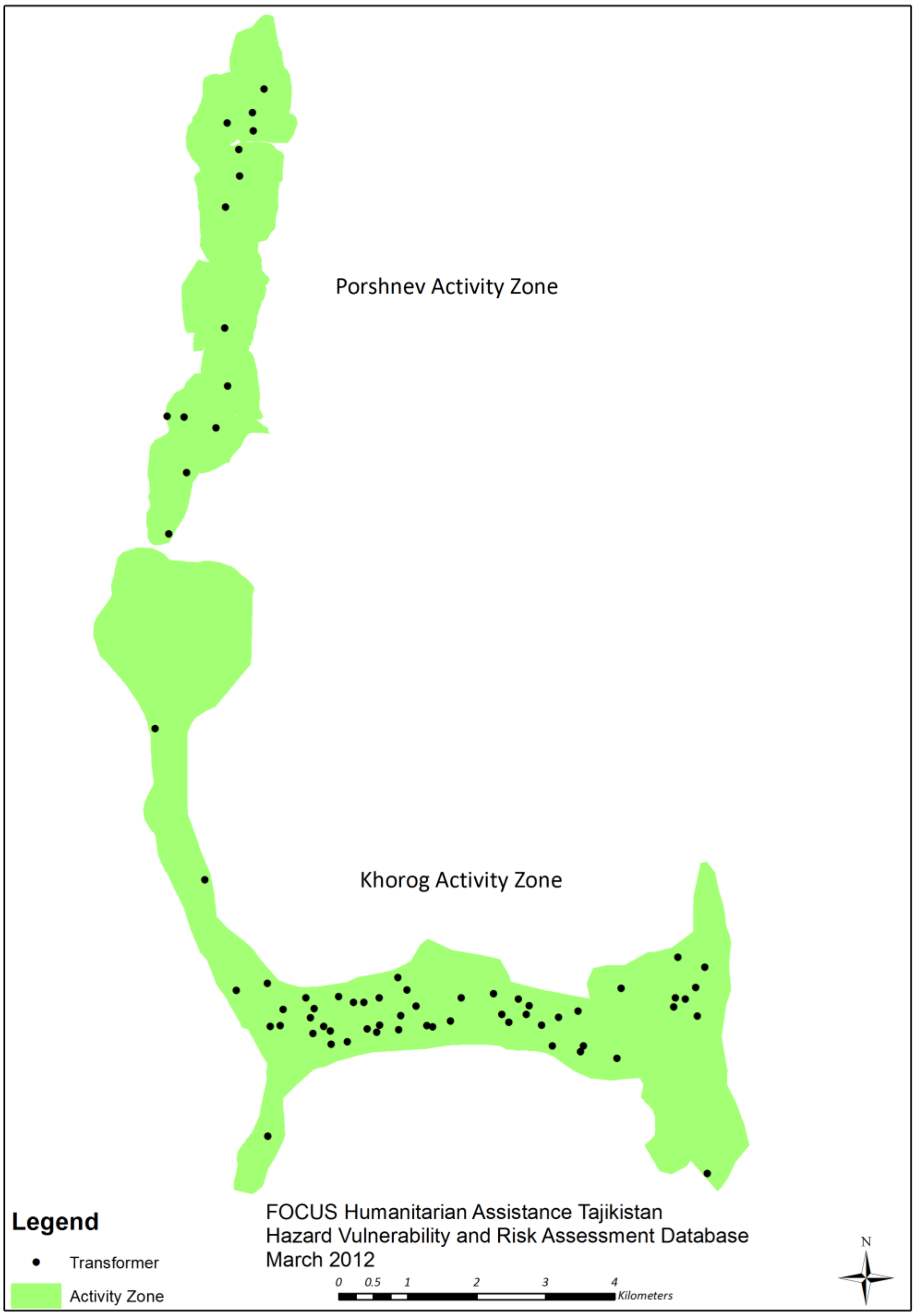


Figure 14: Khorog and Porshnev, Transformers Distribution

The distance buffer was reclassified (See Table 2 for buffer distance) and assigned a suitability ranking (See Figure 15). On the basis of transformers, the picture is similar to that of existing schools, i.e. the northern and central parts of Porshnev are classified as *suitable*. In Khorog, the northern tip of the zone is characterized by *less suitable*, *suitable* and *most suitable* categories including the north east and south east parts.

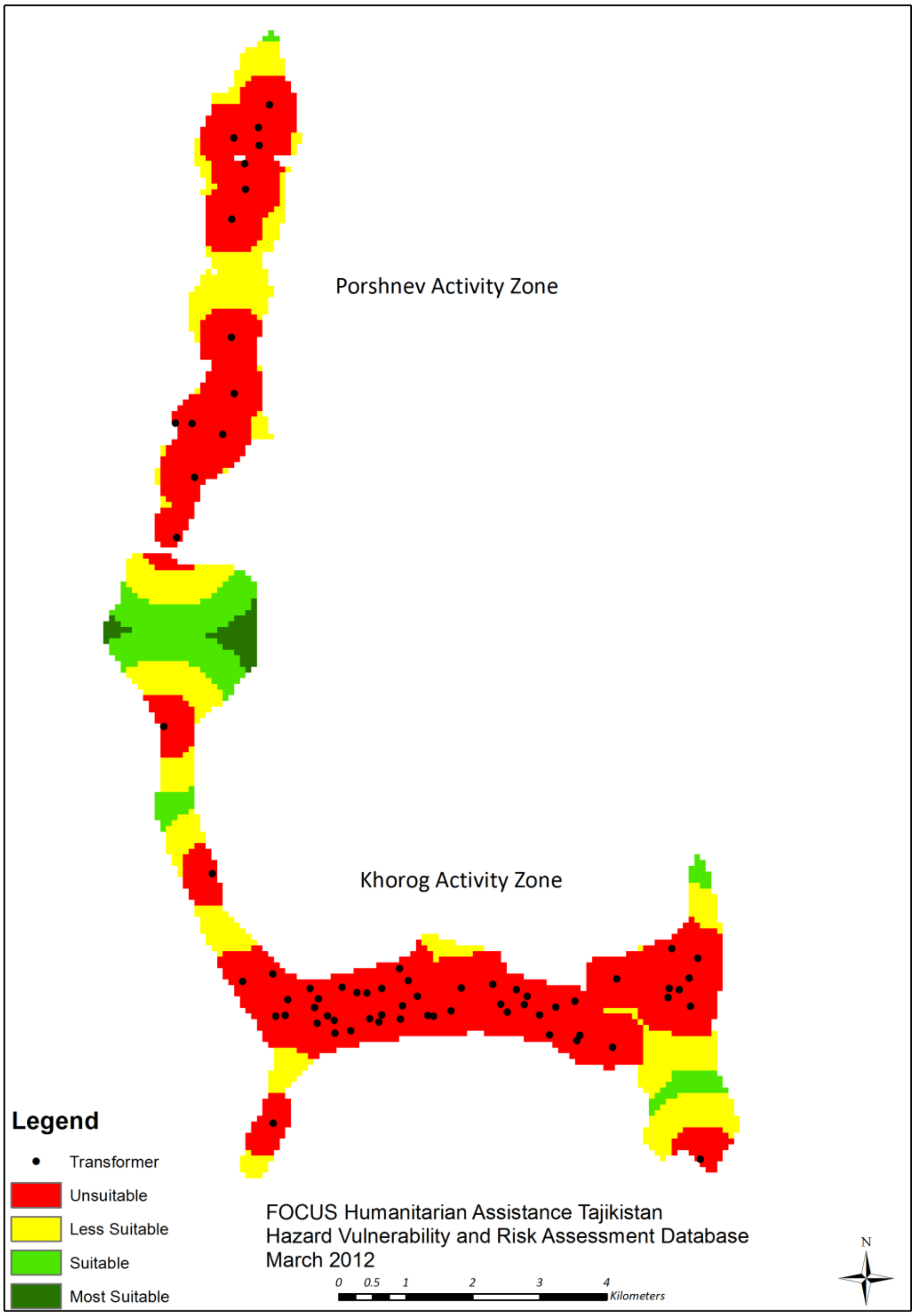


Figure 15: Khorog and Porshnev, Transformers Suitability

2.3.4 River network

The fourth factor dataset used in the analysis was **river network** (See Figure 16).

Figure 16: Khorog and Porshnev, River Network

The selected range for this criterion was between 0m and 600m. The distances were assigned a score based on proximity to a river i.e. the closer the river, the lower the score (1), the further the river, the higher the score (4). The *less suitable*, *suitable* and *most suitable* areas are situated in north eastern, central and south east part of Porshnev. In contrast, in Khorog, the *suitable*, *most suitable* areas are in the north east and the south of the activity zone (See Figure 17).

Figure 17: Khorog and Porshnev, River Network Suitability

The choice of the buffer distances from the river were based on the setting of the study area, a buffer distance of greater than 1000m would have resulted in all areas being unsuitable and which would not have been a reasonable expectation given the limited amount of land and steep mountain faces on either side of the river.

According to the study by (Kazakis, Kougias, & Patsialis, 2015), distance less than 100m from a river have a high flood risk whereas risk decreases with distances greater than 2000m.

2.3.5 Road network

The fifth factor used in the analysis was **road network**. See Figure 18.

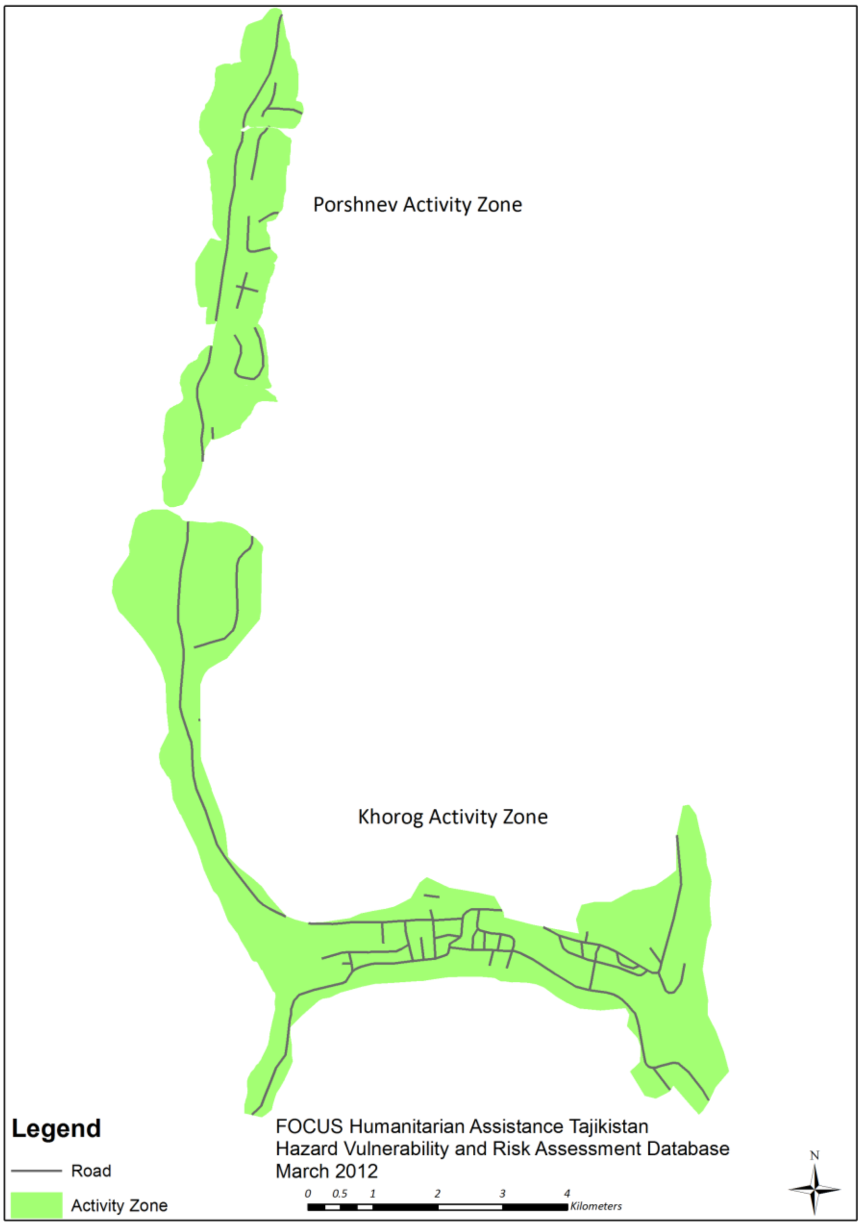


Figure 18: Khorog and Porshnev, Road Network

Based on an accessibility perspective, being closer to a road facilitates transportation access to school, on the other hand, proximity to a road can be associated with higher noise levels, pollution and fatality incidents which is usually the case in with larger metropolitan areas. In this context, these issues are not relevant and therefore the closer the road the higher the weighting. A distance of over 1000m would have resulted in areas beyond the activity zone being selected which is unreasonable and not in scope of the study.

The distances were assigned a score based on proximity to a road i.e. the closer the road, the higher the score (4), the further the road, the lower the score (1).The north western and southern tip of Porshnev activity zone is classified as *suitable* and *most suitable*. In Khorog, the north western part and a band to the west of the activity zone is classified as *suitable* and *most suitable* as well as sections to the south east (See Figure 19).

Figure 19: Khorog and Porshnev, Road Network Suitability

2.3.6 Population density dataset

The sixth and last factor was based on the **population density** for the two activity zones. Due to the lack of population information at the household level, the population statistics for GBAO (See Table 1, page 16 for data source) were extracted for school going children (i.e. 19 years of age and less) for three years (2012, 2013 and 2014). The total population 19 years of age and less was 9,500, 8,900 and 8,900 respectively. The total population for each of the three years was 28,100, 28,600 and 28,800 respectively. The proportion of children 19 years of age and less is therefore approximately **31%**. A population density grid dataset was downloaded from the World Population Dataset (See Figure 20).

