GIS-Based Geo Hazard Assessment of Pakistan for Future Urban Development Using AHP

By

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Remote Sensing and GIS

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(October 2014)

CERTIFICATE

Certified that the contents and form of thesis entitled **"GIS-based geo hazard assessment of Pakistan for future urban development using AHP"** submitted by Mr. Amer Imran Minhas have been found satisfactory for the requirement of the degree.

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DEDICATION

Dedicated to my parents, family and teachers

ACKNOWLEDGEMENTS

In the Name of Allah, most Gracious, most Compassionate for guiding me towards the right path.

I am thankful to my thesis supervisor, Dr. Salman Atif, whose guidance and support during every stage of my thesis enabled me to develop a thorough understanding of the subject and accomplish my objectives.

I am also grateful to all my guidance and examination committee members, Dr Ejaz Hussain, Dr Ali Tahir and Dr Abdul Waheed for their support and guidance.

I am grateful to all my family members who were with me during hardships and prayed for my success.

Amer Imran Minhas

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
GIS	Geographical information systems
RS	Remote sensing
AHP	Analytical hierarchy process
MCDA	Multi criteria decision analysis
USGS	United States geological survey
m	meters
TRMM	Tropical rainfall measurement mission
SRTM	Shuttle radar topography mission

ABSTRACT

Pakistan is subject to frequent earthquakes which are often severe (especially in north and west) and severe flooding along the Indus after heavy monsoon rains (July and August). Losses to life and property remained very high in the recent past. In order to mitigate the losses there is a requirement of integrated decision support which could help planners to take complex decisions accurately and quickly. The study aimed at providing multi criteria decision analysis framework resulting into regionalization of the territory of Pakistan according to the level of vulnerability to these natural disasters. Site suitability for urban development in Pakistan was assessed by the application of GIS and analytical hierarchy process (AHP). GIS can effectively store, retrieve, manipulate, analyze and display the spatial in site selection problems. AHP can be used to calculate weights of criteria while decision maker remains consistent in judging and allocating comparative preference to criteria. Weights of criteria were calculated and aggregated in two clusters namely environmental (elevation, slope, aspect, distance from rivers, land surface temperature and precipitation) and hazard (flood extents, Earthquake density and intensity). The results of two clusters were then synthesized to obtain suitability index map. Indices in the map were classified into four categories representing extremely suitable, suitable, less suitable and worst regions for urban development. This studies shows how an effective multi criteria decision support method can be developed to select suitable sites for urban development using GIS and AHP. Urban development should be planned in extremely suitable areas.

Chapter 1

INTRODUCTION

1.1 Background Information

Recent earthquakes in Pakistan demonstrated that the region is highly seismic (Naseer, Khan, Hussain, & Ali, 2010). The Himalayan Mountains in the north, mid-oceanic ridges in the south and earthquake belts surrounding the Indian plate all render the Pakistan as a risk prone area. The Kashmir Earthquake of October 8, 2005 had widespread destructive effects with in excess of 86,000 people killed and over 80,000 severely injured (Mulvey, Awan, Qadri, & Maqsood, 2008). The Indus monsoon flood in 2010 was one of the greatest river disasters in recent history which affected more than 14 million people in Pakistan (Gaurav, Sinha, & Panda, 2011). Though there has been isolated efforts of mapping these vulnerabilities at various organization, department and even at country level but an integrated data / map containing information on the spatial occurrence of major calamities is not publically available.

1.2 Rational

Urban development in hazardous zones remains an uphill task in Pakistan(Bertaud, 1989; Mustafa, 2005). The pace, scale and spatial reach of anthropological actions make the society increasingly dependent on environmental and urban planning solutions, in order to reduce its exposure to natural hazards. There is a necessity for documentation that briefly presents the type and scale of these events as an aid to urban administration for decision making. Seismic hazards, landslides, rock falls, floods, torrential floods, excessive erosion, droughts, coastal cyclones and forest fires are some of the significant natural hazards within the territory of Pakistan; these natural processes can directly and indirectly endanger the environment, populace and property.

1.3 Literature Review

Though there are numerous studies which combine GIS and MCDA for different areas of study which include studies for site suitability, planning routes and environmental evaluation etc. Few of them are referred here. (Bunruamkaew & Murayam, 2011; Chandio, Matori, Lawal, & Sabri, 2011; Duc, 2006; HOU, JIA, & GUO, 2006; Huang, LUO, & YANG, 2008; Kara & Doratli, 2012; Liu, Li, Liu, & Cao, 2008; Ma, Scott, DeGloria, & Lembo, 2005; Moeinaddini, Khorasani, Danehkar, & Darvishsefat, 2010; Mohit & Ali, 2006; Naghdi & Babapour, 2009; Samani, Hosseiny, Lotfalian, & Najafi, 2010; Ş. Şener, Sener, & Karagüzel, 2011; Ş. Şener, Şener, Nas, & Karagüzel, 2010; Tudes & Yigiter, 2010; Wang, Qin, Li, & Chen, 2009; Ying et al., 2007)

GIS Based Multicriteria Approach to Housing Site Suitability Assessment in Sana'a city, Yemen using data of slope, aspect, elevation, Distance from road, river, waste water treatment plant, airport, reserved forests and industrial area was studied by Al-Shalabi, Shatri et al.(2006). A similar study on geo-environmental evaluation for urban land use planning in Lanzhou city China was conducted by Dai, Lee et al.(2001). Mehmet Centimur.(2010) studied evaluation of settlement sites beyond the scope of natural conditions and hazards by means of GIS based

MCDA in a basin in Turkey using topography, precipitation, temperature, river lines, floods and seismic data.

1.4 Objective

As a Consequence of above said problem, the objective of this research is to provide a multi criteria decision analysis framework resulting into regionalization of the territory of Pakistan according to the level of vulnerability to different natural hazards and environmental conditions.

1.5 Approach to Objective

The integration of GIS and multi criteria decision analysis (MCDA) has attracted significant interest over the last 15 years or so (Malczewski, 2006). At the most rudimentary level, GIS-MCDA can be thought of as a process that transforms and combines geographical data and value judgments (the decision-maker's preferences) to obtain information for decision making (Malczewski, 1999). Using the integral map of different hazards, MCDA will be conducted over areas of low intensity values for all major hazards. The objective of this study is to develop Geographic Information System (ArcGIS)-based land suitability analysis model for locating optimal sites for urban development against environmental threats. For this purpose criteria of topography, precipitation, temperature, distance from rivers, potential risk areas from flood and earthquakes will be used. The outcomes of this study will be land suitability model for urban developments in Pakistan.

1.6 Scope of Study

Knowledge of the susceptibility of a given area to environmental risks is important for spatial development. By understanding the nature and the spatial distribution of natural events in Pakistan, actions can be undertaken to reduce the risks. The aim of this research is to determine the geographical distribution of the major types of hazardous occurrences in Pakistan. Based on this analysis, the ability to create integral map of the natural hazards within the territory of Pakistan will be achieved, identifying the areas prone to certain natural threats. This analysis is especially important as an attempt to categorize areas within the country according to their levels of the risk from these events (Peduzzi, Concato et al. 1996)

1.7 Study Area

Located in South Asia, Pakistan borders Iran to the southwest, Afghanistan to the west and north, China to the northeast, and India to the east (Figure 1). Pakistan is among the most vulnerable areas in the Age of Climate Change (Watson, Iwamura, & Butt, 2013). Urban sprawl is on the rise. Population figures 180 million people, which makes it sixth most populous country. Population density has risen to 270.77 / sq. km. Area is 796,095 sq. km.

Pakistan’s river system consists of more than 60 small and large rivers. These rivers have always provided ideal conditions for human settlement and growth of politics, arts and culture. Frequency and intensity of occurrence of floods remains very high due to unusually heavy monsoon rains during the normal season that runs from July to September resulting into heavy losses. . Pakistan is situated in a highly seismically active region which has experienced many disastrous earthquakes during historical times posing a constant threat to lives and property of people.

Flooding and earthquakes are most frequently occuring destructive phenomenons which keep on inflicting heavy losses to lives and property of people every now and then(Hussain, Arsalan, Siddiqi, Naseem, & Rabab, 2005; Jonkman, 2005; Leroy, 2006). Spatial reach of both these natural clamties encompasses whole of Pakistan and are therefore important to be studied at countary level.

There are five big rivers flowing through the country from north to south namely the mighty Indus and its tributaries, that is, Jhelum, Chenab, Ravi and Sutlej. There is a well-marked monsoon season from July to mid-September in which most of the country receives rainfall(Gaurav, et al., 2011). Riverine flooding is common in the low lying areas along the rivers during monsoon season while flash flooding is also experienced in hilly and semi hilly areas. Since its creation, Pakistan has faced severe floods in 1950, 1956, 1957, 1973, 1976, 1978, 1988, 1992 and now in 2010(Hashmi, Siddiqui, Ghumman, & Kamal, 2012). As per Damage Need Assessment (DNA) report of ADB /World Bank, the 2010 floods claimed about 1,985 lives, damaging around 1.5 million houses, wiping out cropped area of more than 17 million acres, displacing a population of about 20 million and resulting in economic loss of PKR 10 Billion.

On October 8, 2005, an earthquake of magnitude Mw 7.6 shook northern Pakistan and the Kashmir region. With over 70,000 dead, more than 80,000 injured, and more than two million homeless, the earthquake ranks amongst the worst natural disasters in the history of Pakistan and the Indian subcontinent(Durrani, Elnashai, Hashash, Kim, & Masud, 2005). According to early estimates (WB-ADB, 2005), the total cost of reconstruction of the damaged infrastructure and rehabilitation is in excess of five billion dollars in direct losses.

Figure 1. Map of Pakistan and its neighbors.

Chapter 2

MATERIALS AND METHODS

2.1 Integration of GIS And MCDA

Geographical Information Systems (ArcGIS) are computer systems or software that can collect, manage, analyze and display spatially referenced data. GIS have always been considered as good decision support tools because of their map displaying capabilities. Multicriteria Decision Analysis (MCDA) is a set of mathematical tools and methods that help a decision maker solve several kinds of problems such as choice, ranking, sorting, classification. The integration of geographic information system (ArcGIS) and multicriteria decision analysis has attracted significant interest among urban planners since the 1990s (Omitaomu et al., 2012). This integration allows taking multiple criteria into account when dealing with spatial decision problems. The principle of the method is to divide the decision problems into smaller understandable parts, analyze each part separately and then integrate the parts in a logical manner (Malczewski, 1996). Therefore creation of decision tree is a main underlying part of MCDA. Example of of such decision tree was presented by Meng, Malczewski et al in 2010 while they carried out a study for accessibility of housing development sites to existing facilities in canmore, alberta (figure 2). The problem was divided into four parts namely goal, objectives, attributes and alternatives.

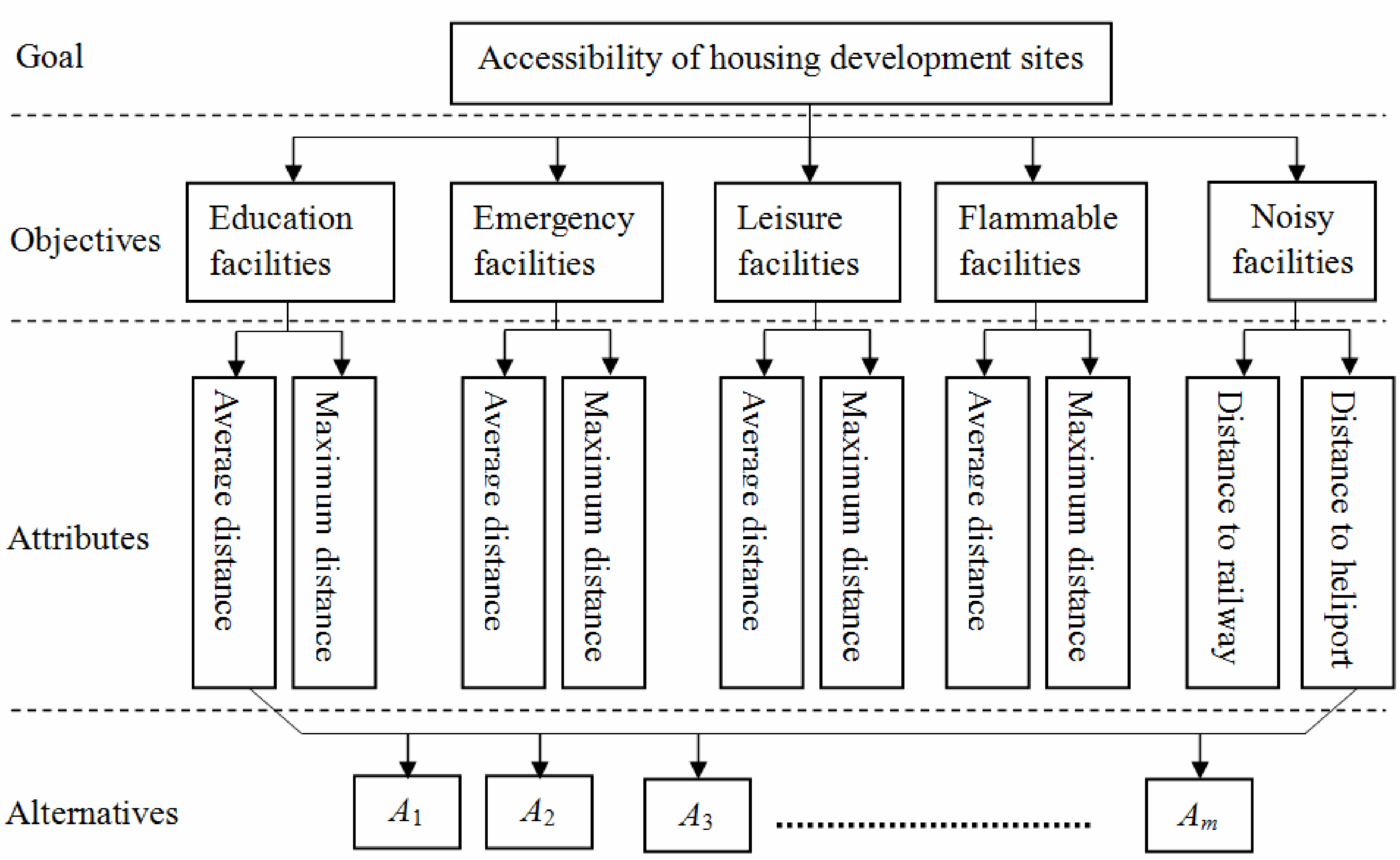


Figure 2. Hierarchical structure of accessibility of housing development sites to existing facilities in canmore, alberta.