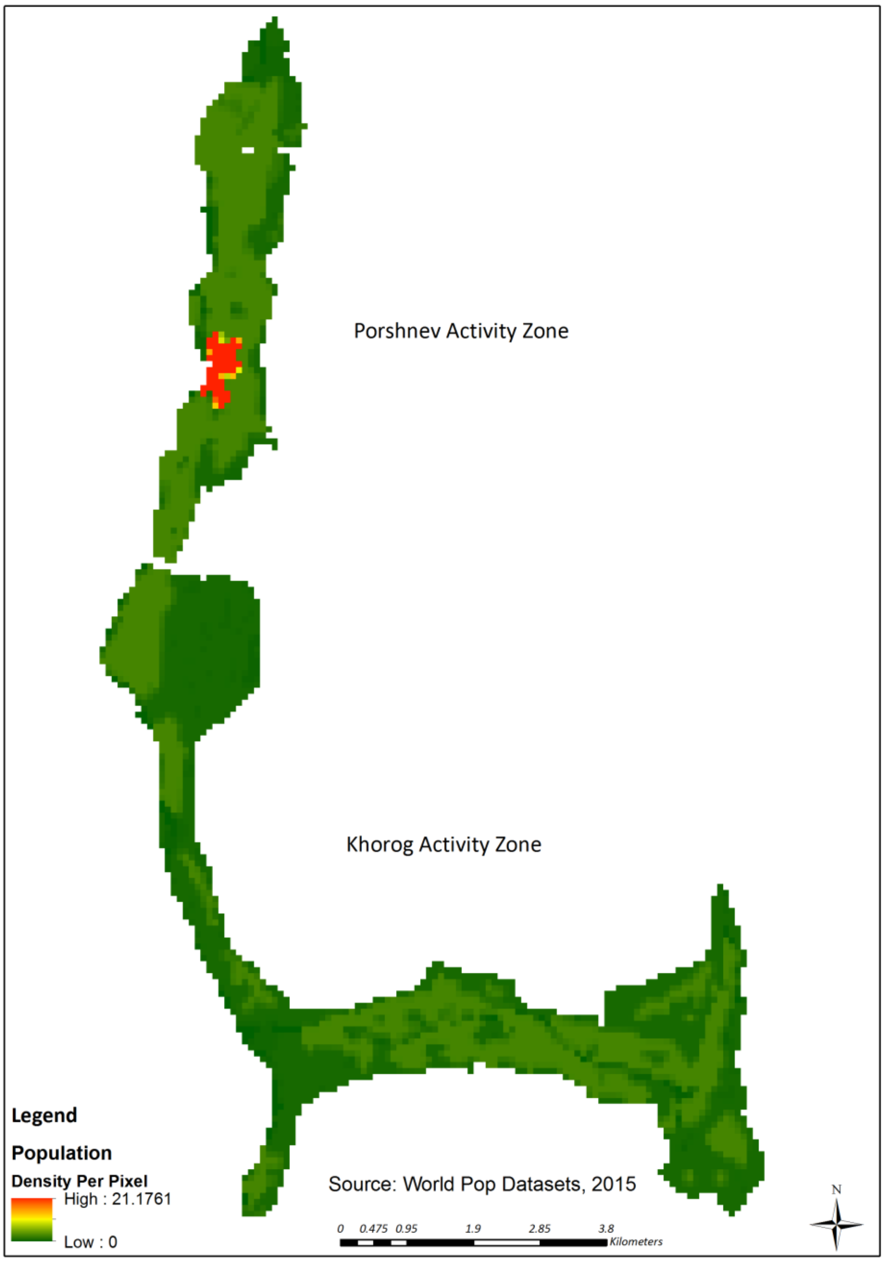


Figure 20: Khorog and Porshnev, Population Density

The raster calculator was used to multiply the cell values by 0.31 to extrapolate population density values for children 19 years of age and less. The population density values were classified according Table 2, page 27 for density classification and associated scores. The distribution of population density in Porshnev is predominantly characterized by *suitable* area whereas in Khorog, the area classified as *suitable* is situated in the northwest and central parts of the activity zone (See Figure 21).

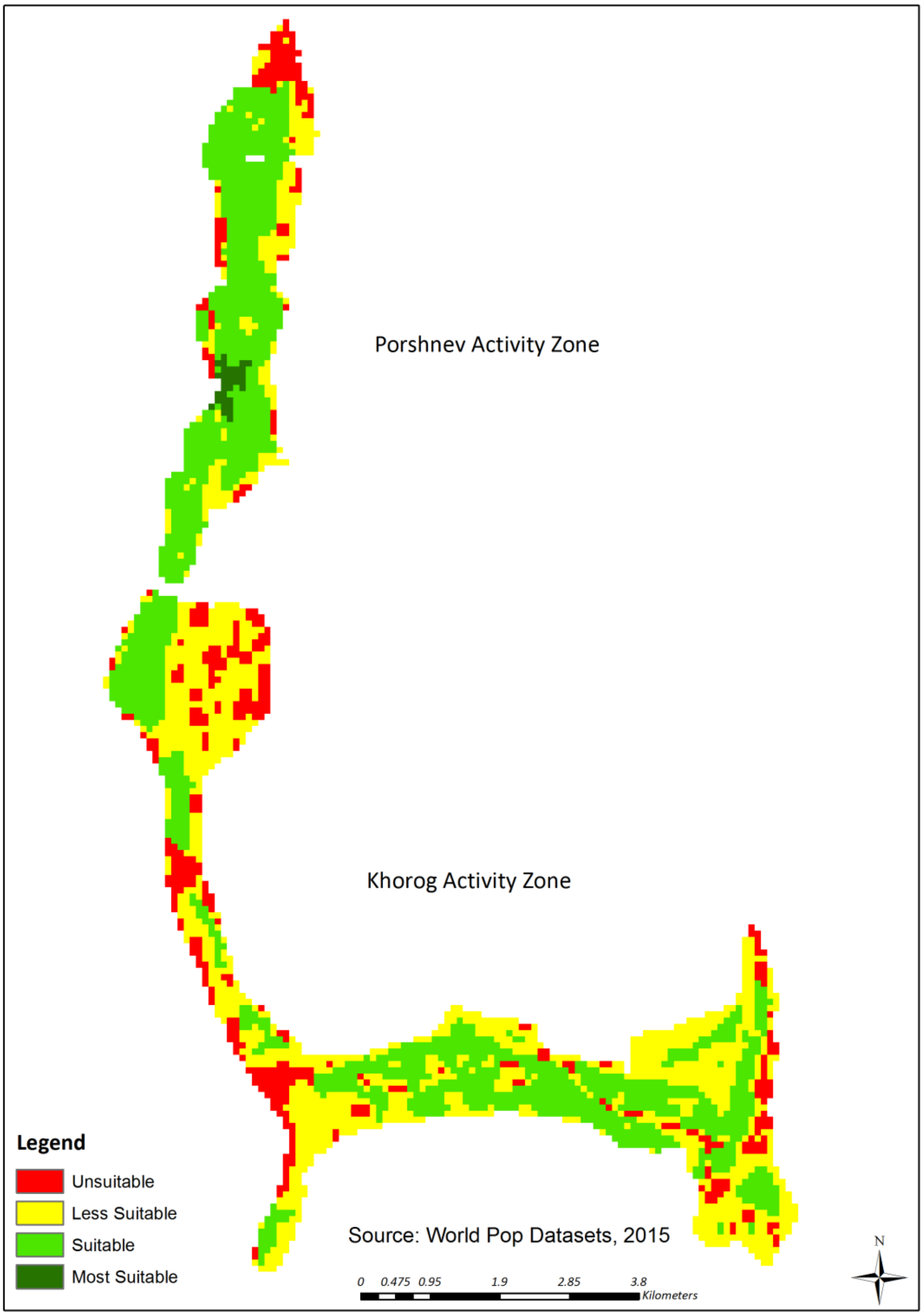


Figure 21: Khorog and Porshnev, Population Density Under 19 Years of Age

2.4 Performing the Analytical Hierarchical Process (AHP)

AHP is a structured and hierarchical decision making process used in solving complex decisions. It reduces complex decisions to a series of pairwise comparisons. This process captures both subjective and objective aspects of decision. Furthermore, the process includes an added step that checks the inconsistency of the decision maker's evaluations to reduce bias in the decision making process.

The AHP process commences with a creation of a pairwise matrix where each criteria (factor) is compared to each other and assigned a numeric scale (Judgement Value from 1 to 9). See Table 3.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one factor over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one factor over another
6	Strong plus	
7	Very strong or demonstrated importance	One factor is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	

Table 3: AHP Pairwise Comparison Ranking

Note: If factor A is compared to factor B, and factor A is assigned one of the numbers above (1-9), then factor B will be assigned the reciprocal value of A (i.e. 1 / (value for A)

In Table 4, each factor is compared to another and assigned a judgement value. To construct Table 4, each factor is compared to another on a pair by pair basis. See (row 2, column 2) - Population Density is compared to Population Density and assigned a 1 (since comparing a factor with itself). In row 2, column 6 – a judgement value of 7 is assigned between the comparison of the Population Density factor with Emergency Facility factor and in column 8, a judgement value of 5 is assigned to the comparison of Population Density with Transformer.

	Population Density	**Existing School**	**Road**	**River**	**Emergency Facility**	**Transformer**
Population Density	1	1	1	1	7	5
Existing School	1	1	4	2	5	4
Road	1	1/4	1	1	4	4
River	1	1/2	1	1	7	2
Emergency Facility	1/7	1/5	1/4	1/7	1	2
Transformer	1/5	1/4	1/4	1/2	1/2	1
Sum of factor column	4.343	3.20	7.50	5.64	24.50	18.00

Table 4: AHP Pairwise Comparison Matrix

On the flipside, in the comparison between Emergency Facility (row 6, column 2) and Population Density (row 1, column 1), a reciprocal judgement value is assigned of 1/7. In an ideal environment, a panel of decision makers or professionals from various professions (stakeholders) including members of the community – the direct beneficiaries of the project would be gathered at a workshop and would then decide on the appropriate ranking comparison between the six factors.

In the preparation of this paper, I did not have the opportunity to arrange such a meeting and therefore the numbers assigned above are based on my personal feeling on the relative importance of one factor over another.

The normalization process involved dividing each of the record in Table 4 by its corresponding column total. The result was a normalized relative weighting. See Table 5 for normalization and weighting calculations.

	Population Density	**Existing School**	**Road**	**River**	**Emergency Facility**	**Transformer**	**Priority Vector (avg of row total)**
Population Density	0.230	0.313	0.133	0.177	0.286	0.278	0.24
Existing School	0.230	0.313	0.533	0.354	0.204	0.222	0.31
Road	0.230	0.078	0.133	0.177	0.163	0.222	0.17
River	0.230	0.156	0.133	0.177	0.286	0.111	0.18
Emergency Facility	0.033	0.063	0.033	0.025	0.041	0.111	0.05
Transformer	0.046	0.078	0.033	0.089	0.020	0.056	0.05

Table 5: AHP Pairwise Comparison Normalized Matrix

According to the normalized Eigen vector (also known as priority vector), existing school was the most important factor weighted at (31%), followed by population density (24%), river (18%), road (17%), emergency facility (5%) and transformer (5%).

The final step of the AHP involved the calculation of the **Consistency Ratio** (CR) of the factors, which should be less or equal to 10% (Saaty, 1987).

CR = *Consistency Index (CI) / Random Consistency Index (RI)*

CI = $(\lambda_{max} - n) / (n - 1)$

Note: λ_{max} is the Principal Eigen value and n = number of factors

The Principal Eigen value (λ_{max}) is obtained by multiplying the summation of products between each element of the Eigen vector above by the sum of columns of the reciprocal matrix (from Table 5)

$\boldsymbol{\lambda_{max}}$ = (4.34 x 0.24) + (3.2 x 0.31) + (7.5 x 0.17) + (5.64 x 0.18) + (24.5 x 0.05) + (18 x 0.05) = 6.51

The CI = (6.51 – 6) / (6-1) = 0.51 / 5 = **0.10**

Based on the Relative Consistency Index Table by Saaty (See Table 6) the Consistency Ratio was calculated as:

CR = 0.10 / 1.24 = **0.08**

0.08 is less than 0.10, this passes the Consistency Ratio therefore the weighting allocation to the factors shown on Table 9 is acceptable. In other words, the pairwise comparison between the various factors is consistent.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 6: Table 11 Random Consistency Index (RI)

2.5 Combining the raster factors and constraints datasets

Now that the weighting allocations have been calculated in Table 5, the factors and constraint data sets can be aggregated by multiplying each factor by its associated weighting as per Table 5. The formula to perform the Weighted Linear Combination is as follows:

$S = \Sigma w_i x_i \times \Pi c_j$

Where:
S – is the composite suitability score
x_i – factor scores (cells)
w_i – weights assigned to each factor
c_j – constraints (or Boolean factors)
Σ -- sum of weighted factors
Π -- product of constraints (1-suitable, 0-unsuitable)

2.6 Allocation of weighting and combining the raster factors and constraints datasets using the Rating Method

The second technique employed in assigning weights to the four factors is the use of a simple rating method.

In this section, seven scenarios have been presented. In the first scenario, all six factors are assigned equal weighting i.e. 0.1667 each, for the remaining six scenarios, each factor is weighted five times the weighting of the other five factors. The rationale for this methodology is to conduct a sensitivity analysis to observe how changing one factor while holding the other factors constant can have a significant influence on the resulting suitability map.

The process of combining the factor datasets with the constraints datasets is identical to the one described in the previous section.

3. Results

This section will illustrate and describe the AHP and Rating method results and provide a comparative analysis of the two methods.

3.1 Analytical Hierarchical Process

The six factors and two constraints were combined using the weighted linear combination on page 45 by using the raster calculator (See Figure 22).

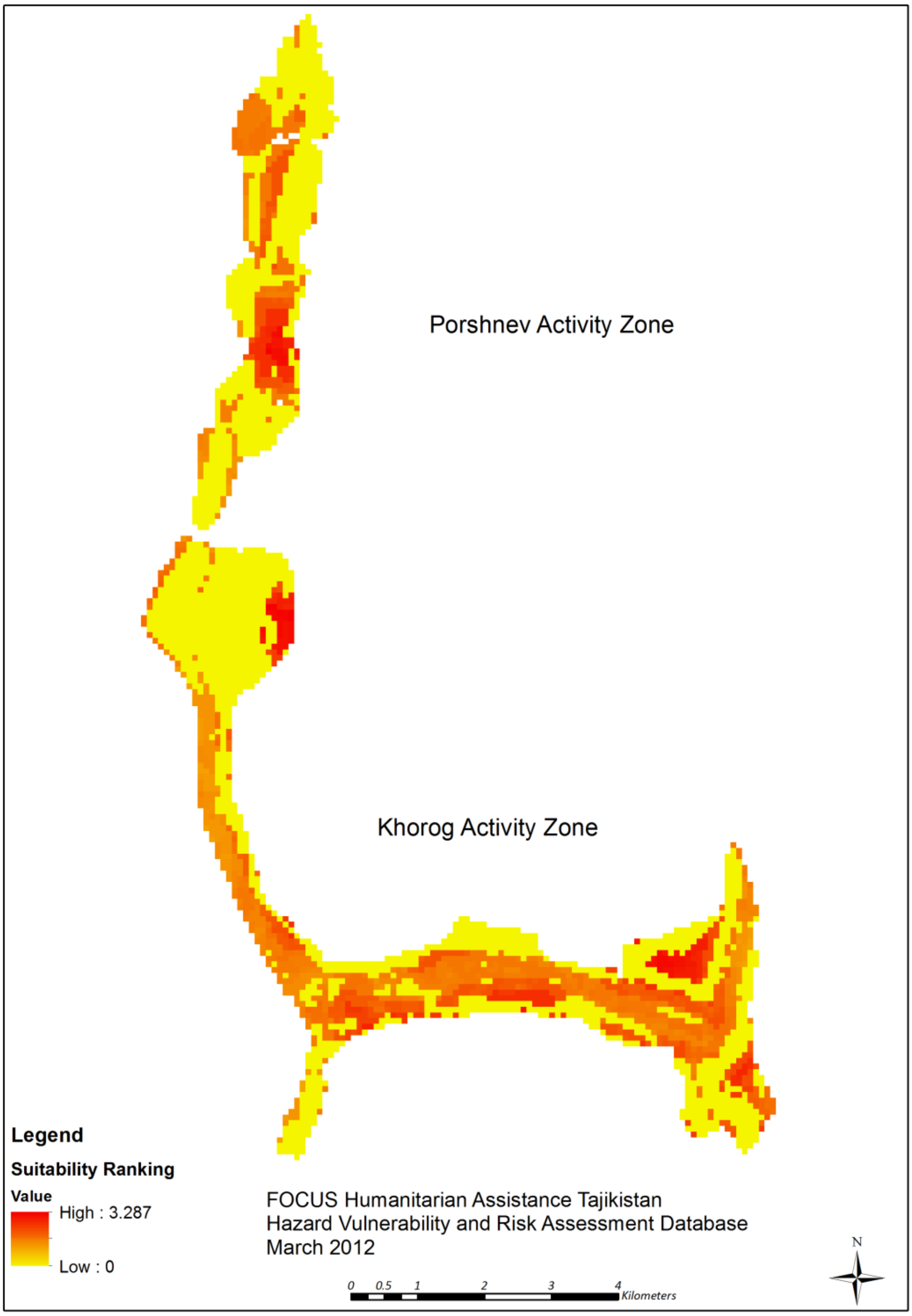


Figure 22: Khorog and Porshnev, Analytical Hierarchical Process

The AHP raster was reclassified into a suitability map. The *less suitable* and *suitable* areas in Porshnev are in the central part of the activity zone and where as in Khorog, the *less suitable* areas are scattered in the north and more pronounced in the central part of the activity zone. On the other hand, the *suitable* areas are in the north, central and south east and south west. In both study areas the *suitable* category occupies the largest amount of land (See Figure 23).

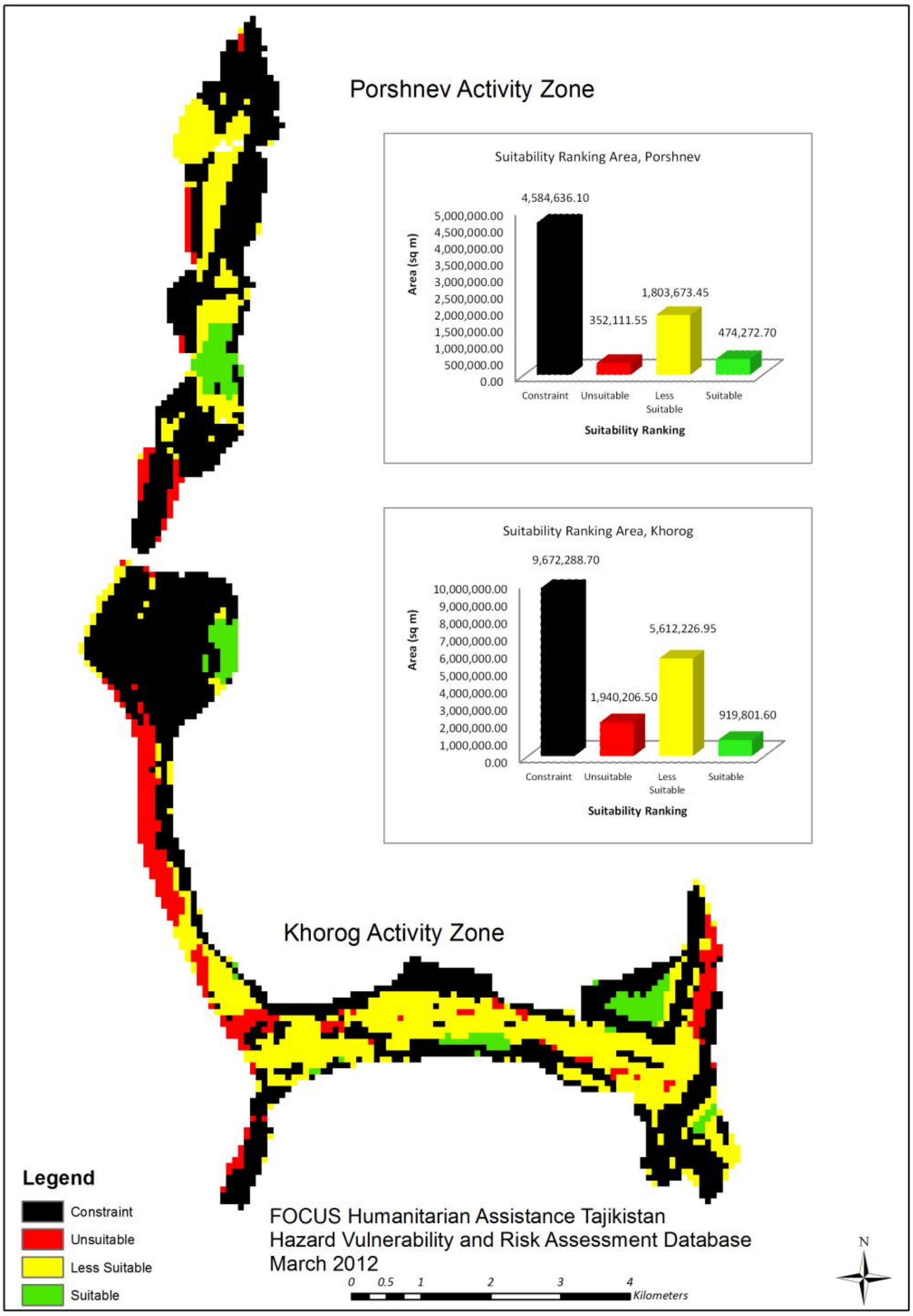


Figure 23: Khorog and Porshnev, Analytical Hierarchical Process Suitability

3.2 Rating Method – All factors equally weighted

The raster below (Figure 24) is a result of all factors weighted equally at 0.1667.

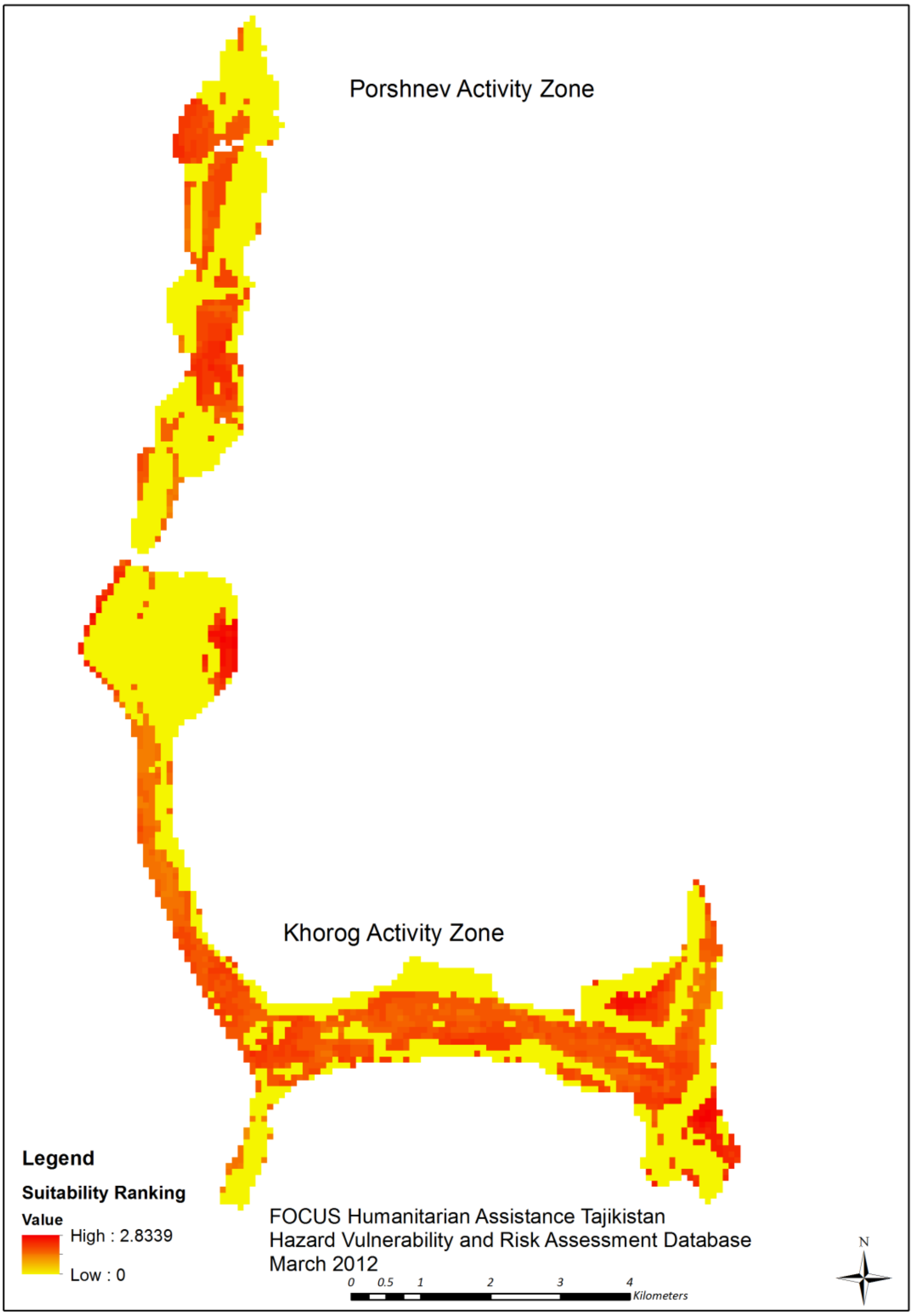


Figure 24: Khorog and Porshnev, Rating Method – All Factors Equally Weighted

The *all factors equally weighted* raster was reclassified into a suitability map (See Figure 25 below). In Porshnev, the activity is dominated by the *less suitable* category and few areas of *unsuitable* category. In contrast, in Khorog, there are a few *suitable* areas to the north, north east and south east and predominantly *less suitable* in the central part of the zone.

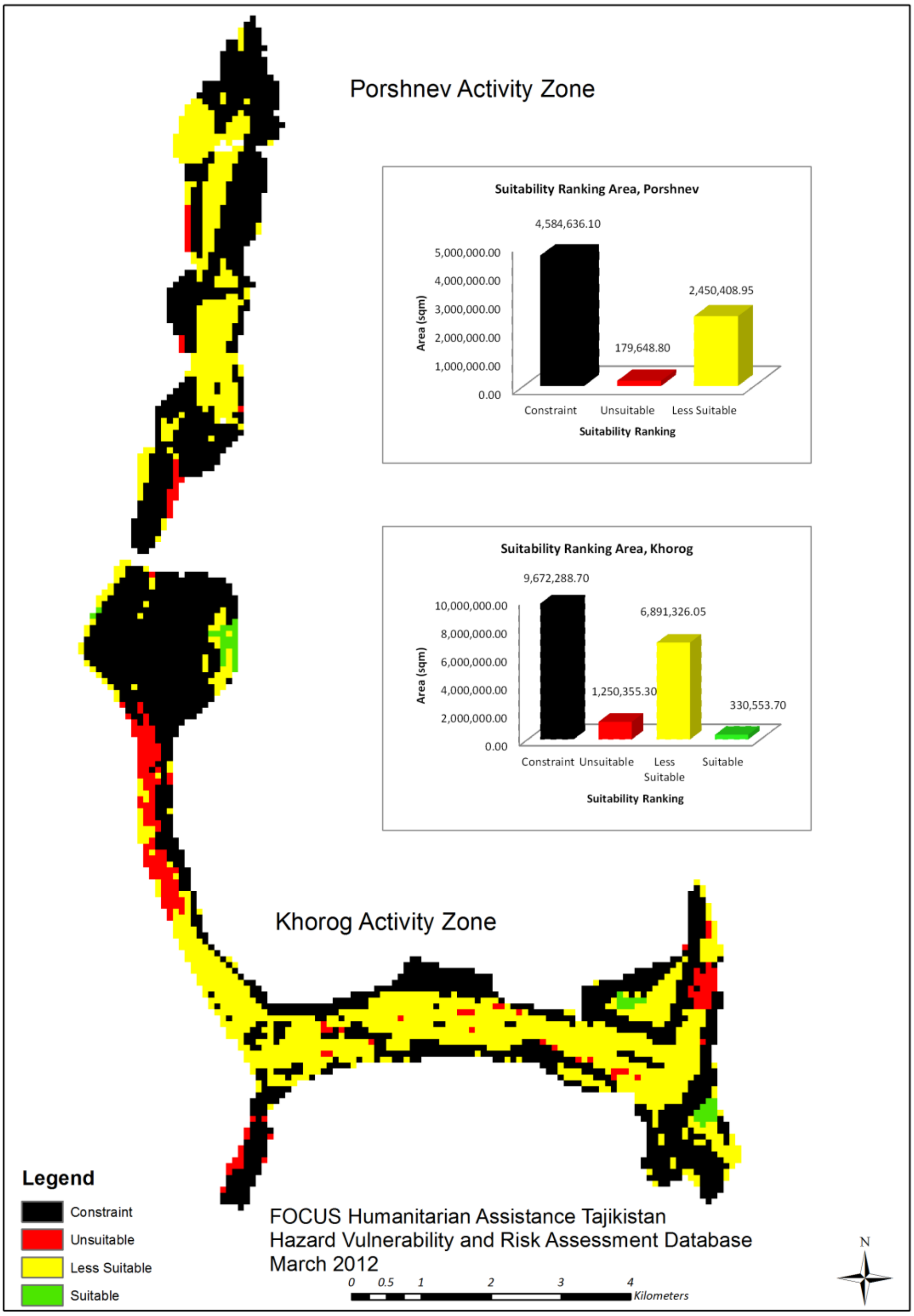


Figure 25: Khorog and Porshnev, Rating Method – All Factors Equally Weighted Suitability

3.3 Rating Method – Population weighted at 50%

The raster below depicts the population factor weighted at 50% (See Figure 26)