2.2 Conceptual Mathodology of MCDA

A broad flow of events for MCDA sudies is shown in figure 2 below. Conduct of MCDA is phased in five stages which are described as under:

2.2.1 Idendify the Problem

Definition of the problem which is required to be resolved is the initial step of the proceedings to be carried out. The tasks such as; where the suitable areas should be located or where the industrial areas should be sited are outlined. According to each defined challenging issue, the steps to be followed will be planned; data, thresholds and base maps will be decided.

2.2.2 Specifying the Criteria

Deciding the correct data layers is essential for the resolution of the identified problem and is disparagingly significant for the result of the study. Simply incorrectly specified layers will produce flawed conclusions. The contributing factors indicated here are the main constituents for the solution of the problem. Also any statutory component or limitation should be realized here in this phase.

2.2.3 Specifying the Priority of Criteria With Respect to Others

To resolve the stated question the importance of each factor is likely to vary. For example if the requirement is to locate the best site for agricultural project, the significance of the closeness to the road and water channels will vary across all criteria. There are many diverse approaches mentioned in the literature for this type of study. Among all the described methods; Analytic Hierarchy Process (AHP) that compares the importance of each criterion to other by the analyst will be employed in this research.

2.2.4 Standardizing the Attributes of Data

To process the spatial data together for various analytical procedures, the attributes of the layers should be of same type. As the acquired data will differ in terms of the attributes (such as degree Celsius for temperature, meters for elevation etc. or text attributes), range of values (like 0-1 or 0-100) statistically for the attributes to be used in all of the methods should be defined and these values should be assigned agreeing to the order of priority in solving the problems. After the transformation of original attribute values to common scale values; it becomes possible to perform various statistical and mathematical processes on all the layers together. So this transformation to common scale values known as standardization makes it possible to combine, manipulate and analyze all the data layers having heterogeneous units of attribute values.

2.2.5 Selecting the Suitable Site

The normalized data are processed together and the output is achieved. The final map is examined and if it is not found as satisfactory as desired, the criteria weights are revised and the procedure is reiterated. This cyclic process continues until the final resultant values of aggregated map are satisfactory to desired standards.

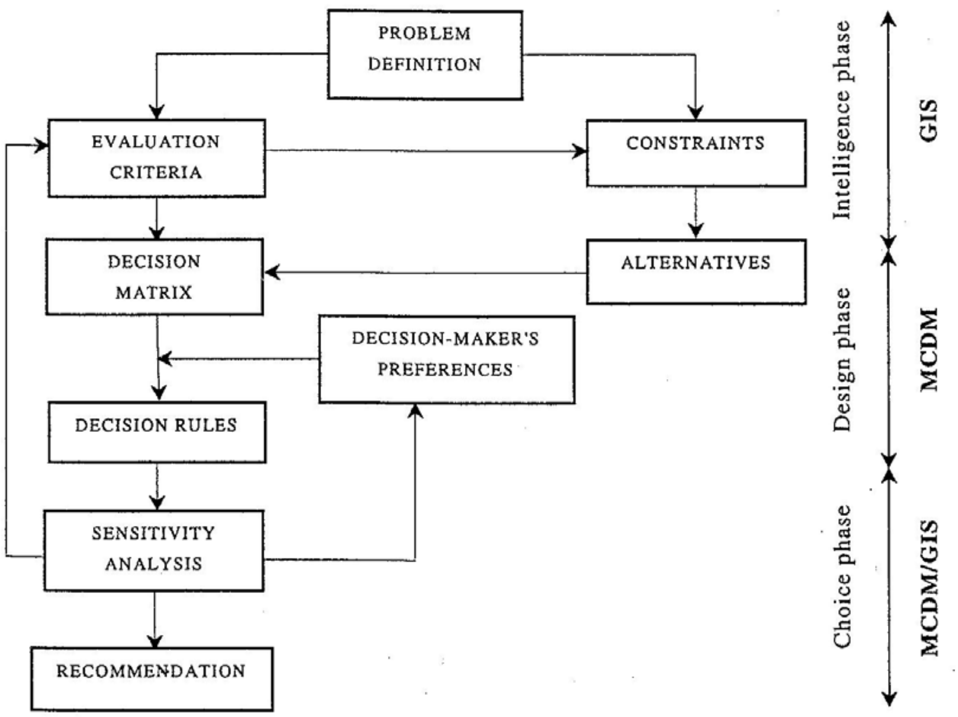


Figure 3. Decision flowchart for spatial multicriteria analysis [Malczewski, 1999].

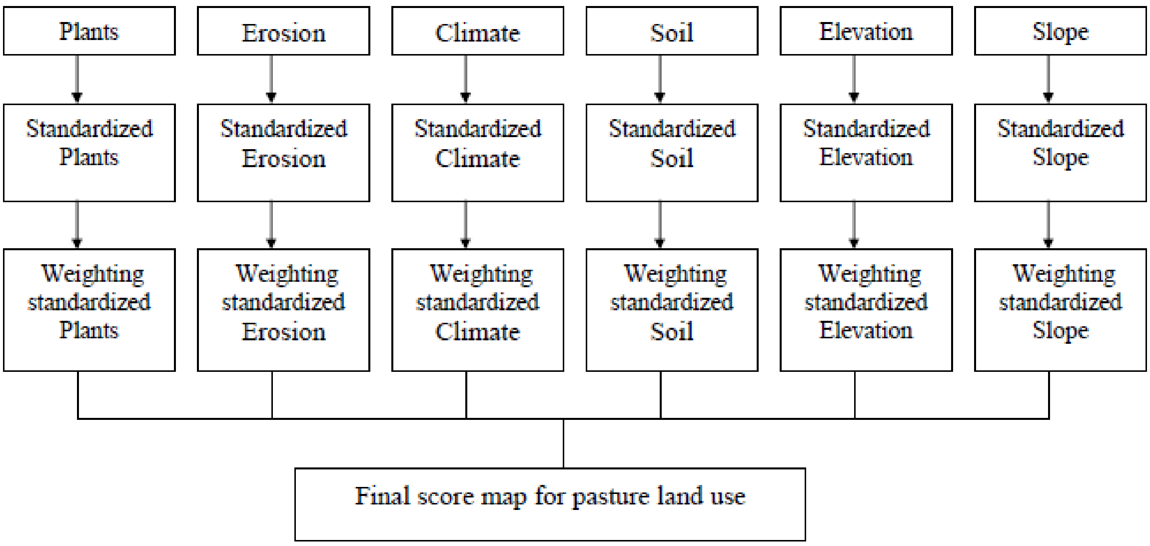


Figure 4. An example of Simple Additive Weighting process scheme

(Bakhtiarifar et al., 2009).

2.3 Various Sub-Techniques for Employing MCDA

Results of individual criterion maps can be aggregated by using different ways known and established as techniques. It is very importantant to choose the best method for a study which directs the approach and produces accurate results. All the available techniques were studied before choosing the final one which are described as under:

2.3.1 Simple additive weighting (SAW)

This method is also known as weighted linear combination or scoring method. It is widely used for combining the values of criteria. In this method first the data is obtained and standardized for all the factors. Then weights are decided and assigined to each one of them. In in final step as the name describes, this technique simply adds all the layer values and gives the final map which represents sums of all geo-colocated values. This method was used by Bakhtiarfiar et al. (2009) for land use planning, the diagram explains implimentation of SAW (figure 4 above).

2.3.2 Ideal point methods

In the ideal point method the criteria are ranked according to their departure from an ideal point. The ideal point is described as the most favorable, weighted, hypothetical option (decision alternative). The criterion, closest to the ideal point is the best one. The departure is measured in terms of distance (Malczewski, 1997).

2.3.3 Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS)

One of the most popular ideal point methods is developed by Hwang and Yoon (1981), the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS). In this method, best alternative is the one that concurrently is the adjacent to ideal point and the rearmost minus ideal unit. The ideal unit is a hypothetical alternative that is the best desired standardized weight level from each criterion among measured choices and likewise minus ideal point comprises worst standardized weight level among alternatives TOPSIS involves either uniform increscent of desirability as explained in figure 5 below (Bakhtiarifar et al., 2009).

2.3.4 Ordered weighted average (OWA)

This particular technique of MCDA Provides a parameterized class of mean type aggregation operators. Many notable mean operators such as the max, arithmetic average, median and min, are members of this class. They have been widely used in computational intelligence because of their ability to model linguistically expressed aggregation instructions (Özgen, 2010). As the name suggests in this technique of MCDA, all the layers or contributing criteria are first standardized for their attributes. Then all layers are assigned priority values. These priority values are allocated in form of weights after a thorough deliberation and consultation process. Once the weights or importance of each layer is decided with regards to the solution of the problem, then the decided weights are assigned to each layer separately and finally aggregated to obtain results.

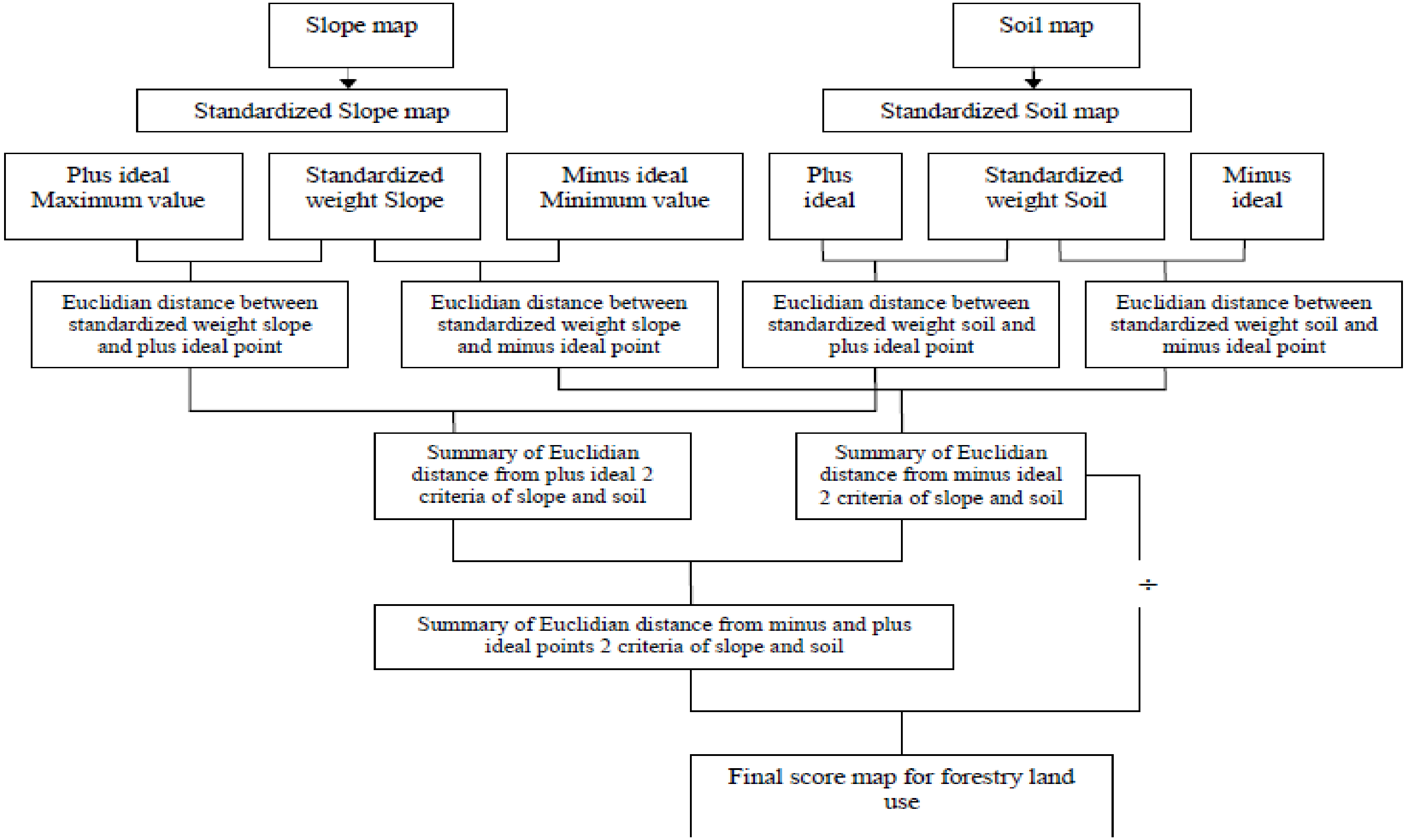


Figure 5. Sample of Technique for Order Preference by Similarity to the Ideal Solution, (Bakhtiarifar et al., 2009).

2.3.5 Analytical Hierarchy Process (AHP)

AHP is a powerful tool in applying MCDA (Bagheri & Azmin, 2010). It was introduced and developed by Saaty in 1980 (Saaty, 1980). In the AHP method, obtaining the weights or priority vector of the alternatives or the criteria is required. For this purpose Saaty (1980) has used and developed the pairwise Comparison Method (PCM), which is explained in detail in next part of the work (Kordi, 2008). An example of similar comparison drawn by Atasoy et al (2008) can be seen in figure 6 below. It can handle inconsistency in judgment of the analyst while allocating importance to each criterion by checking consistency ratio which is not implemented in other techniques like simple additive weighting (SAW) etc.

As a result of assessment of various MCDA techniques (SAW, TOPSIS, AHP, The Ideal Point Methods, OWA) in planning discipline, AHP is considered to be the best fit. The reasons behind this selection is the strong theoretical principles, several applications on multiple studies and decomposing a complex problem into rational and eloquent pairwise comparisons without losing the significance of the criteria beyond the scope of the actual problem. Examples of AHP based studies can be classified into three categories. First is the planning disciplines in which sustainable urban areas was studied by (Reis et al.). second is the site suitability analysis which was done by (Uyan, 2013). Third is the application in agriculture which was conducted by (Bathrellos, Gaki-Papanastassiou, Skilodimou, Skianis, & Chousianitis, 2013).

Table 1. Sample comparison matrix (Atasoy et.al., 2008).

	Slope	**Landslide**	**Geology**	**Soil**	**Aspect**	**River**	**Land Cover**
Slope	1	1	3	3	7	3	5
Landslide	1	1	3	3	7	3	5
Geology	1\3	1\3	1	1	6	1	4
Soil	1\3	1\3	1	1	6	1	4
Aspect	1\7	1\7	1\6	1\6	1	1\6	1\4
River	1\3	1\3	1	1	6	1	4
Land Cover	1\5	1\5	1\4	1\4	4	1\4	1

2.4 Site Selection

Site suitability assessment is similar to choosing an appropriate location, except that the goal is not to isolate the best alternatives, but to map a suitability index for the entire study area (Al-Shalabi, Mansor, Ahmed, & Shiriff, 2006). Combining GIS and MCDA for site planning involves many tasks including data gathering and structuring, and computation of criteria using spatial analysis. Most government departments don't have adequate data available to mitigate hazards. In such a situation, site suitability maps could help planners (Dueker and Barton 1990, Geertman and Toppen 1990, Wang 1994). These maps would be useful for several years and many decisions. Following a similar approach, Eastman et al. (1993) produced a land suitability map for an industry near Kathmandu using IDRISI (a raster GIS) and AHP (Saaty, 1990).

2.5 Selection of Criteria

Various factors influence the choice of urban settlement sites which include social, economic, political, environmental, hazards and availability of services and others. After detailed literature review and consultation of experts, two clusters of criteria were considered i.e. environmental and natural hazard groups. While selecting the environmental criteria only those factors were considered which are not changeable or affected by others over time and they include elevation, slope, aspect, temperature, precipitation and distance to rivers whereas land use land cover, road, rail and trade routes, socio economy and political influences etc. were neglected. While considering the hazards, only majors i.e. floods and earthquakes were used, as their spatial spread covers whole of Pakistan.

2.6 Methodology. Detailed flow is illustrated in figure 6 below.

2.7 Generating Criteria Maps

Data were obtained from various sources as described in Table 2 below. Then they were processed using ArcGIS 10.1 to obtain criteria maps of same spatial resolution and projection system i.e. 100 meters and Universal Transverse Mercator (UTM) respectively (ArcGIS, 2012). In order to process the data together, it was necessary to transform it to a common spatial resolution and projection system.

2.8 Environmental Group Criteria Maps

While considering the factors in this cluster, it was decided to use only those criteria which are not changeable overtime. Criteria such as forests, linear features like roads etc were neglected. The reason was to trace the persistant conditions which favoured and will do the same in future for settlement priorities. Having consulted literature, experts and keeping in view the availability of spatial data; six layers were selected to be analysed togather to produce environmental group map. Details and processing of all the criteria rasters is explained as under:

Table 2. Data description.

Type of Data	**Source**	**Spatial Resolution meters**	**Duration**
Elevation, slope, aspect	Shuttle Radar Topography Mission (SRTM)	90	11 day mission in Feb 2000
Land surface temperature	MOD11C3 product of Moderate Resolution Imaging Spectroradiometer (MODIS)	5600	2000-2013
Precipitation	3B42 product of Tropical Rainfall Measuring Mission (TRMM)		1998-2013
Vector data	Survey of Pakistan	-	-
Earthquake events	USGS earthquake hazard program	-	2000-2013
Flood extents	UN Habitat	-	2010-2013

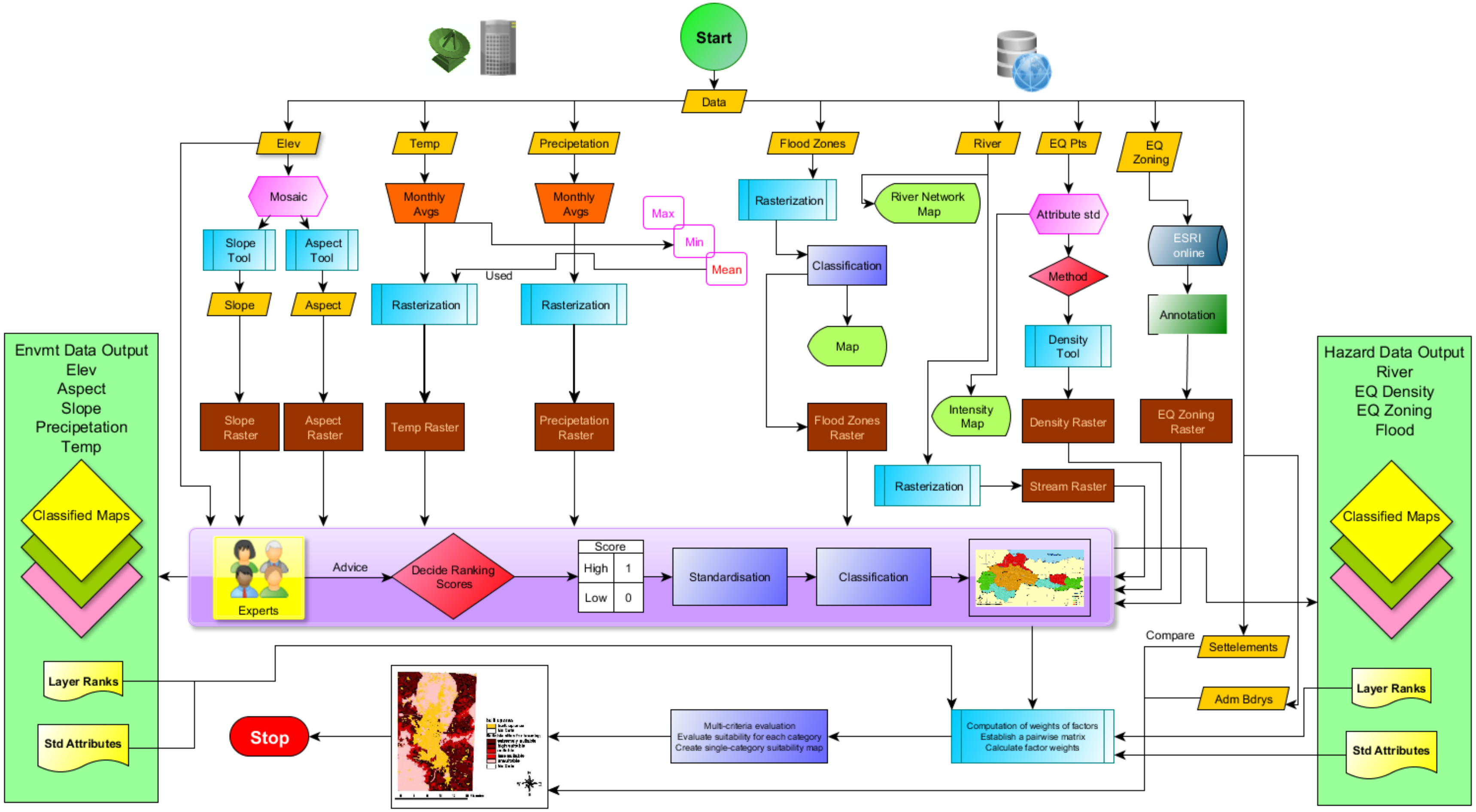


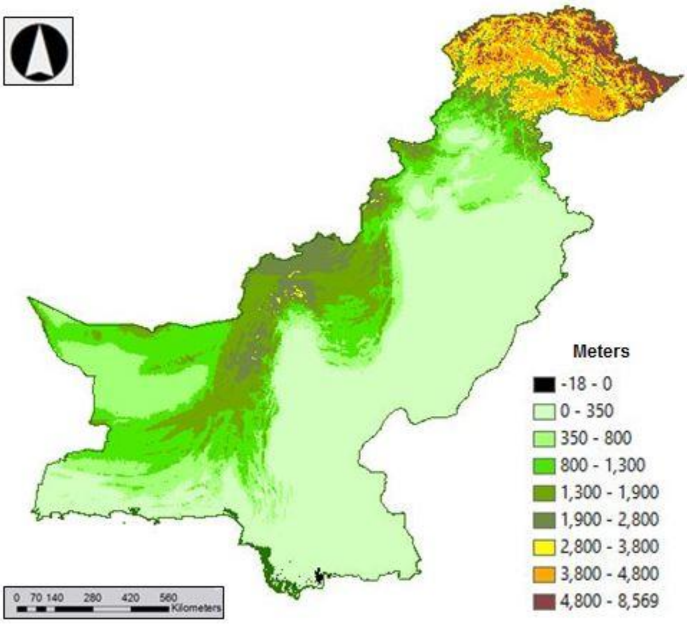
Figure 6. Methodology.

2.8.1 Elevation

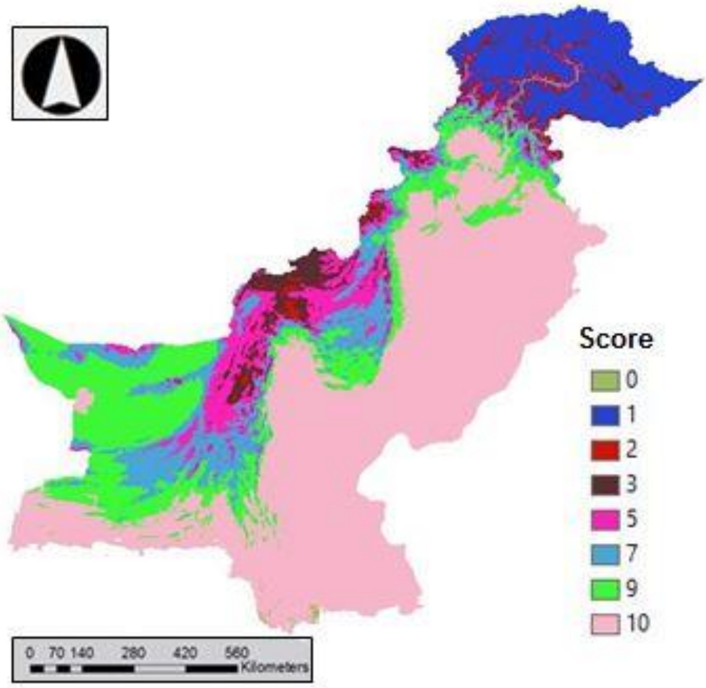
The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The data has a original spatial resolution of 1 arc sec (30m) and it is resampled at 3 arc sec (90 m) for global distribution in 1 degree tiles. The data can be downloaded from USGS website http://dds.cr.usgs.gov/srtm/.

Elevation is one the most important factor considered before planning or opting for a settlement site. The data was obtained from above mentioned sources in tiles for the study area, these tiles were mosaicked to produce an elevation raster which was then cropped to Pakistan boundary using clip tool. The elevation raster is shown in figure 7a below.

Thereafter the important step of standardization was performed in which original values of elevation were rescored to a conceived common scale of 0 to 10. This step was an iterative one till it satisfied the expected result threshold levels. Lower elevations were preferred while allocating priority to the elevation scores. The elevation values along with scores and elevation score map are shown in table 3 and figure 7b respectively.



(a)



(b)

Figure 7 (a) Elevation map and (b) Elevation rank score map.

Table 3. Elevation rank values.

Serial	*Elevation values* *meters*	*Rank value* *0-10*
1	-14- 0	0
2	0-1000	10
3	1000-1500	9
4	1500-2000	7
5	2000-2500	5
6	2500-3000	3
7	3000-3500	2
8	3500-4000	1
9	4000-8569	0

Table 4. Slope rank values.

Serial	*Slope values* *percent*	*Rank value* *0-10*
1	0-3	8
2	3-5	10
3	5-7	7
4	7-10	5
5	10-15	3
6	15-20	2
7	20-<	1
8		
9		

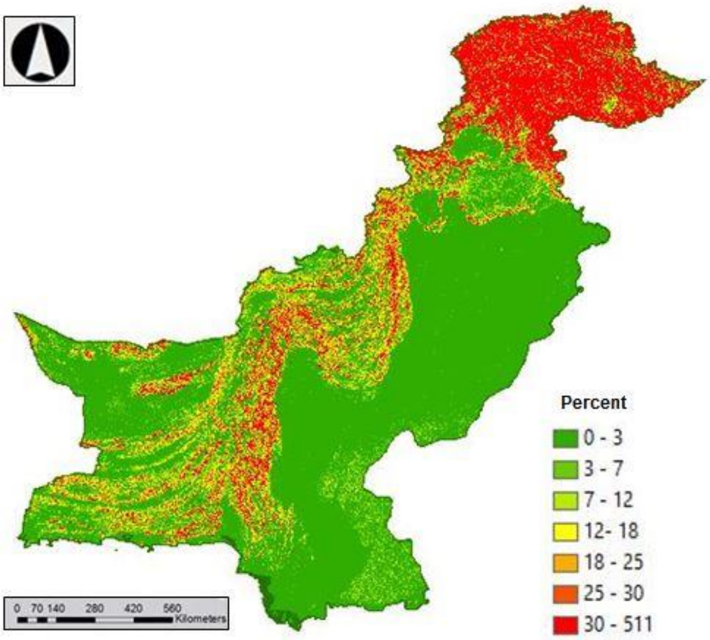
2.8.2 Slope

Slope is another essential contributor in environmental criteria as the economy, comfort and ease of construction, transportation and slope stabilizing requirements in built areas etc. dictate it as an important aspect to be looked after while planning urban development. Slope map was calculated from already available elevation raster using slope tool in percent. The slope map was classified into seven classes based on natural breaks in the data. The resultant map is shown in figure 8a.

These seven classes were then allotted rank scores from 0 to 10. Keeping in view the above mentioned reasons, opinion of experts and literature, gently sloping areas were assigned higher scores and slopes higher than 20% were considered as least ranked. Resultant rank map and values are shown in figure 8b and table 4 above respectively.

2.8.3 Aspect

Aspect data is derived from elevation data using aspect tool. It is an important criterion with regards to the human health and vegetation cover. All the living beings in this world need sunlight for health, food, heating and availability of food through vegetation. It is also important with regards to urban economy which is dependent on it in all seasons i.e. in winters it would provide heating and in summers north facing directions would offer better environment thus requiring less cooling. It was also classified and processed on similar lines as slope and results are shown in figure 9a, b and table 5.