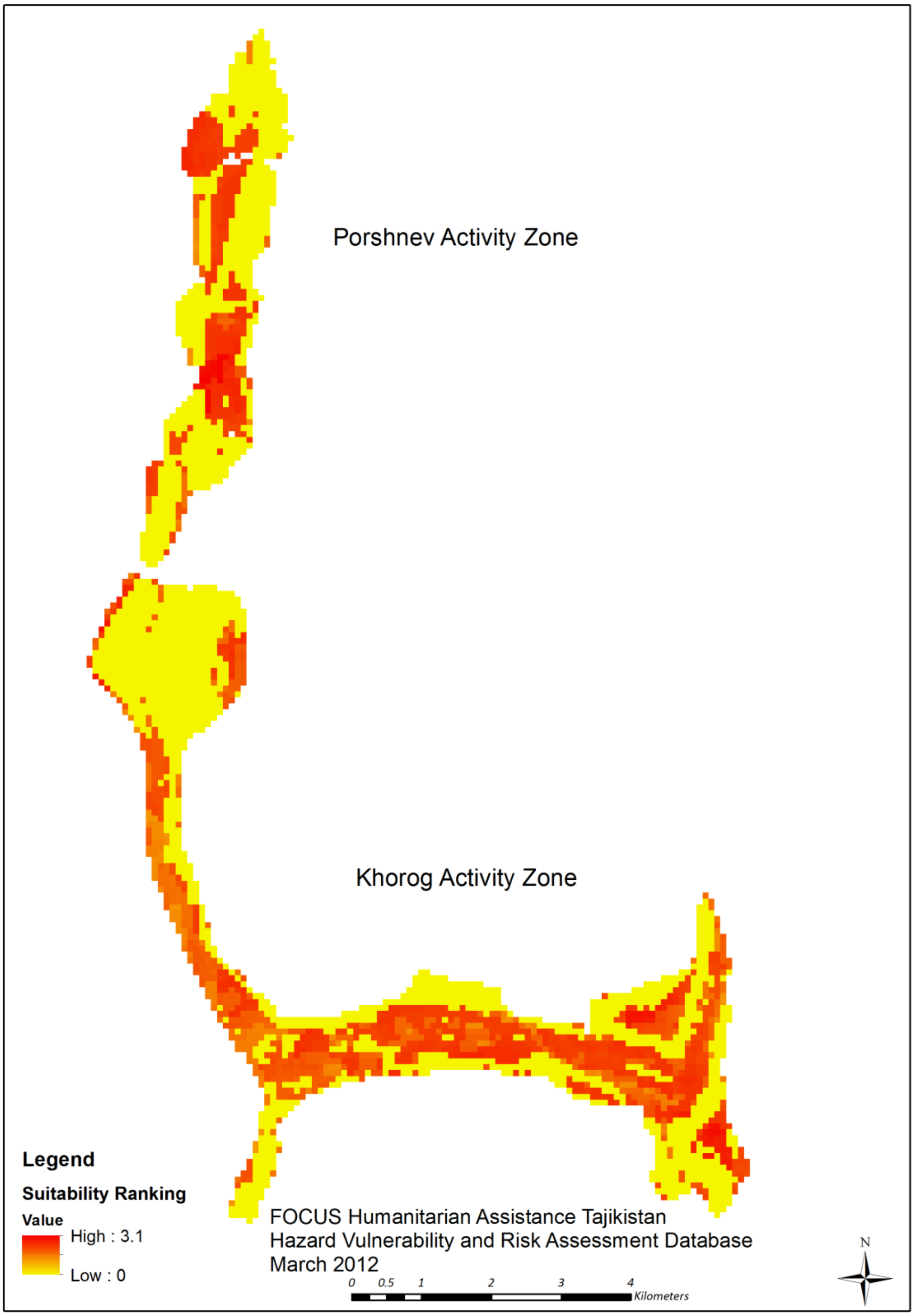


Figure 26: Khorog and Porshnev, Rating Method – Population Weighted 50%

In

Porshnev, *less suitable* areas are in the central and southern part whereas the *suitable* areas in the northern and southern part of the activity zone. As far as Khorog is concerned, the *less suitable areas* are prevalent in the north, north east, central and southern eastern sections. The *less suitable* category as in the previous scenario occupies the largest area in both zones.

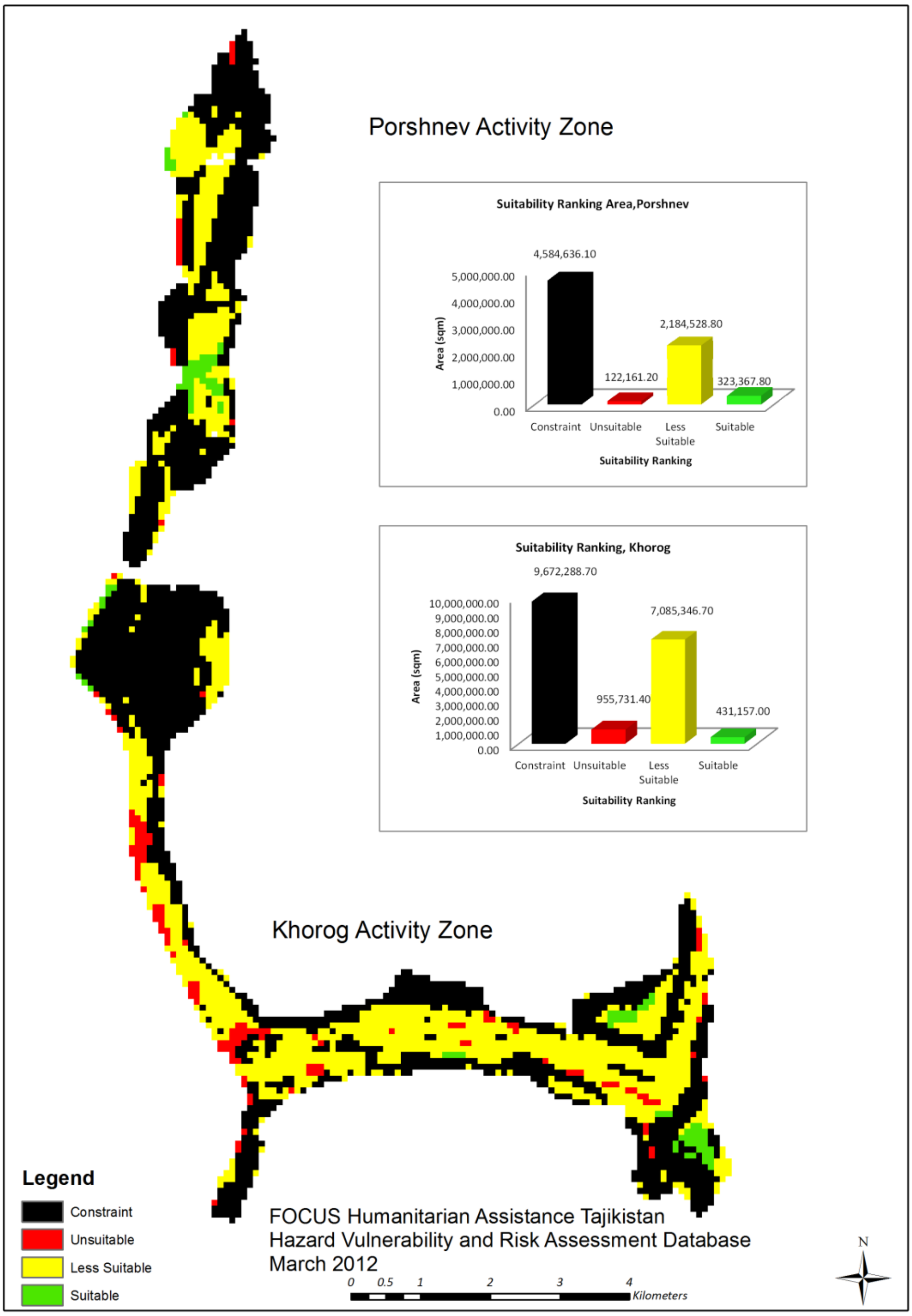


Figure 27: Khorog and Porshnev, Rating Method – Population Weighted 50% Suitability

3.4 Rating Method – Emergency facility factor weighted at 50%

The raster below depicts the emergency facilities factor weighted at 50% (See Figure 28).

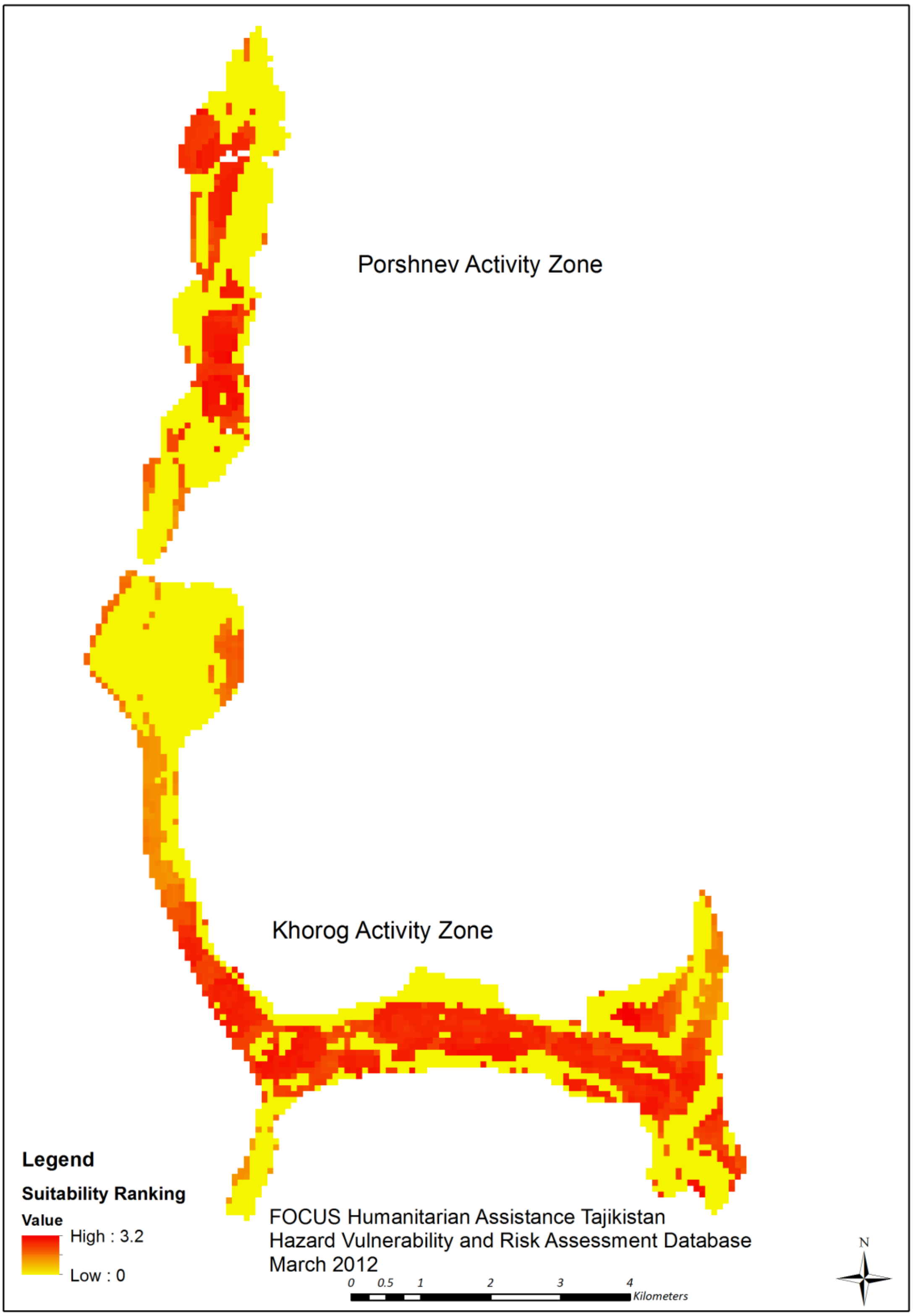


Figure 28: Khorog and Porshnev, Rating Method – Emergency Facilities Weighted 50%

The *less suitable* and *suitable* areas in Porshnev are in the north and south of the zone. In Khorog, the *less suitable* areas are in the north, north east, the central and south east. In contrast the *suitable* areas are located predominantly in the central part of the zone. The largest area in this scenario is represented by the *suitable* category (See Figure 29).

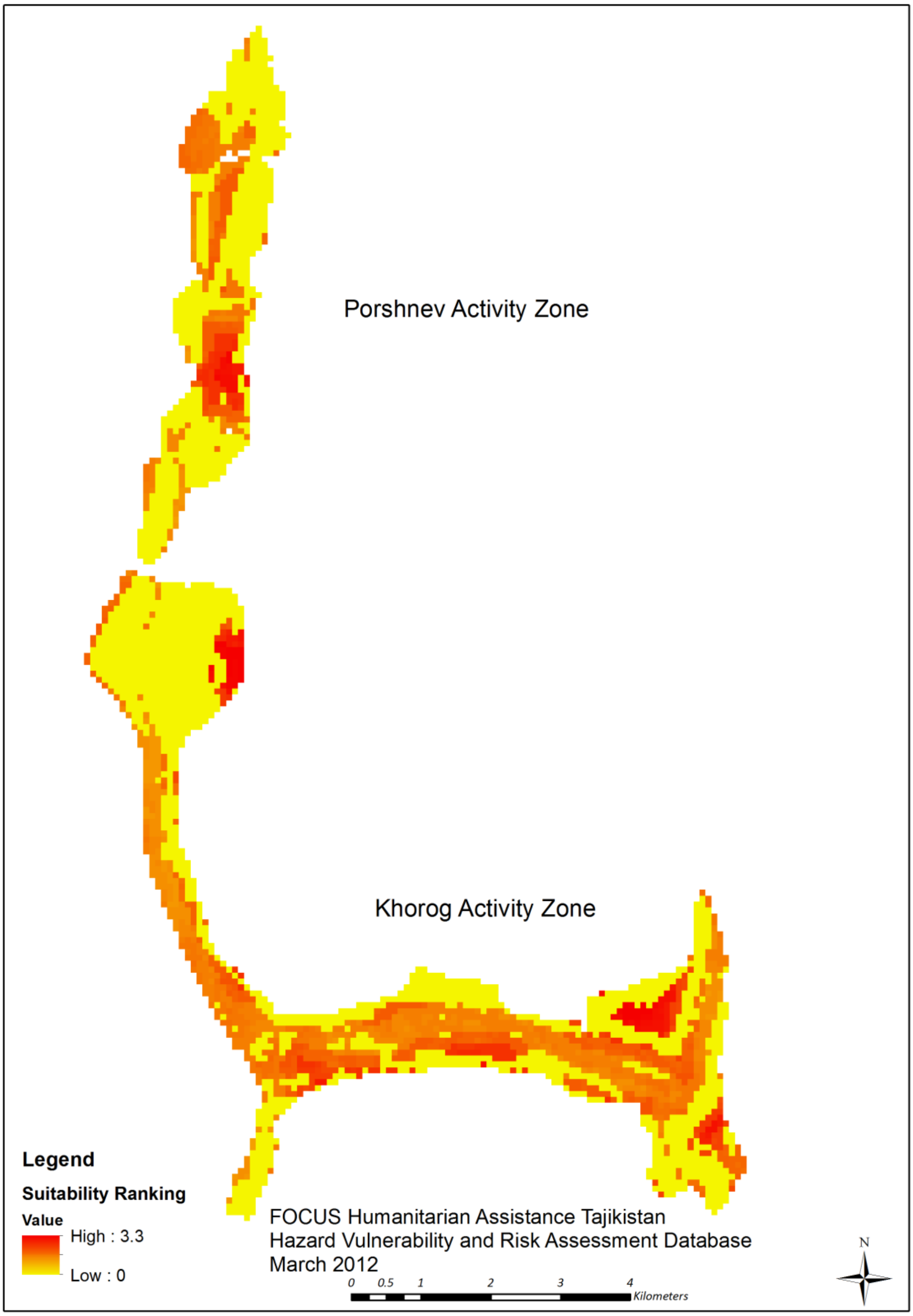


Figure 29: Khorog and Porshnev, Rating Method – Emergency Facilities Weighted 50% Suitability

3.5 Rating Method – River factor weighted at 50%

This scenario illustrates the river factor weighted at 50% (See Figure 30).