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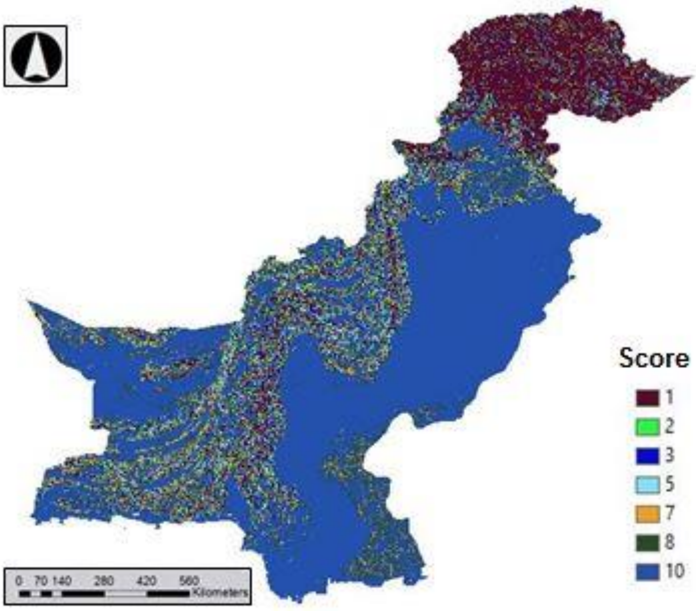
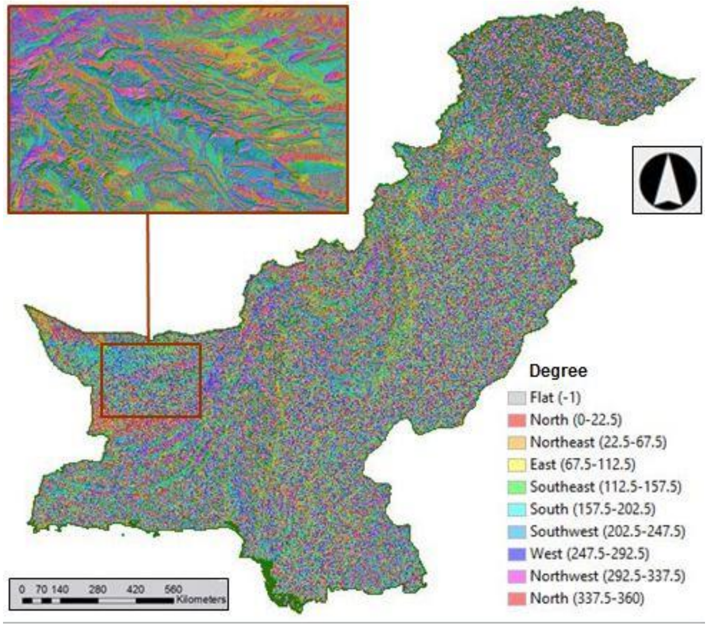


(b)

Figure 8(a) Slope values and (b) Rank score map



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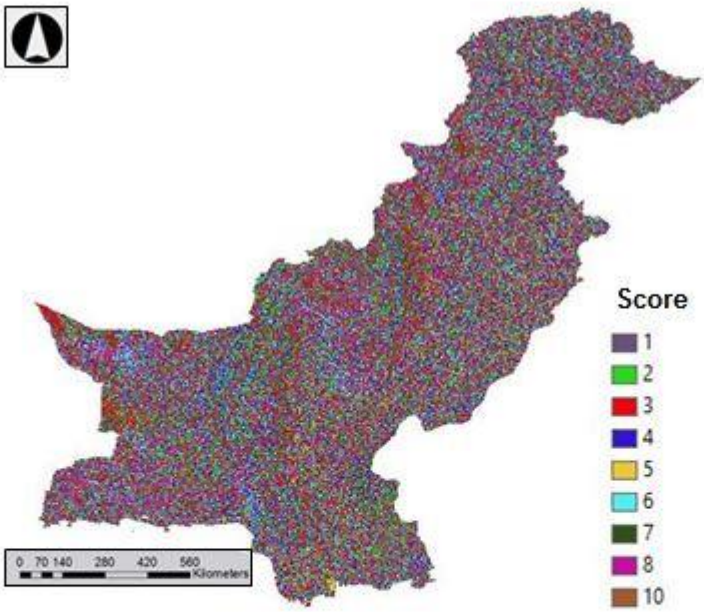


(b)

Figure 9(a) Aspect map and (b) Aspect rank score map

Table 5. Aspect rank values.

Serial	*Aspect values direction*	*Rank value 0-10*
1	Flat	5
2	North	1
3	North east	3
4	East	7
5	South east	10
6	South	8
7	South west	6
8	West	4
9	North west	2

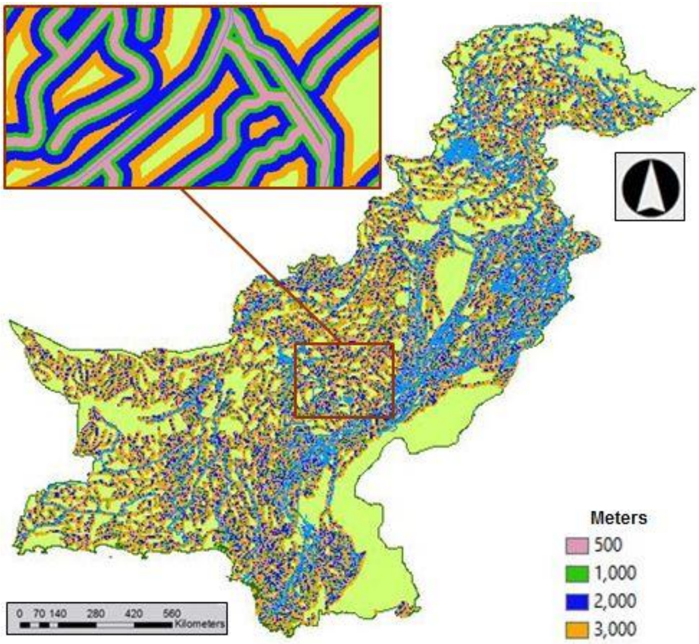
Table 6. Distance to river rank values.

Serial	*Distance to river values meters*	*Rank value 0-10*
1	0-500	1
2	500 -1000	3
3	1000-2000	5
4	2000-3000	8
5	3000-<	10

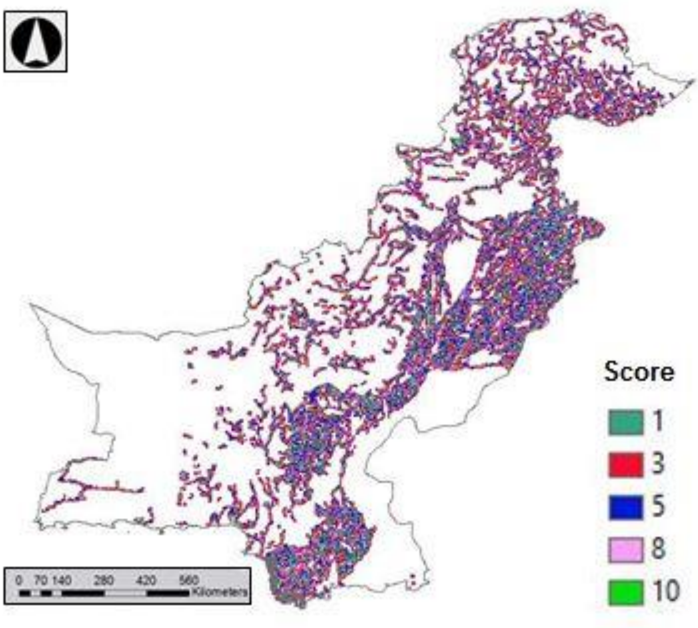
2.8.4 Distance to river

Presence of water source in the vicinity of settlement sites was considered vital for the livelihood and agriculture since ages. Therefore most civilizations and cities can be found in the valleys or planes near to rivers. Water is always considered lifeline of residential areas. However we have seen some devastating floods in the past causing heavy losses to lives and property mostly closer to rivers. Pakistan is hosting a dense network of streams and rivers which serve the people and damage those in their vicinity in seasonal rains.

Keeping above in view the vector data obtained from survey of Pakistan and other open sources was cross checked for errors and then a selection of perennial features was buffered at a distance of 500, 1000, 2000 and 3000m. These buffers were rasterized to obtain distance to river raster. While assigning rank scores, areas within 500m were given least preference due to their potential for being flooded while areas between 500 to 3000m were considered furtile and best suited for settlement due to availability of water sources in near vicinity. Wheras areas beyond 3000m were again considered less important to economy involved in provision of water to these localities. Maps and rank scores are shown in figure 10 and table 6 above.



(a)



(b)

Figure 10(a) Distance to river map and (b) Rank score map

2.8.5 Land surface temperature

The data was obtained from NASA's website *modis.gsfc.nasa.gov/.* MOD11C3 product of Moderate Resolution Imaging Spectroradiometer (MODIS) was downloaded for a period from year 2000 to 2013. The files were first converted from .hdf format to geotiff format using python script for bulk conversion. Then the average of all the images was calculated and clipped to study area. These values were converted to degree Celsius for easy assimilation using simple mathematics in raster calculator.

Values which lie in comfort zones were given higher scores while values in minus and above 40 degree Celsius were assigned lower scores. Maps and rank scores are shown in figure 11 and table 7.

2.8.6 Precipitation

It is another important criterion for availability of food and crops. The precipitation data in netcdf format was downloaded from USGS web http://mirador.gsfc.nasa.gov/ using Mirador visualization tool. TRMM_3B42_daily data of version 7 was downloaded in order to perform detailed analysis. The downloaded data was then converted from "nc" (netcdf) format to raster format netcdf to raster conversion tool. One raster for each day was made by this process.

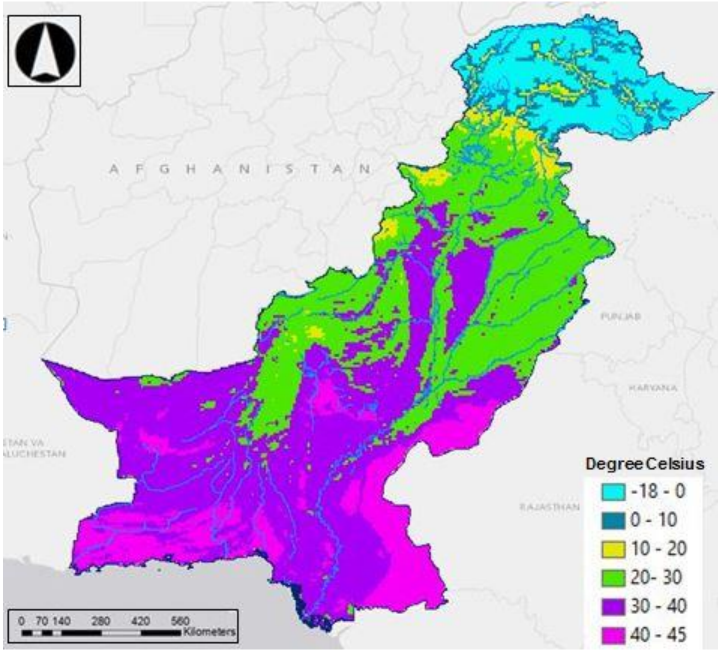
These values were converted to mm / sq km for easy assimilation using simple mathematics in raster calculator. Higher Values were given higher scores while lower values were assigned lower scores. Maps and rank scores are shown in figure 12 and table 8.

Table 7. Land surface temperature rank values.

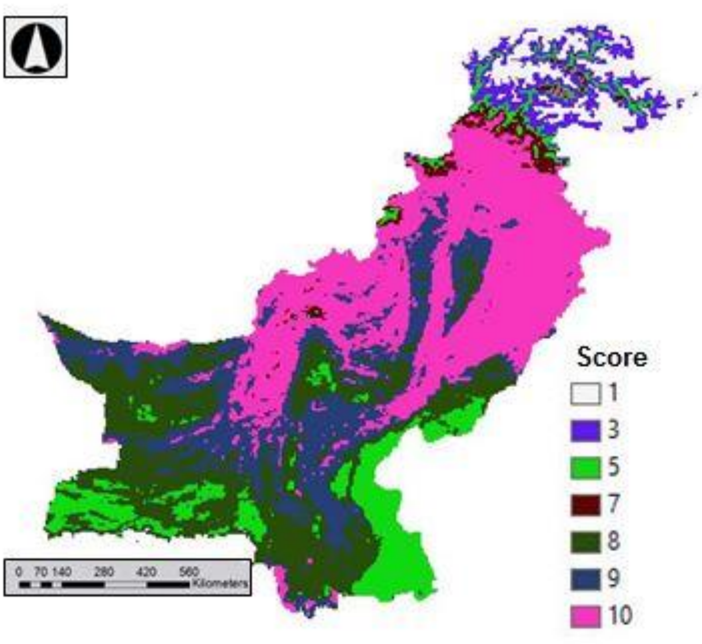
Serial	*temperature values degree cecius*	*Rank value 0-10*
1	-18-0	1
2	0-10	3
3		
4	10-15	8
5	15-25	9
6	25-33	10
7		
8	33-40	7
9	40-46	5

Table 8. Precipitation rank values.

Serial	*precipitation values mm / sqkm*	*Rank value 0-10*
1	0-50	1
2	50-150	2
3		
4	150-200	4
5	200-300	5
6	300-400	7
7		
8	400-500	8
9	500-689	10

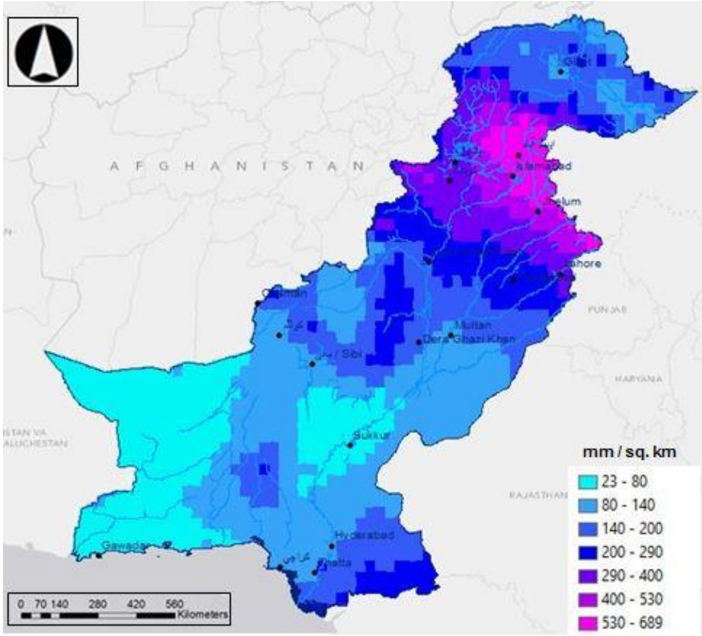


(a)

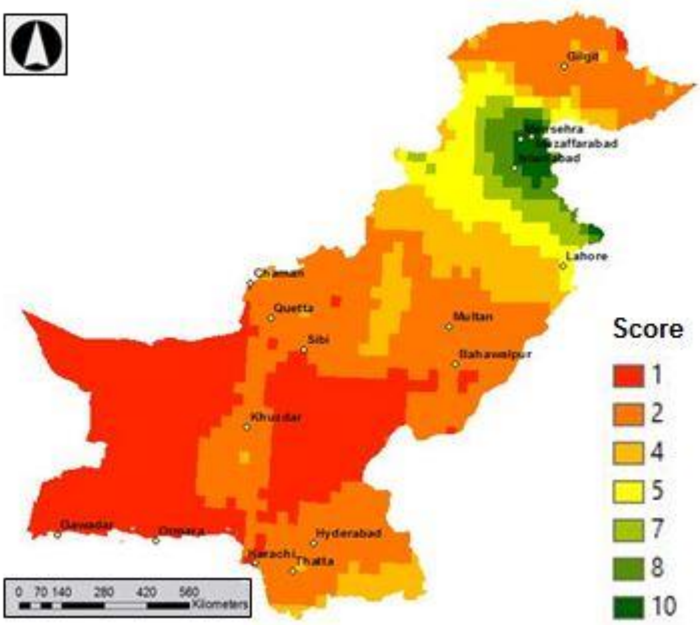


(b)

Figure 11(a) Land surface temperature map and (b) Rank score map.