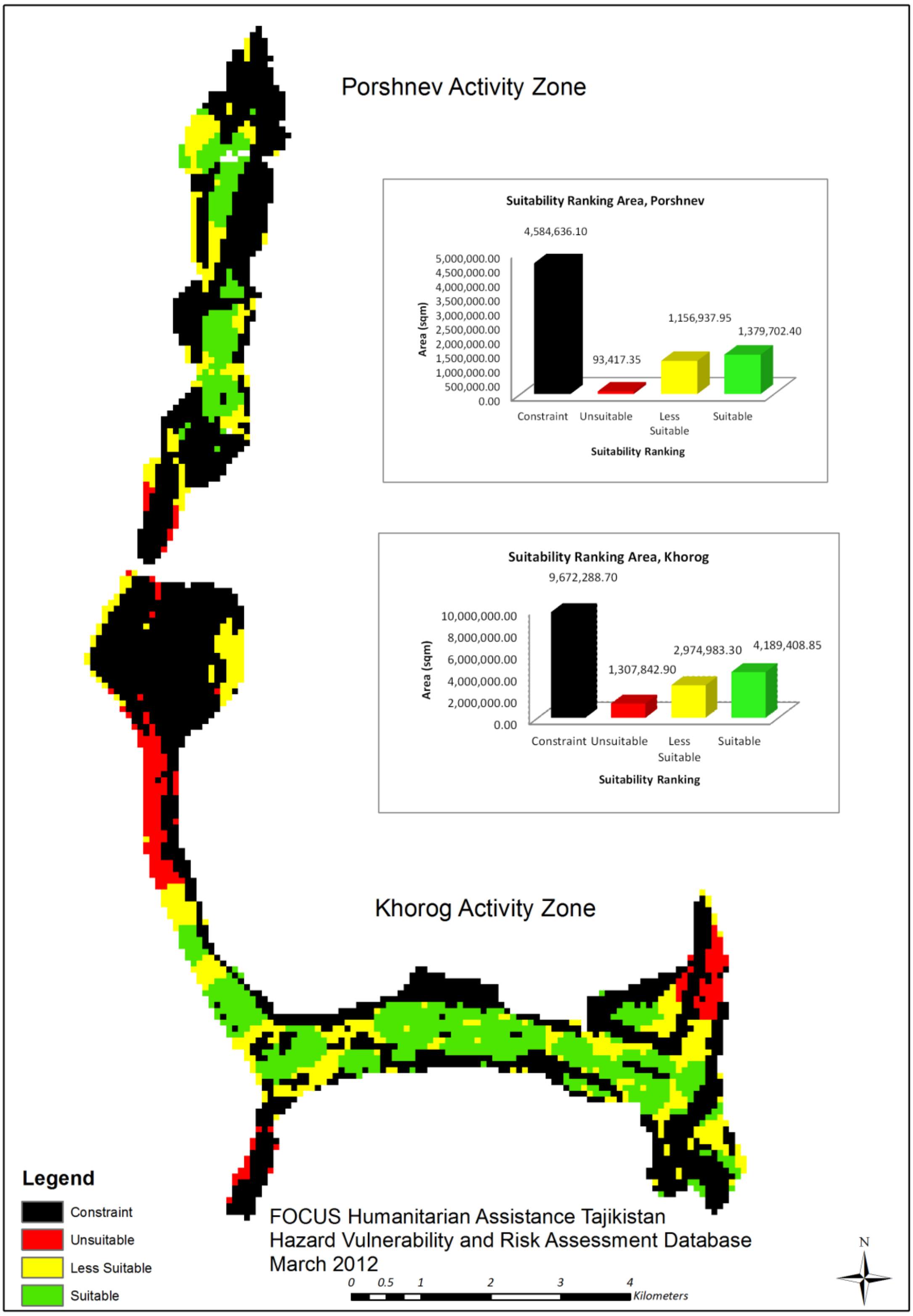


Figure 30: Khorog and Porshnev, Rating Method – River Weighted 50%

In Porshnev, the *less suitable* areas are in the central part of the activity zone with the *suitable* area towards the central portion. In Khorog, the *less suitable* area is located in the central part of the activity zone where as the *suitable* areas are in the north west, north east and south east. There is almost an equal distribution of *unsuitable* and *less suitable* land in this zone (See Figure 31).

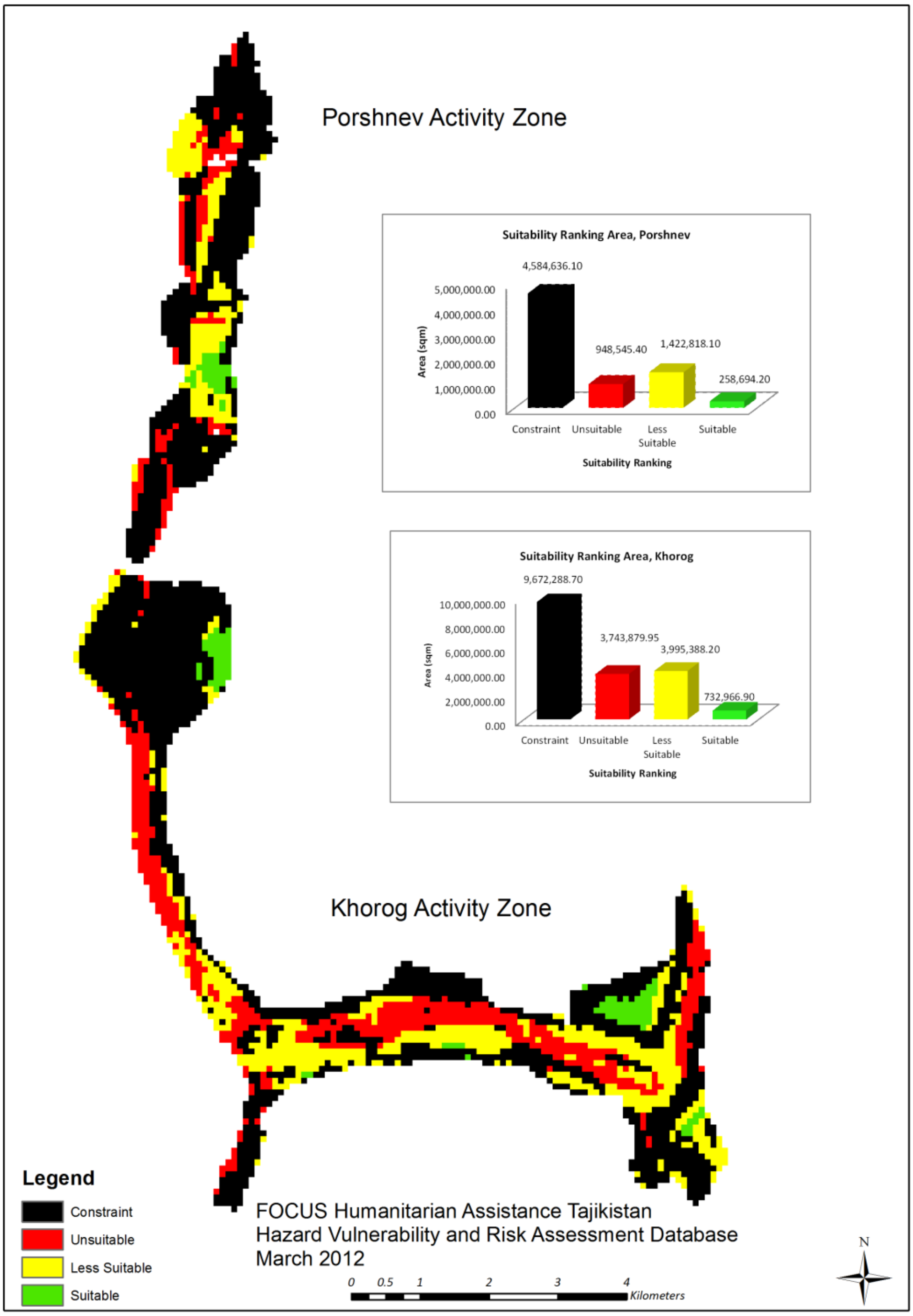


Figure 31: Khorog and Porshnev, Rating Method – River Weighted 50%

3.6 Rating Method – Road factor weighted at 50%

The following is the road raster factor weighted at 50% (See Figure 32).

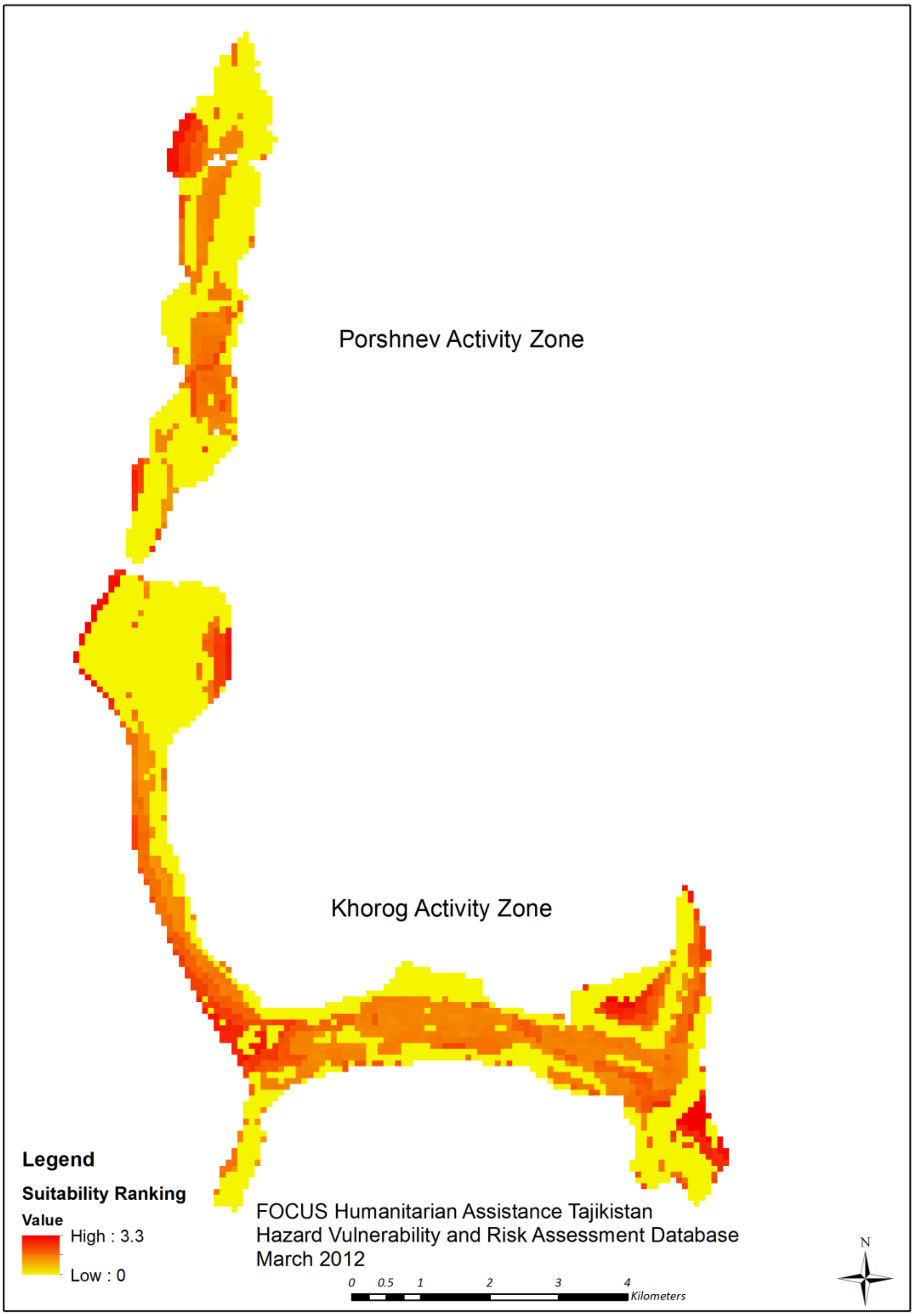


Figure 32: Khorog and Porshnev, Rating Method - Road Weighted 50%

The *less suitable* areas are located in the north, central and southern part of the zone in Porshnev and in Khorog. In contrast, in Porshnev the *suitable* areas are in the north and south of the zone. In Khorog, the *suitable* areas are scattered in the north west, north east and south east. The *less suitable* category is the predominant class in both zones (See Figure 33).