(a)



(b)

Figure 12(a) Precipitation map and (b) Rank score map

2.9 Hazard Group Criteria Maps

In this cluster two major hazard were selected primarily because both had a apatial apread all over Pakistan and both are not only frequent but are catastrophic to lives and property. Though there are other natural and artificial hazards like land sliding, mass movement and crimes etc but they are local in nature.

2.9.1 Earthquake density

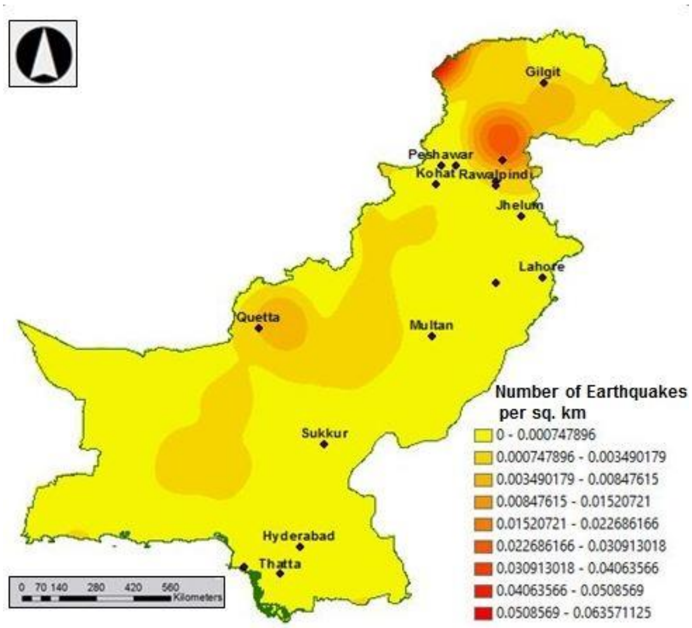
This particular criteria though least important in the cluster is aimed at finding epicentre based density raster irrespective of the magnitude. It is to cover the hazardous effects of frequently occuring smaller magnitude activity which could cause land slides etc. The point data was obtained from USGS website using the study area bounds and contraints of equal to or more than richter scale IV. As the magnitude below IV is considered safe. The catalauge of data was imported into map document and kernel density was calculated using an influence radius of 100 sq km. The same was then classified and ranked. Higher values were assigned lower scores and vice versa. Areas near Muzaffarabad, Chitral and Quetta districts were having high density of events. Maps and rank scores are shown in figure 13 and table 9.

2.9.2 Earthquake intensity

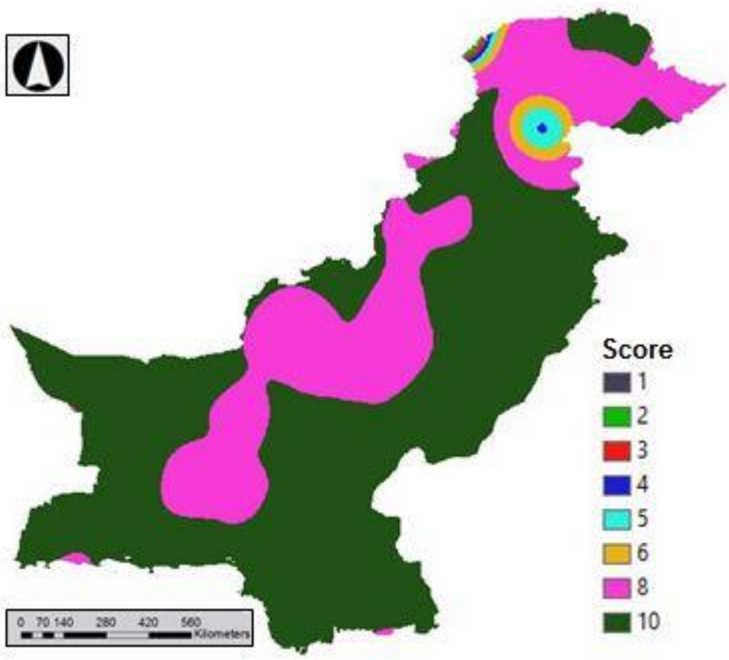
The data for earthquake intensity was downloaded from the available products in Arcgis online resources. A map of earthquake intensity zones was classified to excluded values lower than IV on richter scale. This map is a probability based calculation of future intensity zones. The probability values are 90% accurate for return period of 50 years. The categorized values were assigned rank score values proportional to the intensity of zone. Areas near Muzaffarabad, Chitral and Quetta districts were having high intensity values along with Gawadar district where the intensity of earthquake events remains the highest. Maps and rank score values are shown in figure 14 and table 10.

2.9.3 Flood susceptibility

Preparation of flood model not only requires resources, funding and high degree of proficiency and experience in the particular domain but also consumes lot of time. Keeping the scope of study in view, it was decided to use a rather simple form of decision rule. Flood extents of all major floods were obtained from UN HABITAT and MODIS and were spatially combined to obtained all the flooded areas since year 2000. All flooded areas were considered unsuitable so allocated lowest score of 1 and other areas were given a score value of 10. Plains of Punjab and most areas of Khyber Pakhtun Khua provinces remain safe while Sindh province bears the brunt of flash floods. Maps and rank scores are shown in figure 15 and table 11.

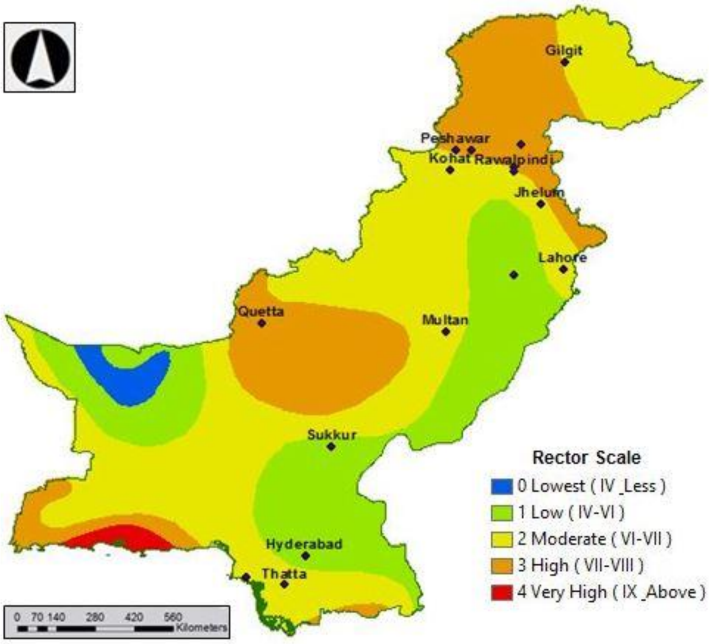


(a)

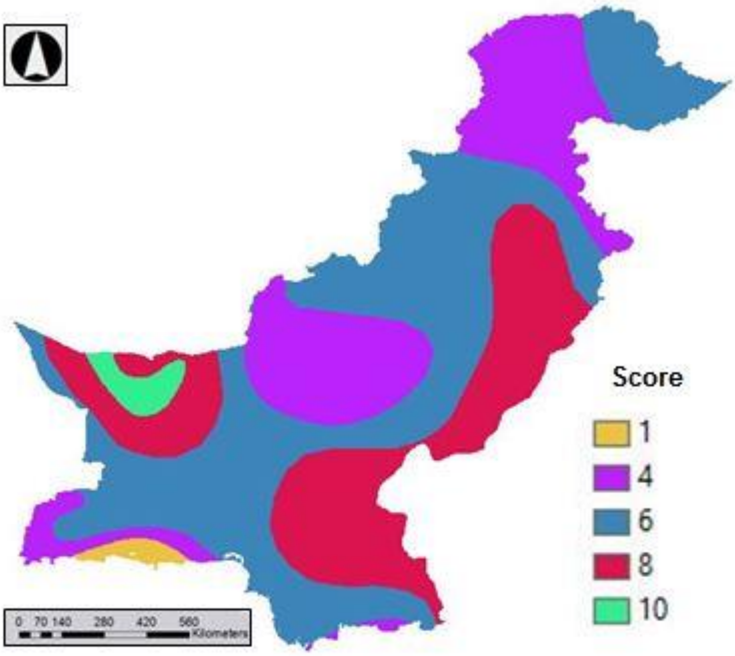


(b)

Figure 13(a) Earthquake density map and (b) Rank score map

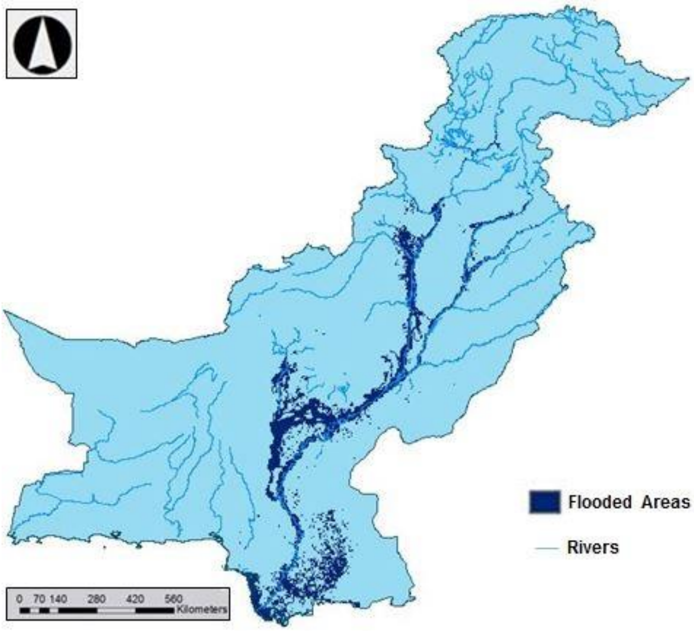


(a)

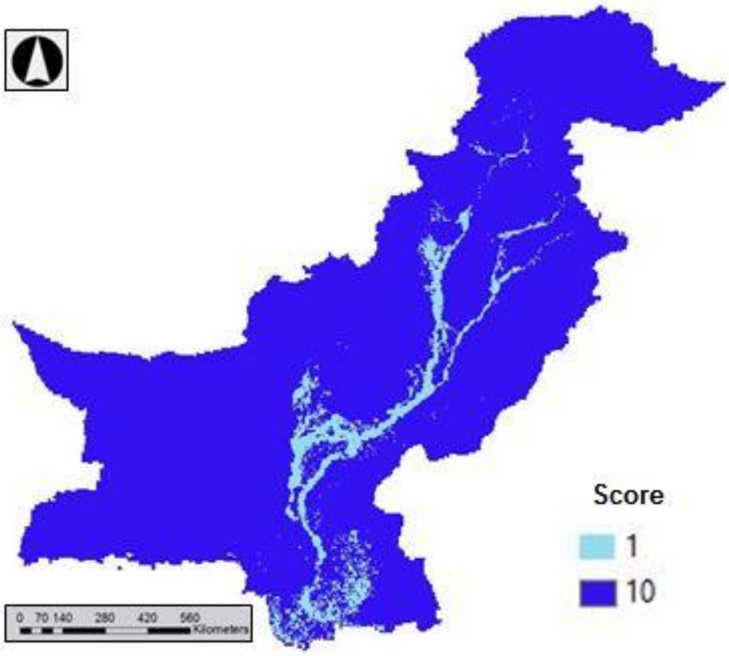


(b)

Figure 14(a) Earthquake intensity map and (b) Rank score map



(a)



(b)

Figure 15(a) Flood extents map and (b) Rank score map.

Table 9. Earthquake density rank values.

Serial	*Earthquake density values events / 100 sq km*	*Rank value 0-10*
1	0-5	10
2	50-100	8
3	100-200	6
4	200-300	5
5	300-400	3
6	400-500	2
7	500-635	1
8		
9		

Table 10. Earthquake intensity rank values.

Serial	*Earthquake intensity values Richter scale*	*Rank value 0-10*
1	IV-Less	1
2	IV-VI	4
3	VI-VII	6
4	VII-VIII	8
5	VIII-<	10
6		

Table 11. Flood extent rank values.

Serial	*Flood extent values*	*Rank value 0-10*
1	0	1
2	1	10

2.10 Calculation of Criteria Scores

AHP was used to calculate the importance of each layer towards achieving the ultimate goal. In order that AHP is used to obtain the contribution value of each layer there is a need to transform the different attribute values to a common scale. Therefore after consulting the experts which are in the teaching faculty of School of Civil and Environmental Engineering (SCEE) in National University of Science and Technology (NUST) Pakistan and consulting similar studies conducted by researchers (Al-Shalabi, et al., 2006; Dai, Lee, & Zhang, 2001; Özgen, 2010), new score values were assigned at a common scale of 0 to 10 and resultant layer maps are shown in figure 16. AHP consists of three steps. In the first step the problem was defined and broken down into simple understandable parts, known as structural hierarchy which is shown in figure 17. While developing a hierarchy the top level is the goal (suitable site selection for urban development) and it ladders down from general to specific levels ending at nine attributes. Each level in the network must be linked with the next one (B. Şener, Süzen, & Doyuran, 2006).

When applying AHP, in second step criteria are compared with each other to determine relative importance of each in accomplishing the objective. This was achieved through pairwise comparison matrix. Which was built by assigning numerical values to each pair of constraints using guidelines given by Saaty and are shown in table 2.

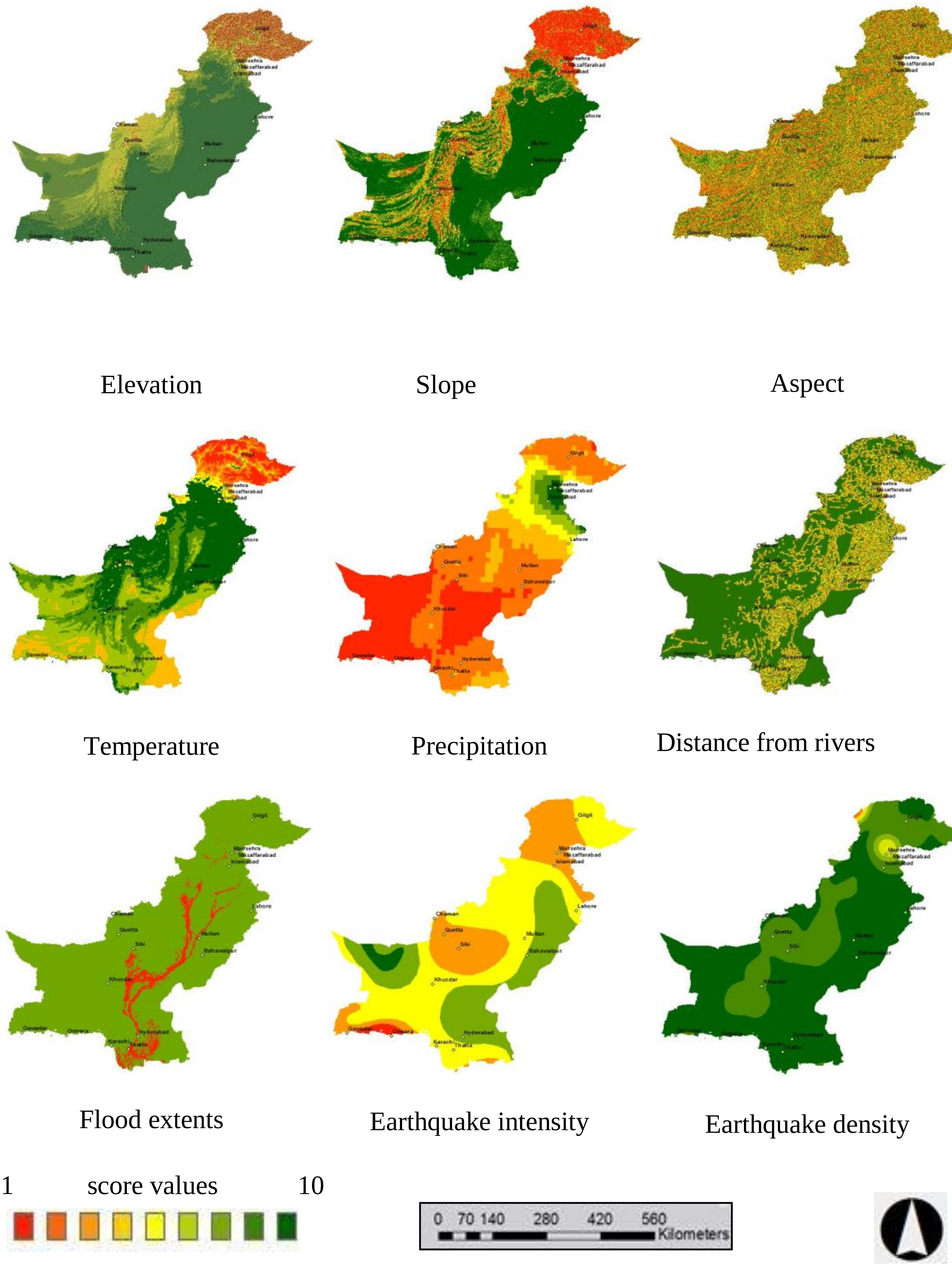


Figure 16. Transformed criteria map layers.

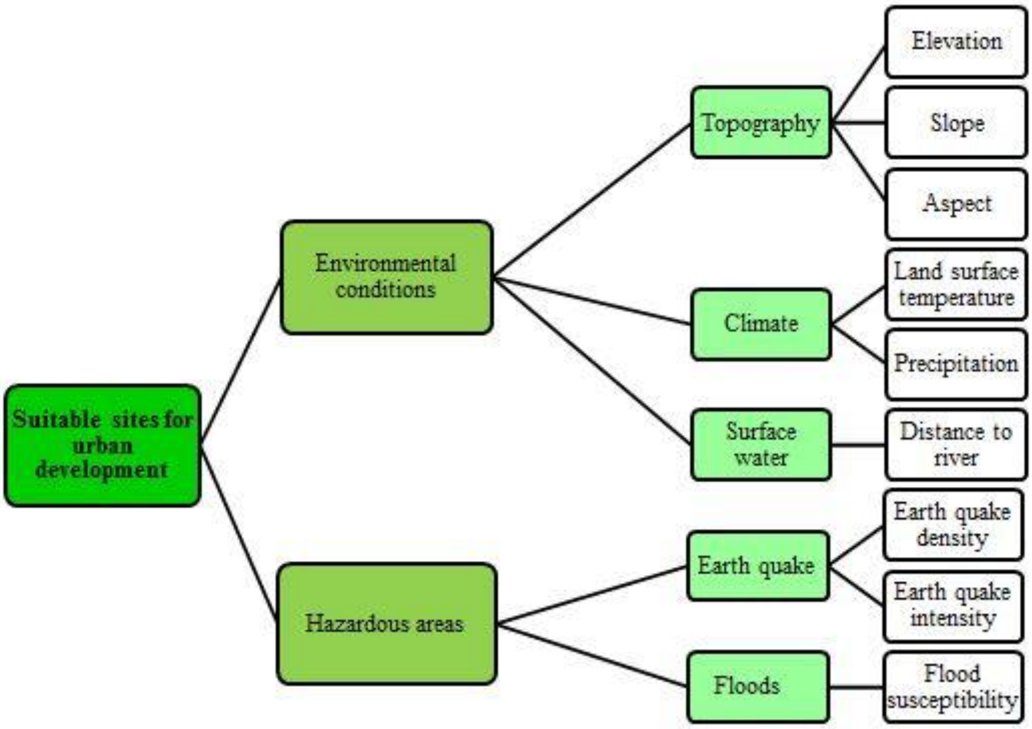


Figure 17. Structural hierarchy of the problem.

Separate matrices were built for environmental and hazard groups. Then the weights of layers were calculated by normalizing values in each column of matrix and calculating the row mean. Consistency of judgment in assigning the priority values was checked by consistency ratio (CR) which was 4% thus being well within the specified limit of 10% by Saaty. It means that the analyst remained 96 % consistant while allocating the priority of judgement to individual factors with respect to each other. If the consistancy ratio exceeds 10 % then the judgement has to be repeated untill the desired threshold of 10 % or less is achieved. So this makes it a cyclic process. After multiplying the weights with score values, weighted layers were obtained. Standardized scores and weighted layer values are shown in table 3. The weighted layers in each group were added to obtain the environmental and hazard maps (figure 18). In third and final step results were synthesized. In order to combine the two resultant maps for obtaining the final suitability index map, each was classified into four classes. Environmental suitability map was classified using values of 1 to 4 and hazard suitability map was assigned values of 10, 20, 30 and 40. Higher the score more suitable the site is for urban development in Pakistan. This classification scheme aimed at retaining the original contributing value of both clusters. These two layers were aggregated to calculate the final suitability score map (figure 19 and 20). The suitability index shows values of 11, 12, 13, 14, 21, 22, 23, 24, 31, 32, 33, 34, 41, 42, 43 and 44. In raster GIS these indices represent alternatives from which better ones can be chosen by town planners for locating settlements.

Table 12 Saaty's pairwise comparison prioritization table

Intensity	*Definition*
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
# 2,4,6 & 8 can be used to express intermediate values $ Reciprocals can be used for inverse judgments	

Table 13 Standardized scores and weighted layer values

Criteria	*Weight*	*Attribute value*	*Rank*	*Score*
Environmental group				
Elevation	38.76	-14- 0 feet	0	0
		0-1000	10	387.60
		1000-1500	9	348.84
		1500-2000	7	271.32
		2000-2500	5	193.80
		2500-3000	3	116.28
		3000-3500	2	77.52
		3500-4000	1	38.76
		4000-8569	0	0

continue

slope	28.77	0-3 percent	8	230.16
		3-5	10	287.70
		5-7	7	201.39
		7-10	5	143.85
		10-15	3	86.31
		15-20	2	57.54
		20-<	1	28.77
Aspect	2.80	Flat	5	14.00
		North	1	2.80
		North east	3	8.40
		East	7	19.60
		South east	10	28.00
		South	8	22.40
		South west	6	16.80
		West	4	11.20
		North west	2	5.60
Distance to rivers	15.56	0-500 meters	1	15.56
		500 -1000	3	46.68
		1000-2000	5	77.80
		2000-3000	8	124.48
		3000-<	10	155.60

				continue
Temperature	5.51	-18-0 Degree Celsius	1	5.51
		0-10	3	16.53
		10-15	8	44.08
		15-25	9	49.59
		25-33	10	55.10
		33-40	7	38.57
		40-46	5	27.55
Precipitation	8.60	0-50 mm/sq. km	1	8.60
		50-150	2	17.20
		150-200	4	34.40
		200-300	5	43.00
		300-400	7	60.20
		400-500	8	68.80
		500-689	10	86.00
		Hazard group		
Earthquake density	10.47	IV-Less Richter Scale	1	10.47
		IV-VI	4	41.88
		VI-VII	6	62.82
		VII-VIII	8	83.76
		VIII-<	10	104.7
Earthquake intensity	25.83	0-5 events / 100 sq km	10	258.3
		50-100	8	206.64
		100-200	6	154.98
		200-300	5	129.15
		300-400	3	77.49
		400-500	2	51.66
		500-635	1	25.83
Flood extents	63.70	0	1	63.70
		1	10	637

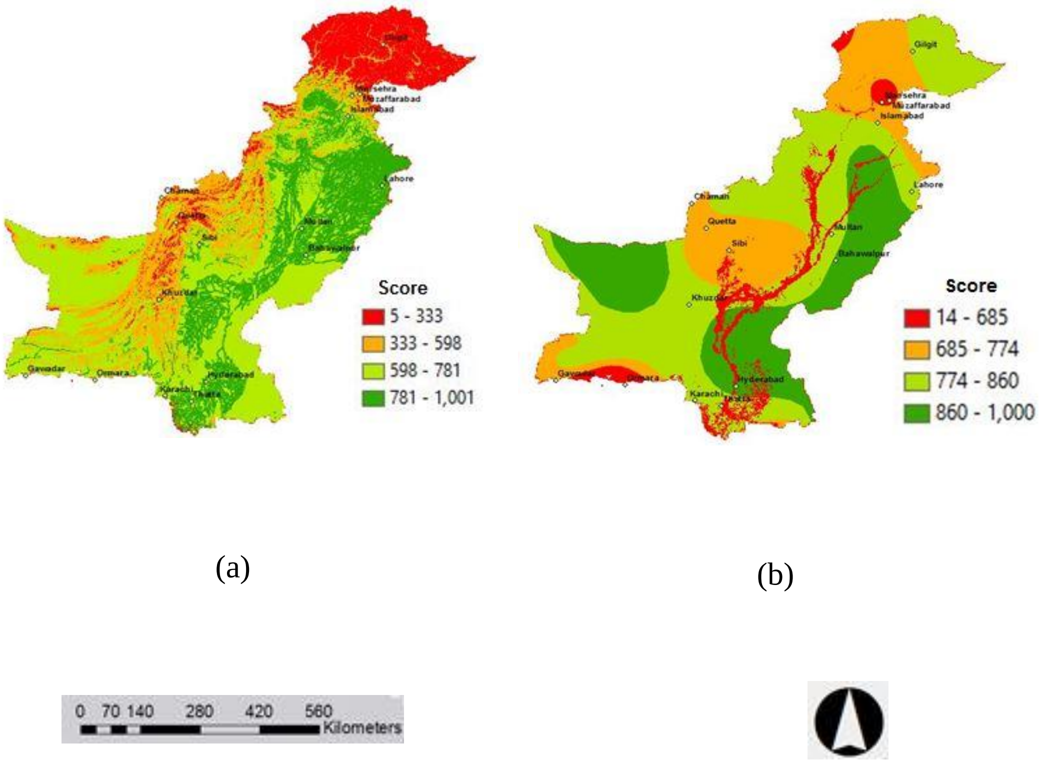


Figure 18(a) Environmental and (b) hazard group maps.

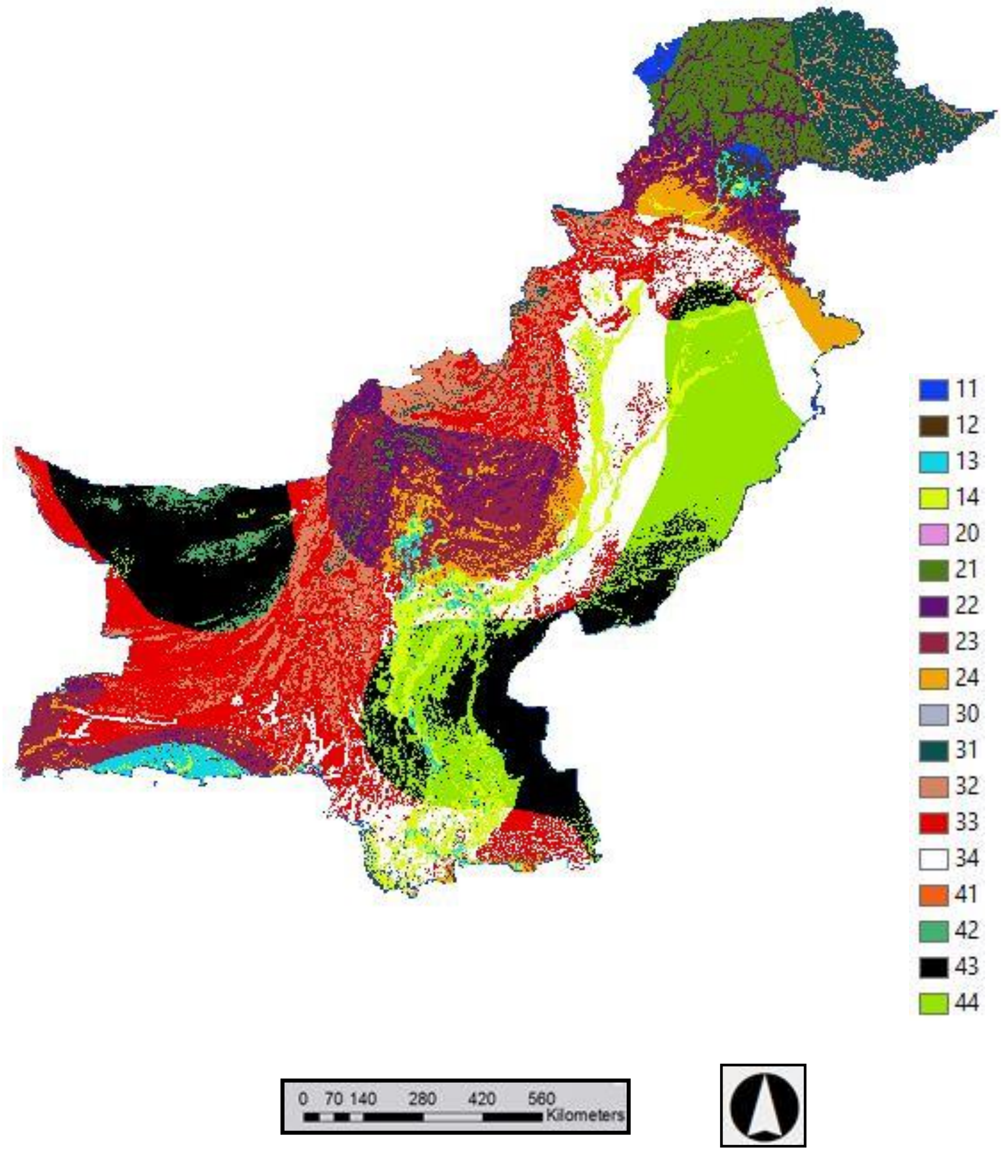


Figure 19. Final suitability index map.