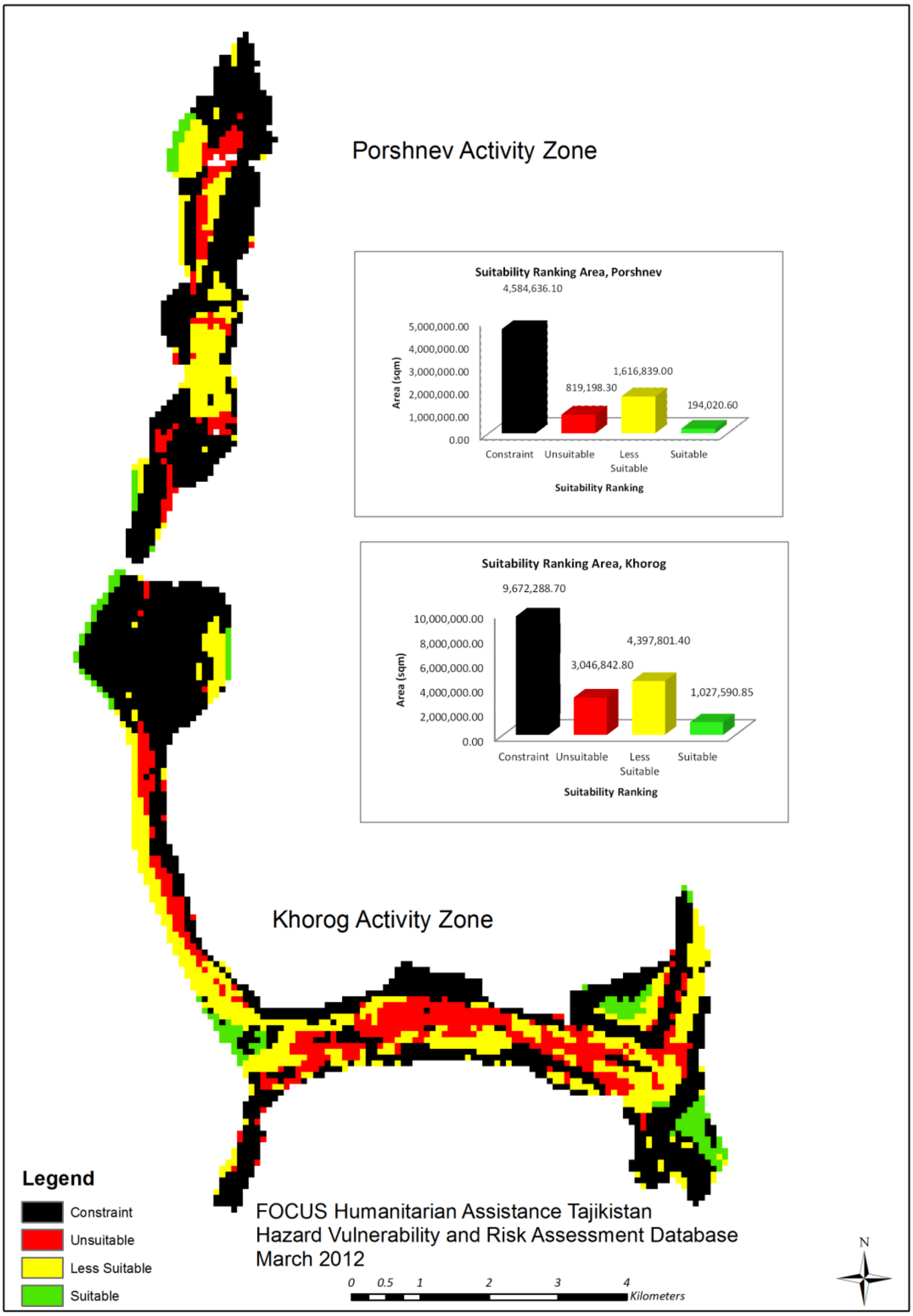


Figure 33: Khorog and Porshnev, Rating Method - Road Weighted 50% Suitability

3.7 Rating Method – Existing schools factor weighted at 50%

The existing school raster weighted at 50% is shown below (See Figure 34).

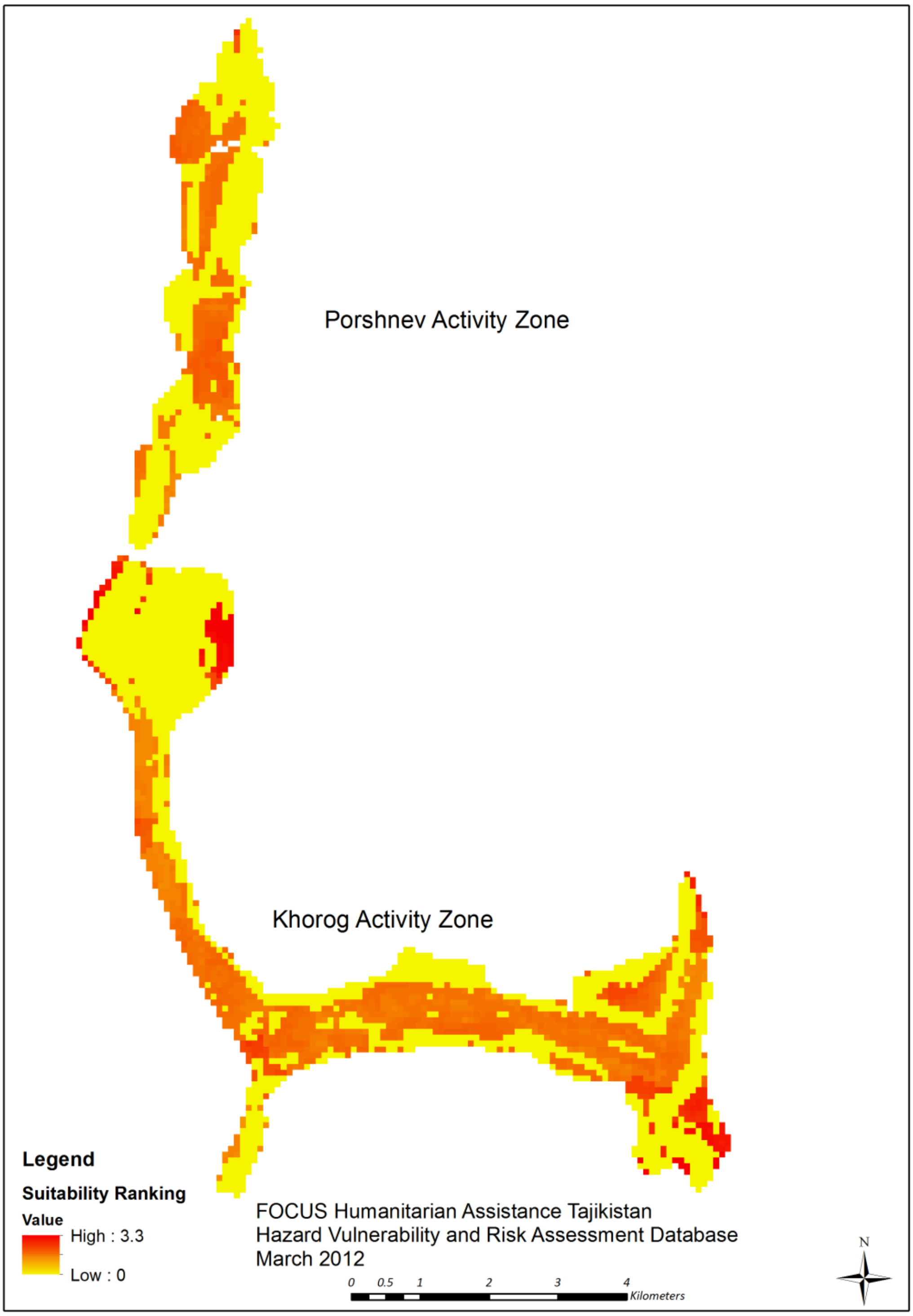


Figure 34: Khorog and Porshnev, Rating Method Existing Schools Weighted 50%

In this scenario, Porshnev is characterized by *less suitable* area in the north and central part of the zone and *unsuitable* areas scattered throughout from north to the southern part. There are no areas representing the *suitable* category. In Khorog, the *less suitable* areas are concentrated in the central part of the zone with the *suitable* areas situated in the north west and south east. The zone is dominated by *unsuitable* category (See Figure 35).

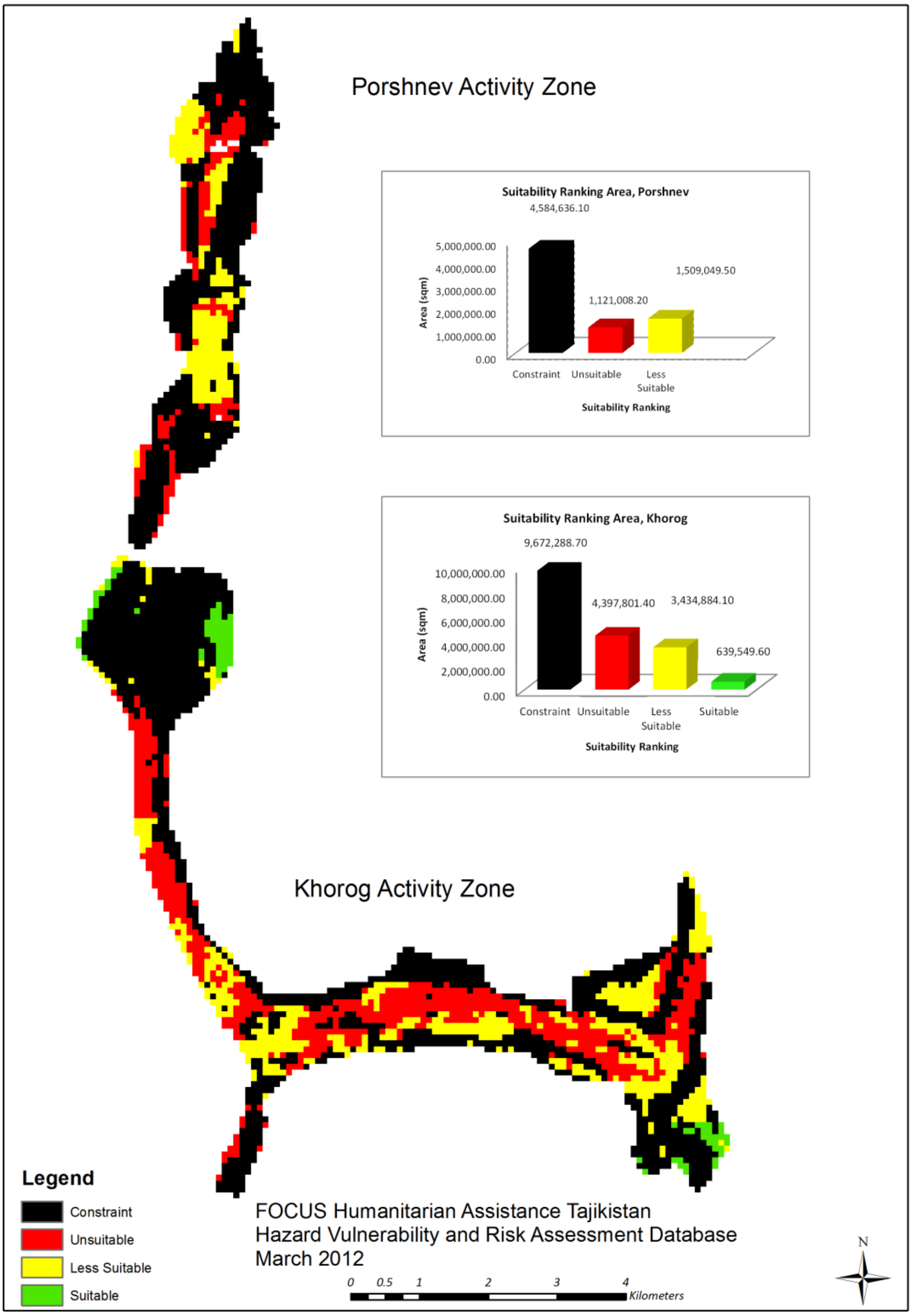


Figure 35: Khorog and Porshnev, Rating Method – Existing Schools Weighted 50% Suitability

3.8 Rating Method – Transformer factor weighted at 50%

The last factor, transformers weighted at 50% is shown below (See Figure 36).

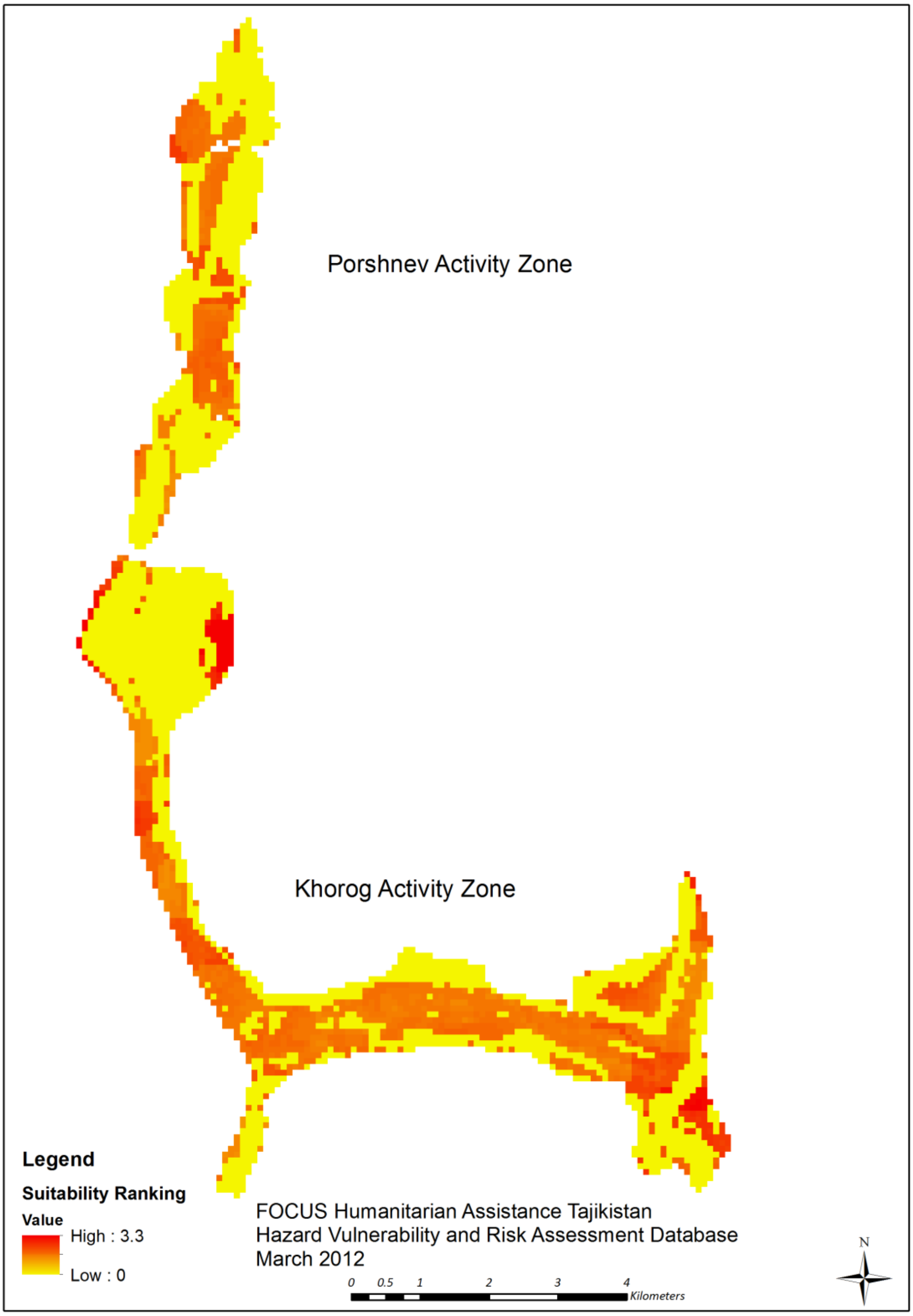


Figure 36: Khorog and Porshnev, Rating Method – Transformers Weighted 50%

In Porshnev and Khorog, the *less suitable* class is scattered from the north to the centre of the activity zone. The *unsuitable* category is sparsely situated from the north to the south. There is no *suitable* classification for Porshnev. In contrast in Khorog, the *suitable* category is situated in the north west and south east parts of the zone (See Figure 37).

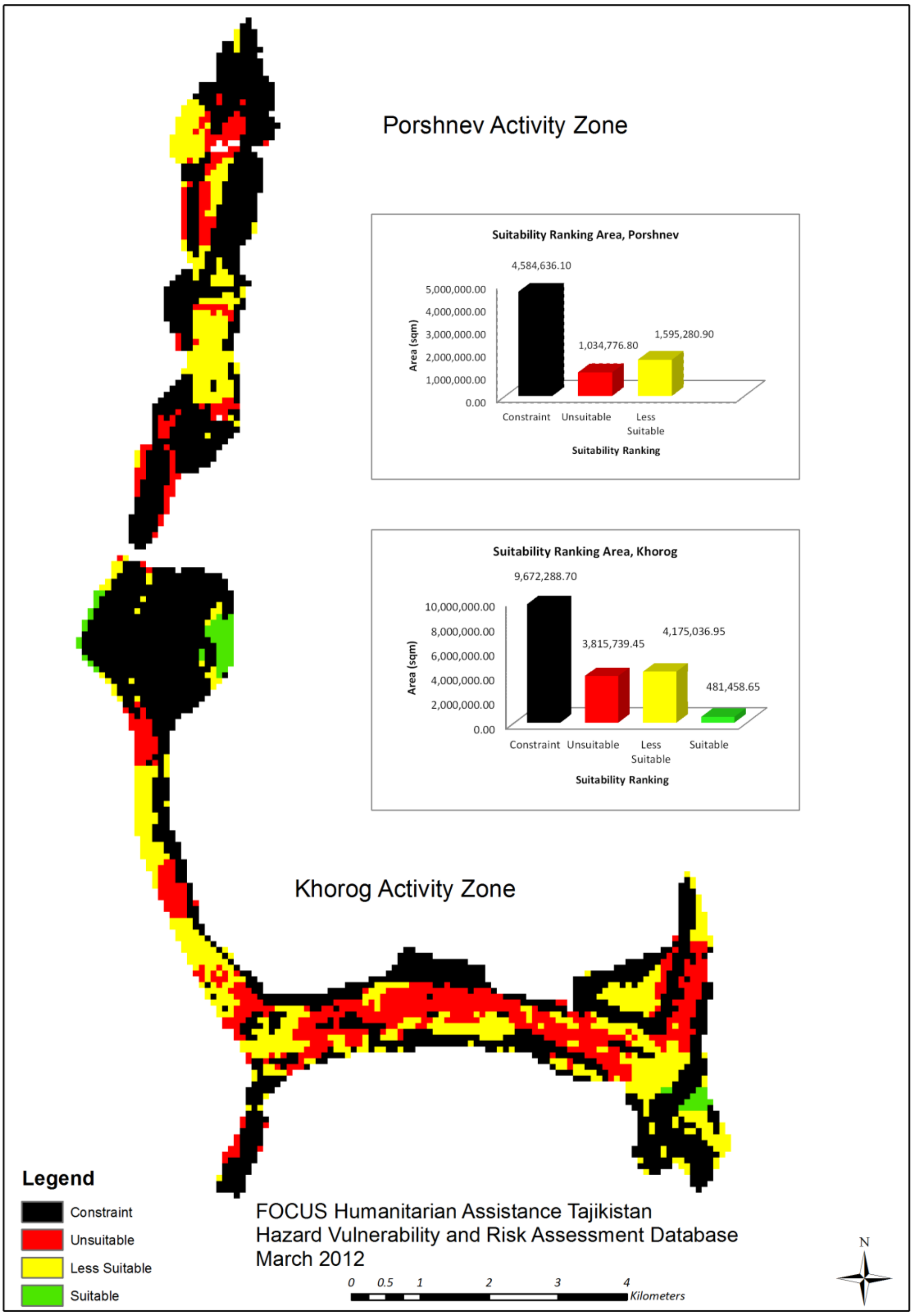


Figure 37: Rating Method – Transformers Weighted 50% Suitability

In the comparison between *AHP* and the *Rating* method (See Figures 38 and 39, pages 58-59), there were five key observations worth noting:

1. Neither of the two methods resulted in areas of either Porshnev or Khorog being characterized as *most suitable.*

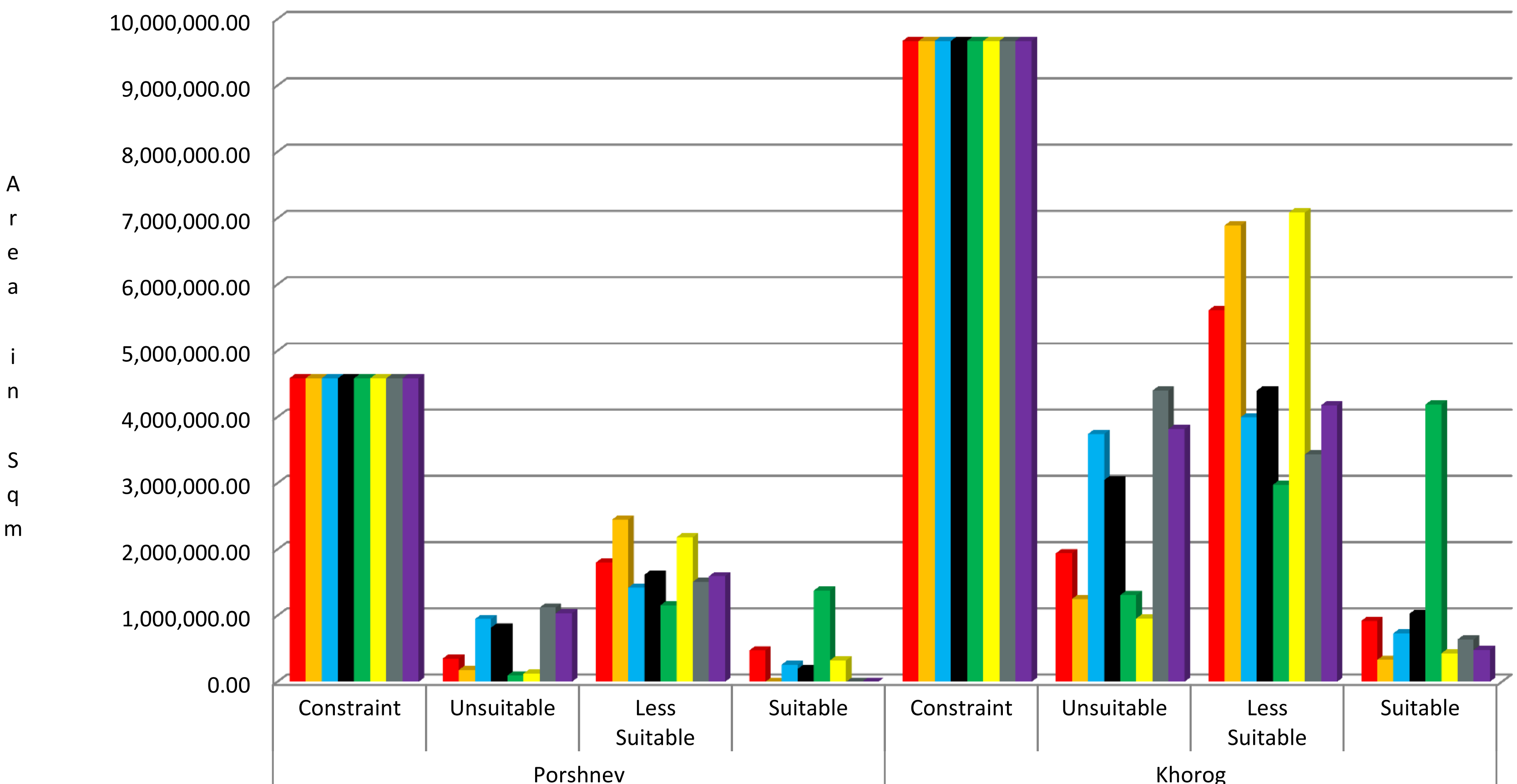
2. There were three scenarios in Porshnev that had no areas classified as *suitable*. These are; *all factors equally weighted, school weighted 50% and transformer weighted 50%.*

3. The scenario that resulted in the greatest amount of land being classified as *suitable* for both activity zones was *emergency facilities weighted 50% .* The areas were *1,379,702* sq. m for Porshnev and *4,189,408* sq. m for Khorog, accounting for *19%* and *23%* respectively of the total area of each zone.

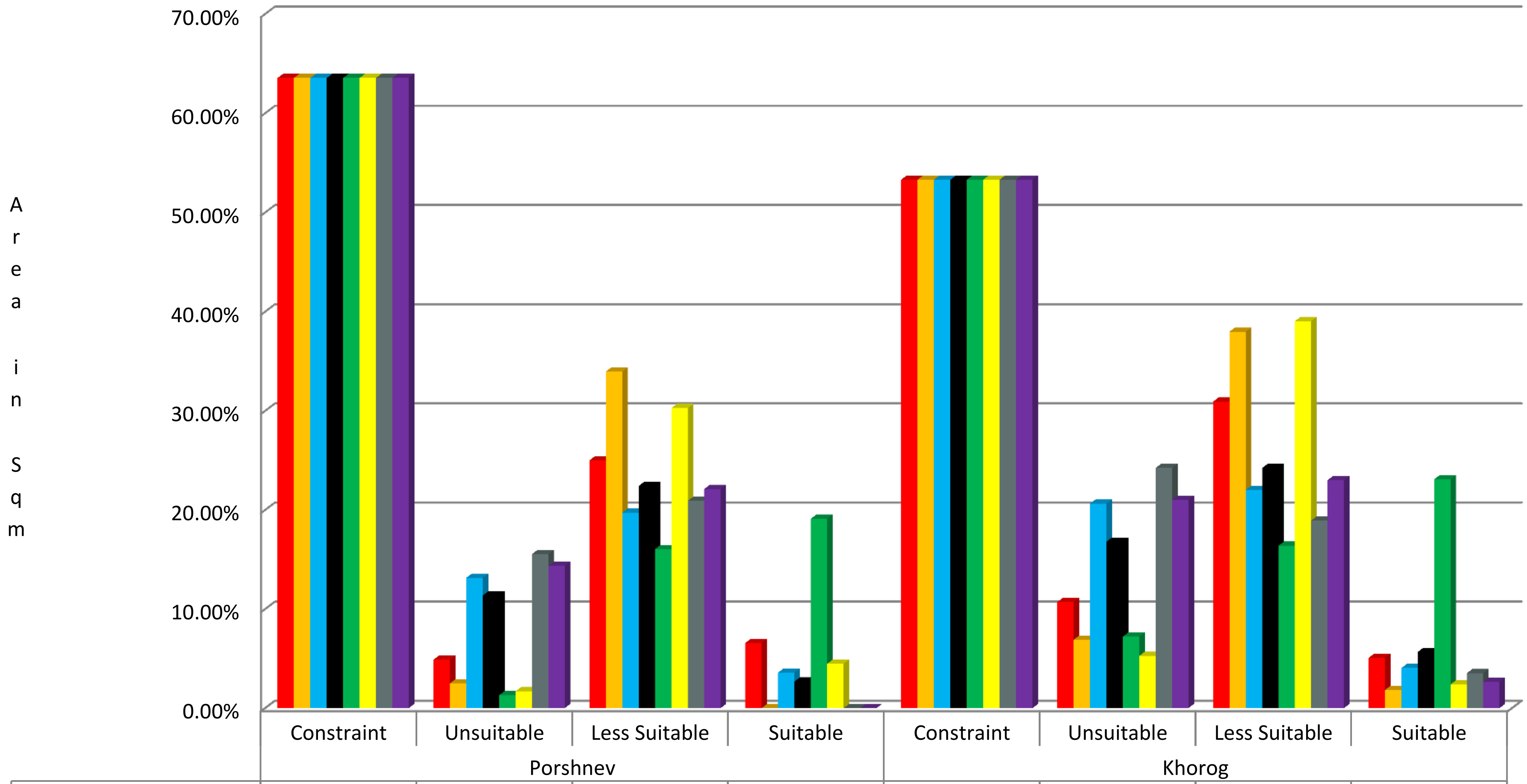
4. The scenario with the least amount of land being classified as *unsuitable* in Porshnev was *emergency facilities weighted 50%* with an area of *93,417* sq. m or *1.29%* of the total area. In contrast in Khorog, *the population weighted 50%* resulted in the least amount of land being classified as *unsuitable*, approximately *955,731* sq. m or *5.27%* of the total area.

5. The scenario that yielded the largest amount of *unsuitable* land in Porshnev and Khorog was school weighted 50% with 1,121,008 sq. m (15% of the activity zone) and 4,397,801 sq. m (24% of the activity zone).