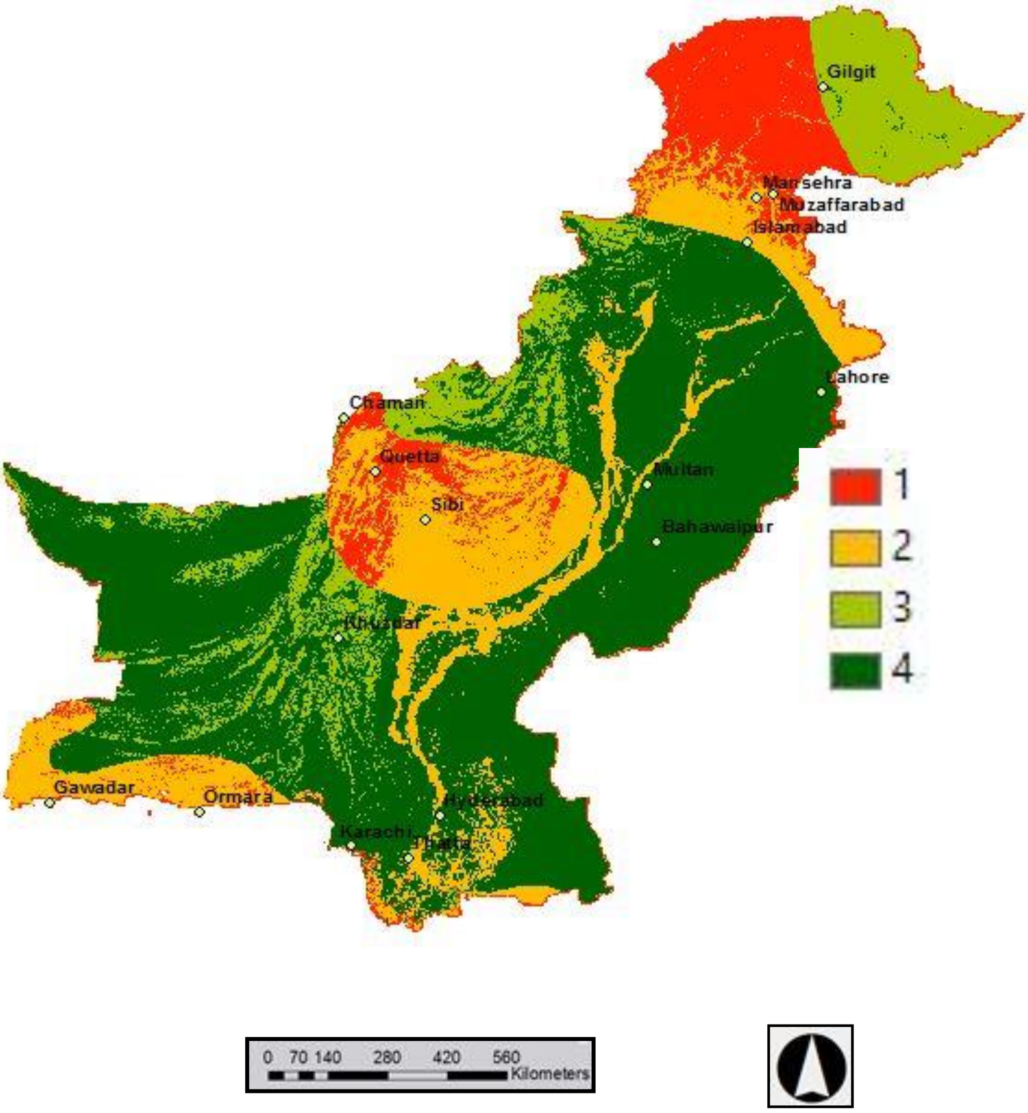


Figure 20. Classified final suitability index map.

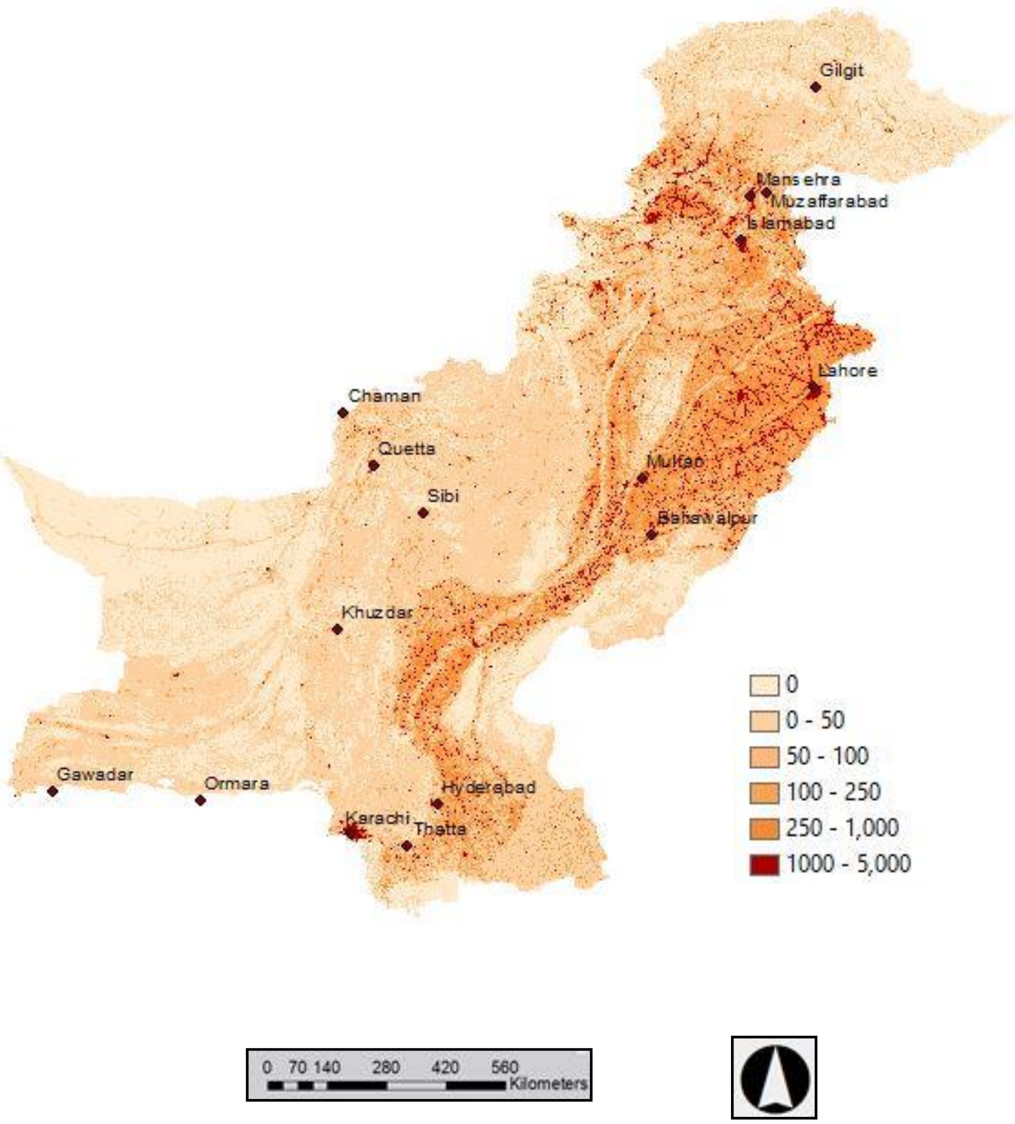


Figure 21. Population density map.

2.11 Statistical Analysis

Though the visual analysis revealed general results however in order to specify the conformity of population, rails and roads etc there was a requirement to perform statistical based analysis so that the exact areas and percentages can be specified in ech zone of suitability. The final suitability map with four zones was vectorized using raster to vector conversion tool. This provided us with polygons having one of the attribute value as that represented there suitability. Then a spatial merger was performed to obtain master polygons based on the suitability value. Once the polygon layer was obtained then various statiscal analysis were performed using overlay tools which are described as under.

2.11.1 Area and population conformity to suitability zones

The population raster obtained from LANDSCAN represented population estimates 0f 2010 (figure 21). It was overlayed with suitability polygon layer to calculate percentage and area falling in each zone and the results were saved as table. Similarly population figures and percentage were calculated using overlay analysis and the result was saved as table. These two tables were exported to excel sheets and aggregation was performed to obtain result summaries and graphs for easy assimilation. The obtained statistics are shown in result an discussion chapter. Result show that 72 % population lives in extremely suitable areas which are 54% of the total terrotory of Pakistan.

2.11.2 Roads, tracks and rail conformity to Suitability Zones

A Similar analysis for roads, tracks and rail tracks was also considered useful to streghten the findings. Lengths and percentages were calculated using overlay analysis and the result was saved as table for each one of the input features. These three tables were exported to excel sheets and aggregation was performed to obtain result summaries and graphs for easy assimilation. The results are shown in chapter 3. Extremely suitable zone contains most of the roads, tracks and railway tracks. However the suitable zone has less of the features as compared to the anticipated figures of above mentioned analysis.

2.11.3 District risk index

In order to specify the risk and population profile of each district, there was a need to perform a detailed district level analysis which could identify the districts at risk and districts suitable for urban development. A district level vector file was obtained from open sources mentioned in table showing description of data in chapter 2. It was also overlaid with suitability map polygons to find the percentage of area and population distribution in those zones. And the result was saved as table for each one of the input features. These three tables were exported to excel sheets and aggregation was performed to obtain result summaries and graphs for easy assimilation. A few high population density districts falling in lower suitability areas are shown in table 14.

Table 14. High risk districts.

District	Area distribution in suitability zones (%)				Population distribution (%) as per Density (Pers / Sq km)			
	Worst	Less suitable	Suitable	Extremely suitable	Scarce (5)	low (200)	High (3k)	Very high (60k)
Abbottabad	46	54	0	0	6	58	33	3
Islamabad	0	63	0	37	4	60	35	1
Muzaffarabad	70	30	0	0	16	40	42	2
Narowal	0	97	0	3	11	60	29	0
Nowshera	0	66	5	28	7	60	33	0
Peshawar	0	60	0	40	61	36	3	0
Quetta	39	61	0	0	2	6	88	4
Sialkot	0	81	0	19	84	14	2	0

Chapter 3

RESULTS AND DISCUSSION

The study was performed in a manner that the encient settlement priorities of the masses could be traced back through their roots in commonly known environmental conditions. The same priorities are represented in the form of suitablility zones for future planning of urban development. Secondly two major natural hazards i.e. floods and earthquakes were mapped and aggregated to mitigate future losses. The processing of data resulted into three kinds of suitability maps i.e. environmental, hazard and aggregated final score map. The scores of environmental and hazard group maps represent higher suitability for urban development in areas with higher index value and vice versa in their respective criteria domain. Whereas the scores of final suitability map are required to be decoded keeping in view the score values in the two contributing group maps. Combination of higher values in both represents suitability while the union of lower values shows lesser suitability.

3.1 Environmental Goup Map

Environmental group map encompassed the contribution of six factors namely elevation, slope, aspect, distance to rivers, mean temperatures and precipitation since year 2000 onwards. The percentage of emphasis each criterion layed on to this group map is described in figure 22. After a detailed consultative and cyclic process of evaluation; analyst found elevation as the biggest contributor or in other words it was hieghest priority of the people who settled in Pakistan since ages. As the weight of this layer came out to be 39 percent. Whereas aspect remained at the lowest ebb being the least priority of the people who settled in Pakistan despite being a mountanous country all along its reach. The weight of this layer came out to be just 3 percent. This shows that the people in pakistan almost disregarded the importance of the availaibility of sunlight for their agricultural and settlement purposes as compared to other important factors.

Aggregated results of all six weighted layers showed scores from 5 to 1001. Higher score values showed higher suitability for settlement and vice versa. It means that the combined effect of all six layers when analysed collectively showed dinstinct results for every 100 sq. M. Which is spatial resolution of the analysis. The area of Pakistan was devided into four zones. First zone contained scores from 5 to 333 and represented the least priority area for settlement. These areas are shown in red color in figure 18(a). Second zone contained score values from 333 to 598 and represented less suitable areas for settlement. These areas are shown in yellow color in figure 18(a). Third zone contained score values from 598 to 781 and represented suitable areas for settlement. These areas are shown in light green color in figure 18(a). fourth zone contained score values from 781 to 1001 and represented most suitable areas for settlement. These areas are shown in dark green color in figure 18(a).

While comparing the map of environmental group and population shown above in figure 18(a) and figure 21. It is evident that the extents of most suitable zone in first map shown in dark green color generaly conforms to the extents of high density population areas in darker shades of brown color in second map. It is because the masses choose environmentally better places owing to awareness.

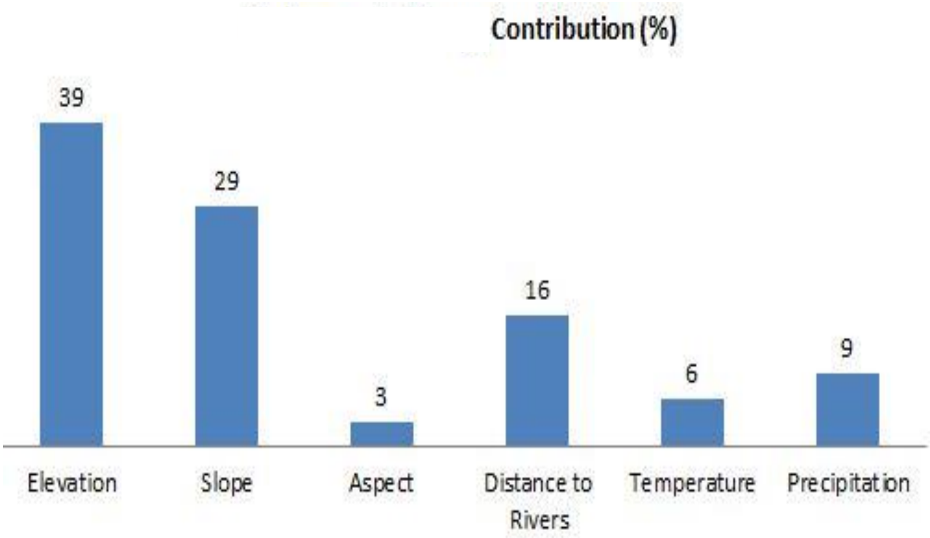


Figure 22. Environmental group contribution.

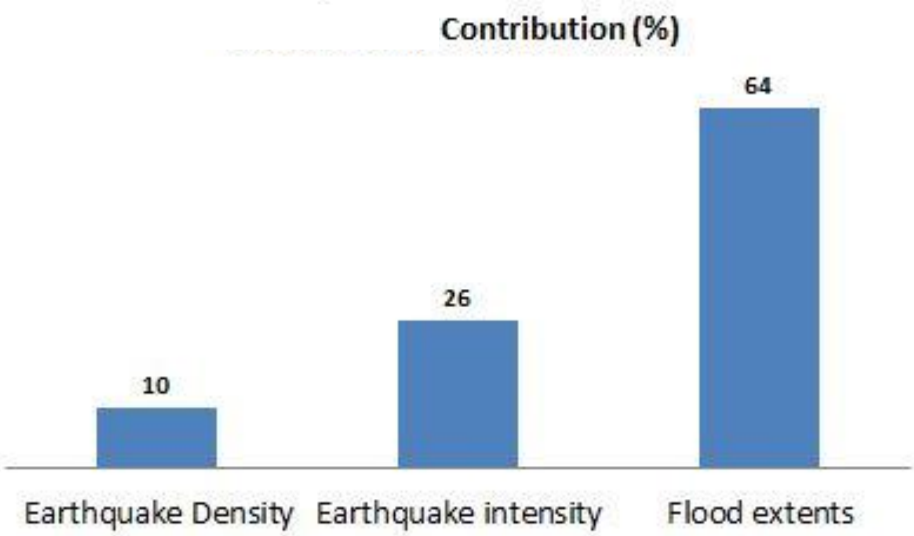


Figure 23. Hazard group contribution.

3.2 Hazard Goup Map

Hazard group map encompassed the contribution of three factors namely flood extents of major events, earthquake density and earthquake intensity since year 2000 onwards. The percentage of emphasis each criterion layed on to this group map is described in figure 23. After a detailed consultative and cyclic process of evaluation; analyst found flood extents as the highest contributor. As the weight of this layer came out to be 64 percent. Whereas earthquake density remained at the lowest ebb being the least priority of the analyst and experts as it counted all the events above Richter scale IV and above irrespective of its intensity. The weight of this layer came out to be just 10 percent. This shows that the importance of more number of events is less for settlement purposes as compared to the more intensity of similar events i.e. earthquakes.

Aggregated results of all three weighted layers showed scores from 14 to 1000. Higher score values showed higher suitability for settlement and vice versa. It means that the combined effect of all three layers when analysed collectively showed dinstinct results for every 100 sq. M. Which is spatial resolution of the analysis. The area of Pakistan was devided into four zones. First zone contained scores from 5 to 685 and represented the least priority area for settlement. These areas are shown in red color in figure 18(b). Second zone contained score values from 685 to 774 and represented less suitable areas for settlement. These areas are shown in yellow color in figure 18(b). Third zone contained score values from 774 to 860 and represented suitable areas for settlement. These areas are shown in light green color in figure 18(b). fourth zone contained score values from 860 to 1000 and represented most suitable areas for settlement. These areas are shown in dark green color in figure 18(b).

While comparing the map of hazard group and population shown above in figure 18(b) and figure 21. It is evident that the extents of most suitable zone in first map shown in dark green color generaly do not conform to the extents of high density population areas in darker shades of brown color in second map. It is because the masses were not aware of the hazodous conditions surrounding them.

3.3 Synthesis of Environmental And Hazard Group Layers

In order to combine the two group layers and maintain the soveranity of individual groups; first each one was classified into four classes and allocated separate series numbers. Series 1, 2, 3 and 4 was alloted to environmental group and series 10, 20, 30 and 40 was alloted to hazard group. After reclassifying and simply adding the two groups final score map was obtained which showed suitability score values of 11, 12, 13, 14, 21, 22, 23, 24, 31, 32, 33, 34, 41, 42, 43 and 44. And the map is shown in figure 19 above. Generally the higher scores reprensented higher suitability and vice versa. But a critical review of the score values resulted into the fact that actually the combination of higher score values in both the contributing maps i.e. environmental and hazard groups represent more suitability and not a numerically heigher score value. Therefore When traced back to their original routes it was determined that the indices can be grouped into four clusters. The first cluster having a combination of lower values in both the group layers can be grouped i.e. first two values from each which are 11, 12, 21 and 22. The second cluster having a combination of lower middle values in both the group layers can be grouped i.e. first two values from hazard group and third / fourth value of environmental group which are 13, 14, 23 and 24. The third cluster having a combination of lower values environmental group and higher values in hazard group which are 31, 32, 41 and 42. The fourth cluster having a combination of higher values from environmental group and higher values in hazard group which are 33, 34, 43 and 44.

3.4 Reclassified Final Map

The final map was complex to read and assimilate the individual score values. Therefore based on the discussion in section 3.3 above the map was reclassified into four zones and shown in figure 20. The first zone having values of 11, 12, 21 and 22 were assigned red color and it represented areas which were worst for living or future urban development. The second zone having values of 13, 14, 23 and 24 were assigned yellow color and it represented areas which were less suitable for living. . The third zone having values of 31, 32, 41 and 42 were assigned light green color and it represented areas which were suitable for living. The fourth zone having values of 33, 34, 43 and 44 were assigned dark green color and it represented areas which were most suitable for living.

A visual comparison of final classified map (figure 20) and population density map (figure 21) showed that the settlement areas in Pakistan are mostly within the highest suitability zone however areas in northern Punjab and Khyber Pakhtun Khua (KPK) provinces whereas most of Balochistan and some areas in western Sindh province near Hyderabad district lay in lower suitability areas.

3.5 Statistical Analysis

3.5.1 Statistical analysis of area and population conformity

Statistical analysis of Area and Population Conformity to Suitability Zones show that 72 % population lives in 54% of the total area which is extremely suitable for living thus conforming to the desired standards. However the suitable zones are thinly populated. There is an increased population in less suitable zones as compared to suitable zone. Worst zone is thinly populated. The details are shown in figure 22.

3.5.2 Statistical analysis of roads and rails

Statistical analysis of linear feature also shows a similar trend as that of population. Most suitable zone comprises bulk i.e. 66% metaled roads, 60% tracks and 78% rail roads. The details are shown in figure 23.

3.5.3 District risk index analysis

District risk index analysis resulted into two kinds of outputs. One was the high population density districts and the second was high risk districts which were overlapping with less suitable and worst zones. When high profile districts were compared in both sheets it was found that some major high population districts are also in high risk zones. These districts are shown in table 14 which include Islamabad, Sialkot, Narowal, Muzaffarabad and Quetta.

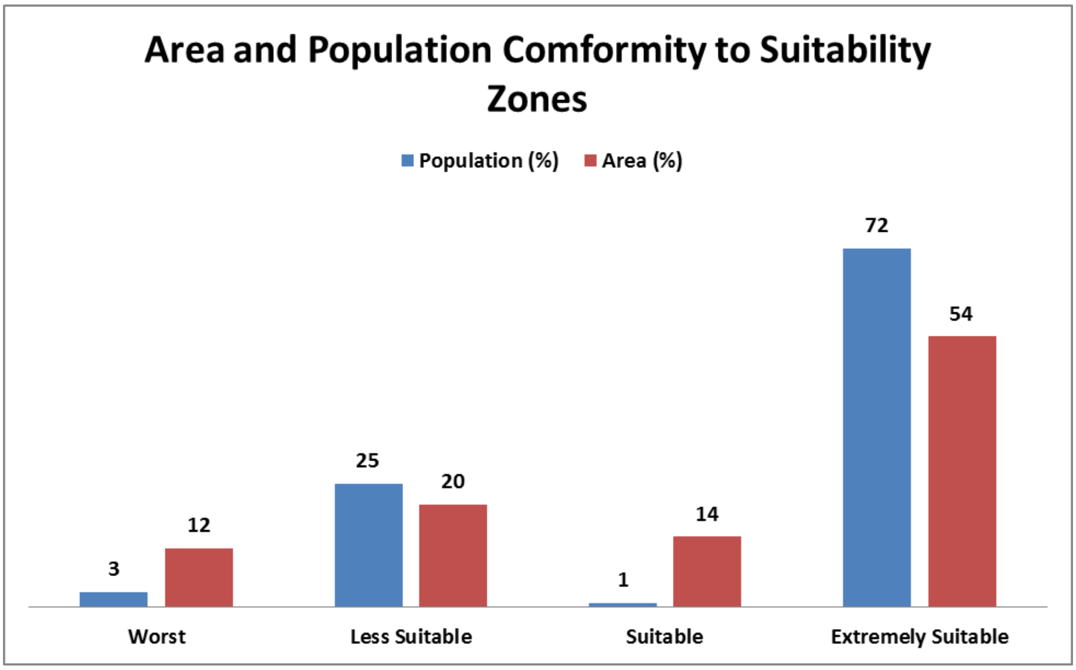


Figure 24. Area and Population Conformity to Suitability Zones.

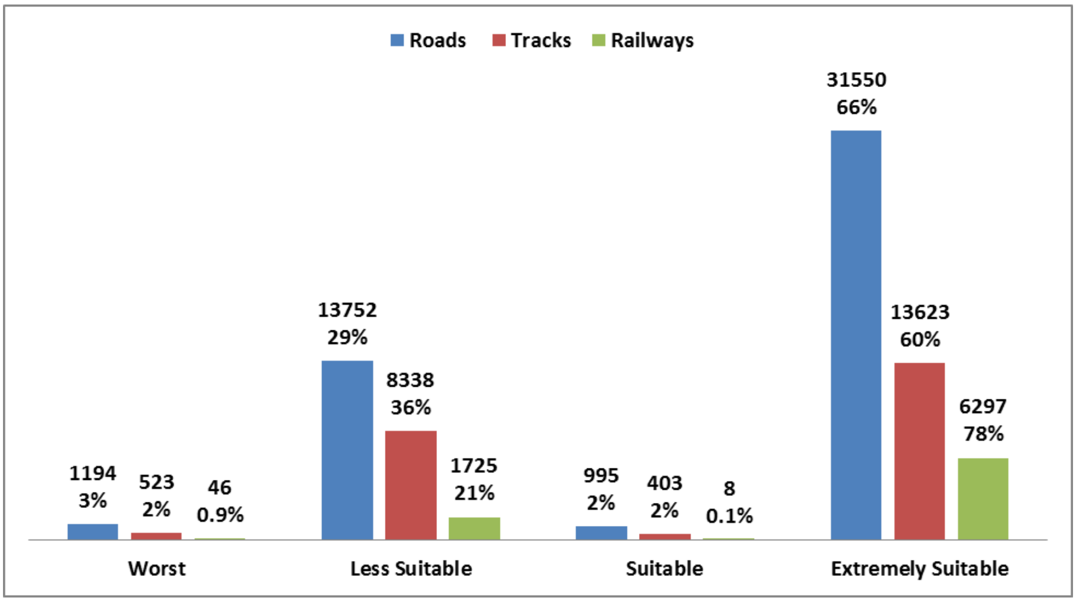


Figure 25. Roads, Tracks and Rail vs Suitability Zones.

3.6 Areas for Further Improvement

Though the results are observed as conformal and correct in with regards to spread of the population in Pakistan but still there are some areas for improvement of results like the spatial resolution of data used for analysis and extents of study area. Certainly if the resolution is increased and the extent is reduced to province or a district level, the problem will be disintegrated into smaller sub-area boundaries, which would produce a better illustration of environmental conditions.

Suitable site selection for urban development cannot exclusively be based upon spatial statistics; some other aspects should also be incorporated such as scale reliant limited economies, and social influences which are preference for type of education or school, linguistic preferences, type of community and ethnic affiliation etc. But the spatial data for these categories is not easily generated and available. If such sort of data is made available and can be incorporated in the analytical process, the resultant statistics would be more accurate.

In MCDA the decision problem is divided into smaller understandable parts, analyzed separately and then assimilated in a rational way. By its very nature MCDA comprises subjectivity of decisions. It means that the result can be changed, if the analyst is changed, even if the same discipline and people evaluate the problems at different times and work environment, they would assign different priority of scores and judgment. Having stated all the reasons, there are still limitations to the problem of "selecting a suitable site" in planning discipline as it already has substantial amount of subjectivity in its typical site selection processes.

Additionally there are some of the influences in selection of suitable settlement sites which cannot be quantified in a spatial way and used statistically.

One of the undefined factors is political decisions, administrators or policy makers decide to plan development in a certain area and keep others for future plans. If certain area starts getting influx of industrial development because of the availability of raw materials, cheap labor or energy required for production then that area becomes the center point of that particular region. The other ambiguity is the vicinity of some important feature, building or major road / rail route like grand trunk road or motorway. Sparse amount of indecisions within this context could not be solved spatially, not only for the reason that the absence of or insufficient quality of ancient data, but also the tough nature of modeling social preferences spatially.

Another important priority for selecting suitable sites for future development is the minimum area requirement for the planned communities. As the size of desired areas remains major factor in such decisions of planners, therefore prior to such sort of analyses, the area required should be determined, hence the population being envisaged to be settled should also be provided, while the method or the bias through which data is to be processed is finalized.

Though the aim of study was to analyze the major hazards which were spatially spread over complete territory of Pakistan however for local level studies more hazards can be incorporated as factors. These include natural hazards like land sliding in hilly areas mostly located in north and west also cyclones, forest fires, droughts and thunder storms etc. are some of the natural calamities which have inflicted heavy losses to lives and property in the past.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Suitable site selection for urban development is a multifaceted problem which considerably affects the cost and time in building and maintaining urban facilities. The research aimed at achieving the objective by the integration of multicriteria decision analysis (MCDA) framework using analytical hierarchy process (AHP) and GIS. This involved four steps including selection of criteria, preparation and standardization of criteria maps, pairwise comparison through AHP to calculate contributing weights of each criteria layer and synthesis of results. The methodology resulted into regionalization of the territory of Pakistan according to the level of suitability for future urban development thus achieving the goal of study. Territory of Pakistan was classified into four levels of suitability for future urban development. Settlement pattern of population in Pakistan conforms to environmental conditions whereas it is vice versa in case of hazardous conditions

The study was conducted at regional level using environmental and hazard factors. The results can either be used by all concerned for mitigating hazards and locating environmentally suited localities or as a base template for overlying by additional factors for optimized local area level studies.

4.2 Recommendations for Further Research

Future urban planning should be considered in most suitable zone.

a. The results of the study should be used by all concerned for:

I. Mitigating hazards.

II. Locating environmentally suited localities.

III. As a base template for overlying by additional factors for optimized local level studies.

b. The methodology is generic therefore can be implemented at any scale and in any area.

c. Integration of MCDA techniques with GIS should be practiced for other site suitability problems so as to assess best ones.

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