Figure 38: Suitability Ranking Comparison – Area in Square Metres -AHP versus Rating Method



	Porshnev Constraint	Porshnev Unsuitable	Porshnev Less Suitable	Porshnev Suitable	Khorog Constraint	Khorog Unsuitable	Khorog Less Suitable	Khorog Suitable
AHP	4,584,636.10	352,111.55	1,803,673.45	474,272.70	9,672,288.70	1,940,206.50	5,612,226.95	919,801.60
All Factors Equal	4,584,636.10	179,648.80	2,450,408.95	0.00	9,672,288.70	1,250,355.30	6,891,326.05	330,553.70
River 50%	4,584,636.10	948,545.40	1,422,818.10	258,694.20	9,672,288.70	3,743,879.95	3,995,388.20	732,966.90
Road 50%	4,584,636.10	819,198.30	1,616,838.75	194,020.60	9,672,288.70	3,046,842.80	4,397,801.40	1,027,590.85
Emergency Facility 50%	4,584,636.10	93,417.35	1,156,937.95	1,379,702.40	9,672,288.70	1,307,842.90	2,974,983.30	4,189,408.85
Population 50%	4,584,636.10	122,161.20	2,184,528.80	323,367.80	9,672,288.70	955,731.40	7,085,346.70	431,157.00
School 50%	4,584,636.10	1,121,008.20	1,509,049.50	0.00	9,672,288.70	4,397,801.40	3,434,884.10	639,549.60
Transformer 50%	4,584,636.10	1,034,776.80	1,595,280.90	0.00	9,672,288.70	3,815,739.45	4,175,036.95	481,458.65



	Porshnev Constraint	Porshnev Unsuitable	Porshnev Less Suitable	Porshnev Suitable	Khorog Constraint	Khorog Unsuitable	Khorog Less Suitable	Khorog Suitable
AHP	63.55%	4.88%	25.00%	6.57%	53.31%	10.69%	30.93%	5.07%
All Factors Equal	63.55%	2.49%	33.96%	0.00%	53.31%	6.89%	37.98%	1.82%
River 50%	63.55%	13.15%	19.72%	3.59%	53.31%	20.63%	22.02%	4.04%
Road 50%	63.55%	11.35%	22.41%	2.69%	53.31%	16.79%	24.24%	5.66%
Emergency Facility 50%	63.55%	1.29%	16.04%	19.12%	53.31%	7.21%	16.40%	23.09%
Population 50%	63.55%	1.69%	30.28%	4.48%	53.31%	5.27%	39.05%	2.38%
School 50%	63.55%	15.54%	20.92%	0.00%	53.31%	24.24%	18.93%	3.52%
Transformer 50%	63.55%	14.34%	22.11%	0.00%	53.31%	21.03%	23.01%	2.65%

Figure 39: Suitability Ranking Comparison –Percentage of Total Area - AHP versus Rating Method

4. Discussion

The main goal of this study was to identify suitable locations for building schools in isolated mountainous communities, particularly in areas with limited land due to rapid population growth and surrounding natural hazard risk. In order to achieve this goal, the following two objectives have been outlined along with the associated findings of this analysis.

1. *The development of a standardized set of criteria for school suitability analysis in GBAO.*

The selection of these factors is based on reviewing the literature discussed earlier in the literature review section. In this section, a critical analysis of the relevance of the selected criteria will be discussed. Furthermore, the range of values used in deriving the buffer distances for the analysis of each criterion had to be modified within the context of the topography of the activity zones. The location of the activity zones lying between a river on one side and steep mountain faces on either side required careful selection of a buffer distances that did not extend beyond the extent of the activity zones. In addition, while these factors were selected for determining school location suitability, these criteria could be used for siting medical facilities, place of worship or community centres.

In the analysis of the constraints dataset – *slope* is an important aspect and highly relevant to this study area given the mountainous terrain and natural hazard vulnerability of the region. In terms of the validity of this criterion for the analysis, its inclusion and the value of 20% are relevant to this study. In addition to the use of a slope, the creation of contour lines would have been beneficial in assessing terrain change and therefore a useful indicator of where potential flooding or inundation will occur.

In regards to the *hazards* dataset, the selection of the hazard polygons while providing a starting point would have added greater value had they been rendered in a three dimensional format on high resolution satellite imagery. Nevertheless, the buffering of the hazard polygons within the extent of the activity zones provided a constraint parameter. This type of data input was unique to this study, in the sense that none of the reviewed articles incorporated the use of hazard dataset used in this study.

As mentioned earlier, the study area lies in a high seismically active area and therefore it is critical that a school should not be located over an earthquake fault line or a fault trace line. The use of hazards polygon alone is not sufficient to determine inclusion or exclusion of a suitable area. This inclusion of fault line data would have been a more relevant criteria then simply using polygons to represent location of known hazards. Furthermore, the use of soil type data (i.e. certain soil types like rock are less vulnerable to earthquakes then soft soils like sandy soils) specifically soil bearing capacity would also have provided a better evaluation of site suitability in the analysis. In addition, the geology of flood hazard areas can amplify flood events, rock formations that are permeable allow rapid infiltration whereas Karst and Crystalline rock favour surface runoff (Kazakis, Kougias, & Patsialis, 2015).

The use of *emergency facilities* in this analysis was another factor unique to this analysis. Since the locational information of medical facilities, safe havens and emergency communication centres was available from the Focus Humanitarian database it provided a valuable opportunity to leverage these locations in determining suitable areas for school site selection. The buffer distances were chosen in consideration of the unique setting of the study area. Larger buffer distances would have resulted in selection of areas outside the living zone which is unrealistic and irrelevant to the study. This criterion, its subsets and the chosen buffer distance are highly relevant and applicable to the study area.

With respect to *distance from existing schools*, the study by (Talam & Ngigi, 2015) suggested buffer values of between 0 – 2000m, with distances greater than 2000m being *Most Suitable*. This value Seemed appropriate for this study and was adopted for generation of the buffer distances. The maximum distance of 2000m is also within the acceptable 2,400m acceptable walking/biking distance guideline (United States Environmental Protection Agency, 2011).The guidelines, while providing a useful benchmark, had to be nevertheless modified to fit the current context. The rationale for selecting this factor was to assign a lower weighting to areas that were relatively close to an existing school.

In regards to the *distance from transformers*, this factor is unique to this study area, the two studies reviewed earlier ((Bukhari & Noordin, 2010) and (Talam & Ngigi, 2015) incorporated proximity to transmission lines. The distances used by the two studies were buffer distances ranging from 0 – 450m, however, in the context of this study, those were unacceptable distances for being in proximity to a transformer. These are typically noisy facilities and furthermore pose a major fire risk in the event of a natural disaster.

In reviewing the *distance from river network*, both studies ((Bukhari & Noordin, 2010) and (Talam & Ngigi, 2015) suggested buffer distances between 0 – 450 m. As was discussed in the methods section the study by (Kazakis, Kougias, & Patsialis, 2015) suggested that with distances greater than 2000m flood hazard risk decreases. The choice 0 – 600m was selected given the limited availability of land thus restricting the selection to within the extent of the study areas.

Distance from a river network alone is not sufficient enough to determine school site suitability, the rate of discharge of the river is equally important. The rate of discharge requires certain factors to be considered (Jackson, 2012); 1. *Size of drainage basin* – a large drainage basin implies a larger catchment area and therefore a large collection of water which increases discharge. 2. *Permeability of soil and rock* – this was covered earlier in the discussion on hazard constraints dataset, rocky surface have poor infiltration thereby increasing river discharge causing run-off. 3. *Vegetation cover* – if a basin has large amount of vegetation cover, this will absorb the amount of water entering the river, reducing discharge. 4. *Steepness of basin* – steep river sides will result in rapid water entering the river causing an increase in discharge. 5. *Number of tributaries* – the larger the number of tributaries entering the river, the greater the amount of discharge.

In addition to discharge, the elevation of the potential flood plain in relation to the river is also a contributing factor. Settlements that are close to a river bank but are of high elevation will have a low risk of being inundated by the flood waters.

As far as *distance from road* is concerned, the literature suggests a mixed opinion regarding the buffer distances. The two studies (Bukhari & Noordin, 2010) and (Talam & Ngigi, 2015) used buffer distances ranging from 0 – 450m whereas the study by (Samad et al., 2012) suggested using a distance of 50 m (most suitable) and 1000m (less suitable). In this study, a buffer distance of between 0 – 450m was selected. In this analysis, the closer a school was located to a road, the higher the attributed score whereas in the first two studies, the closer the road to a school the lower the score. The rationale used for the two studies is that proximity to a road is associated with noise and pollution. The selected buffer distance is appropriate for this study.

In the analysis of the last factor – *population density*, there was huge challenge in getting georeferenced population Figures for the various villages in each activity zone. The rationale for using this criterion was to assess the level of demand for schools based on the school age group. This resulted in a very rough estimate of the population density for the less than 19 years age group. Furthermore, there is a limitation in the methodology since age distribution is not relevant as it would be evenly distributed. Families with young children will typically locate themselves to areas where there are schools. Moreover, population density itself is not sufficient enough to determine site suitability but rather the population growth rate needs to be factored in as well to identify sites which can be further developed to accommodate this growth in population.

2. The comparative analysis of the site suitability results obtained using the two approaches (AHP versus Rating).

The results of the analysis have an element of subjectivity with regards to the weighting of the factors. Starting with the *Analytical Hierarchy Process (AHP)*, ideally a panel of experts would have been involved in conducting the pairwise comparison of the criteria. Naturally, the background or discipline of the expert in the panel would influence the assignment of weights between the six factors used in the analysis. A disaster risk reduction expert would place a higher weight on the safety of the community and would rank distance from road and river to have higher relative importance then population density. On the other hand a social planner's perspective would perhaps have ranked population density higher than proximity to a road or river.

In five of the seven studies reviewed in the introduction section, a panel of experts was consulted in the pairwise comparison of factors and their relative weight assignment. In this study, a panel of experts was not available to participate in such a process.

In the same manner, the weighting assigned in the *ranking* method is also highly subjective depending on the perspective of the individual responsible for making the selection. In the analysis, six scenarios were chosen to provide a sensitivity analysis (i.e. *all factors equally weighted, river weighted 50%, transformer weighted 50%, existing schools weighted 50%, road weighted 50%, emergency facilities weighted 50% and population density weighted 50%*) to illustrate the weighting biases of the decision maker(s) and to evaluate whether the outcome of the results may be influenced by holding other factors constant.

In the interpretation of the observations made in the results section, although each of the factors individually consisted of a *most suitable* classification when combined together the constraints rasters (hazards and slope) came into play and consequently masked out these *most suitable* classifications in the final AHP and Rating rasters. The same rationale can be applied in the *all factors equally weighted*, *school weighted 50%* and *transformer weighted 50%* for Porshnev activity zone which explains none of the these rasters being classified as *suitable.*

In the case of *emergency facilities weighted 50%* resulting in the greatest amount of land for both activity zones can be explained by observing Figure 11, page 30. The *suitable* classification dominates both activity zones and becomes more pronounced in the simple additive weighting due to the 50% assigned weighting.

Similarly, the explanation for *emergency facilities weighted 50%* characterized by the least amount of land being classified as *unsuitable* is due to the fact that the majority of the activity zone is classified as *suitable* with a few pockets of *less suitable* land. Furthermore at the southern tip of the activity zone where the area is classified as *unsuitable*, the simple additive weighting process introduces the natural hazards constraint that eliminates a large portion of the area classified as *unsuitable,* leaving a small portion of land classified as *unsuitable*. In the case of Khorog, the population weighted 50% has the least amount of land classified as *unsuitable* due to the combination of the natural hazard and slope constraint rasters.

Finally, the school weighted 50% scenario with the largest amount of land classified as *unsuitable* in Porshnev and Khorog is attributed to the classification of the dataset (Figure 13, page 32) prior to the simple additive weighting. It can be Seen the majority of the classification for both activity zones is *unsuitable*. In the process of integration with the constraint datasets the amount of *suitable* land is significantly eliminated from consideration.

In the comparison of the AHP results with the Rating results as a whole, the combined *less suitable* and *suitable* categories results in 4% difference which is consistent for both activity zones i.e. 32% using AHP versus 28% for the Rating method and 36% versus 32% for Porshnev and Khorog respectively.

The advantage of the *AHP* methodology over the *Rating* method is the usage of the *Consistency Ratio* which ensures reliability and consistency of the decision maker(s). If the Consistency Ratio yields a value of 10% or greater, the decision maker(s) can refine the pairwise comparison matrix to satisfy the less than 10% condition (Saaty, 1987). In the case of the *Rating* method, there is no check for consistency and consequently one factor can be disproportionately weighted higher than other factors as was demonstrated in the various scenarios.

There were several challenges in conducting this study due to the lack of adequate and/or detailed datasets. In terms of building on and improving the results of the current study, the following is a recommendation of datasets that could be incorporated in future studies for school site selection suitability:

1. *Georeferenced population data* - Population distribution spatially referenced to settlement or household locations. The use of the World Population Density datasets offered a rather coarse distribution of the population density of the study area.
2. *High Resolution Satellite imagery* – This data would have enabled the generation of a much finer digital elevation model. The 90m DEM resolution of the Shuttle Radar Topographic Mission (SRTM) used in this analysis was quite coarse.
3. *Landuse* - This would have provided a spatial representation of agriculture, and the built-up environment (residential versus commercial). The availability of high resolution imagery would have permitted the extrapolation of land use features.
4. *Land Cover* – this data could have been extracted with the availability of high resolution satellite imagery.
5. *Seismic Intensity Zone/ Seismic Microzonation* - The availability of microzonation readings would have been useful in identifying sites that are seismically active. Earthquake zone data was not used in the analysis since the available data was generalized for the whole region. The inclusion of this data is necessary because it is not uncommon to have earthquake induced landslides and avalanches in the region.
6. *Panel of experts/residents* – In order to avoid bias in the pairwise comparison of the factors, it would be highly recommended to include professionals and residents alike in the selection of the appropriate weightings.

5. Conclusion

This paper set out to identify optimum locations for school construction in isolated mountainous communities of Khorog and Porshnev in Gorno-Badakhshan Autonomous Oblast (GBAO), Eastern Tajikistan. The urgency of this research is highly significant due to the fact that the region is experiencing rapid population growth, yet limited land for agriculture and construction is available due to the mountainous topography which is further compounded by proximity to natural hazards.

In regards to school site selection in Tajikistan, a gap exists in the literature on a standardized set of criteria for Multi-Criteria Decision Analysis (MCDA). Furthermore, the study aimed at analyzing the results of the popular *Analytical Hierarchical Process* (AHP) with that of the *Rating* method. Consequently, as a result of the study, the two objectives were accomplished:

1. *The establishment of standardized criteria for school site selection suitability analysis in GBAO*.

    a. <u>Unique approach to natural hazard data integration</u> – This study adopted a unique approach in the usage of natural hazard datasets representing hazard polygons (i.e. Flooding, Bank Erosion, Landslides, Avalanche, Rockfall and Debris flow) not seen in the literature review.

    b. <u>Implication for Disaster Risk Reduction Planning (DRR)</u> – The criteria used in this analysis will be provide a valuable starting point to build on and refine for local and provincial governments in the region in mainstreaming DRR planning in school site selection analysis.

    c. <u>Identification of data gaps</u> – Despite the fact that the study was valuable in identifying a series of datasets for multi-criteria decision analysis, it also uncovered two major data gaps: i) the lack of georeferenced household population ii) earthquake fault line data at the suburban level both of which could have provided for a more robust analysis.

2. *A comparison between the Analytic Hierarchical Process (AHP) and the Rating method with site suitability analysis results.*

    a. <u>Weight assignment influences final suitability selection</u> – a stakeholder's perspective and subsequent assignment of weighting plays a major role in determining final selection suitability.

    b. <u>AHP reinforces consistency in weighting pairs</u> – in spite of the fact that weighting allocation affects the final site suitability, AHP has an advantage over the Rating method in maintaining consistency in criteria weighting assignment on a criterion pair by pair basis.

Ultimately, a field visit to Khorog and Porshnev to validate or ground truth the suitability results of the analysis will provide an interesting topic for future research.

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