GIS BASED GEO HAZARD ASSESSMENT OF PAKISTAN FOR FUTURE URBAN DEVELOPMENT USING AHP

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ABSTRACT

Pakistan has been subject to frequent earthquakes, which are often severe (especially in the north and west), and severe flooding along the Indus River after heavy monsoon rains (July to August every year). Loss to life and property as a result of these natural disasters has been very high in the recent past. In order to mitigate these losses, an integrated decision support which could help planners make complex decisions accurately and quickly is required. This first ever study aims to provide a multi criteria decision analysis framework resulting in the regionalization of the territories 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 the Analytical Hierarchy Process (AHP). GIS can effectively store, retrieve, manipulate, analyse and display the spatial in site selection problems. AHP can be used to calculate weights of criteria while the decision maker remains consistent in judging and allocating comparative preferences to criteria. Weighted scores were 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 these two clusters were then synthesized using an innovative scheme to obtain a 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 study shows how an effective multi criteria decision support method can be developed to select suitable sites for urban development in order to reduce exposure to natural disasters. Urban development should be planned in extremely suitable areas.

Keywords: GIS; Analytical Hierarchy Process (AHP); Urban Development; Pakistan; Hazard

1. Introduction

Urban development in non-hazardous zones remains an uphill task in Pakistan. 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

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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. Recent earthquakes in Pakistan demonstrated that the region is highly seismic (Naseer, Khan et al., 2010). The Himalayan Mountains in the north, mid-oceanic ridges in the south and earthquake belts surrounding the Indian plate all render Pakistan 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 et al., 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 et al., 2011). Though there have been isolated efforts to map these vulnerabilities at various organizations, departments and even at the country level, an integrated data / map containing information on the spatial occurrence of major calamities is not publicly available. Consequently, the objective of this research is to provide a multi criteria decision analysis framework that results in the regionalization of the territory of Pakistan according to the level of vulnerability to different natural hazards and environmental conditions. 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). Knowledge of the susceptibility of a given area to these 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 an integral map of the natural hazards identifying the areas prone to certain natural threats within the territory of Pakistan will be achieved.

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 a Geographic Information System (GIS)-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 a land suitability model for urban developments in Pakistan.

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2. 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 et al., 2013). Urban sprawl is on the rise with population figures totalling 180 million people, making it the sixth most populous country. Population density has risen to 270.77 / sq. km. The area is 796,095 sq. km. and Pakistan's river system consists of more than 60 small and large rivers. All of Pakistan's major rivers originate in the northern highlands of the Himalaya, Karakoram and Hindukush mountain ranges and flow south. These rivers have always provided ideal conditions for human settlement and the growth of politics, arts and culture. The frequency and intensity of the occurrence of floods remains very high due to unusually heavy monsoon rains during the normal season that runs from July to September resulting in heavy losses of life and property. 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.

Figure 1. Map of Pakistan and its neighbours

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3. Materials and methods

3.1 Integration of GIS and MCDA

Geographical Information Systems (GIS) are computer systems or software that can collect, manage, analyse and display spatially referenced data. GIS have always been considered 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, and classification. The integration of GIS and MCDA has attracted significant interest among urban planners since the 1990s (Omitaomu, Blevins et al., 2012). This integration allows multiple criteria to be taken into account when dealing with spatial decision problems. The principle of the method is to divide the decision problems into smaller understandable parts, analyse each part separately and then integrate the parts in a logical manner (Malczewski, 1996). Therefore, creation of a decision tree is a main underlying step of MCDA.

3.2 Analytical Hierarchy Process (AHP)

AHP is a powerful tool in applying MCDA and was introduced and developed by Saaty in 1980 (Bagheri & Azmin, 2010; 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 the next part of the work (Kordi, 2008). The AHP can handle inconsistency in judgment of the analyst while allocating importance to each criterion by checking a consistency ratio which is not implemented in other techniques like simple additive weighting (SAW) etc.

3.3 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 et al., 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 & Barton, 1990; Geertman & 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).

3.4 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 a 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. These criteria 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 the whole of Pakistan.

3.5 Generating criteria maps

Data were obtained from various sources as described in Table 1. Then they were processed using ArcGIS 10.1 to obtain criteria maps of the same spatial resolution and projection system i.e. 100 meters and Universal Transverse Mercator (UTM) respectively (ERSI, 2012). In order to process the data together, it was necessary to transform it to a common spatial resolution and projection system. A detailed flow diagram of this methodology followed for this study is shown in Figure 2.

Table 1
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

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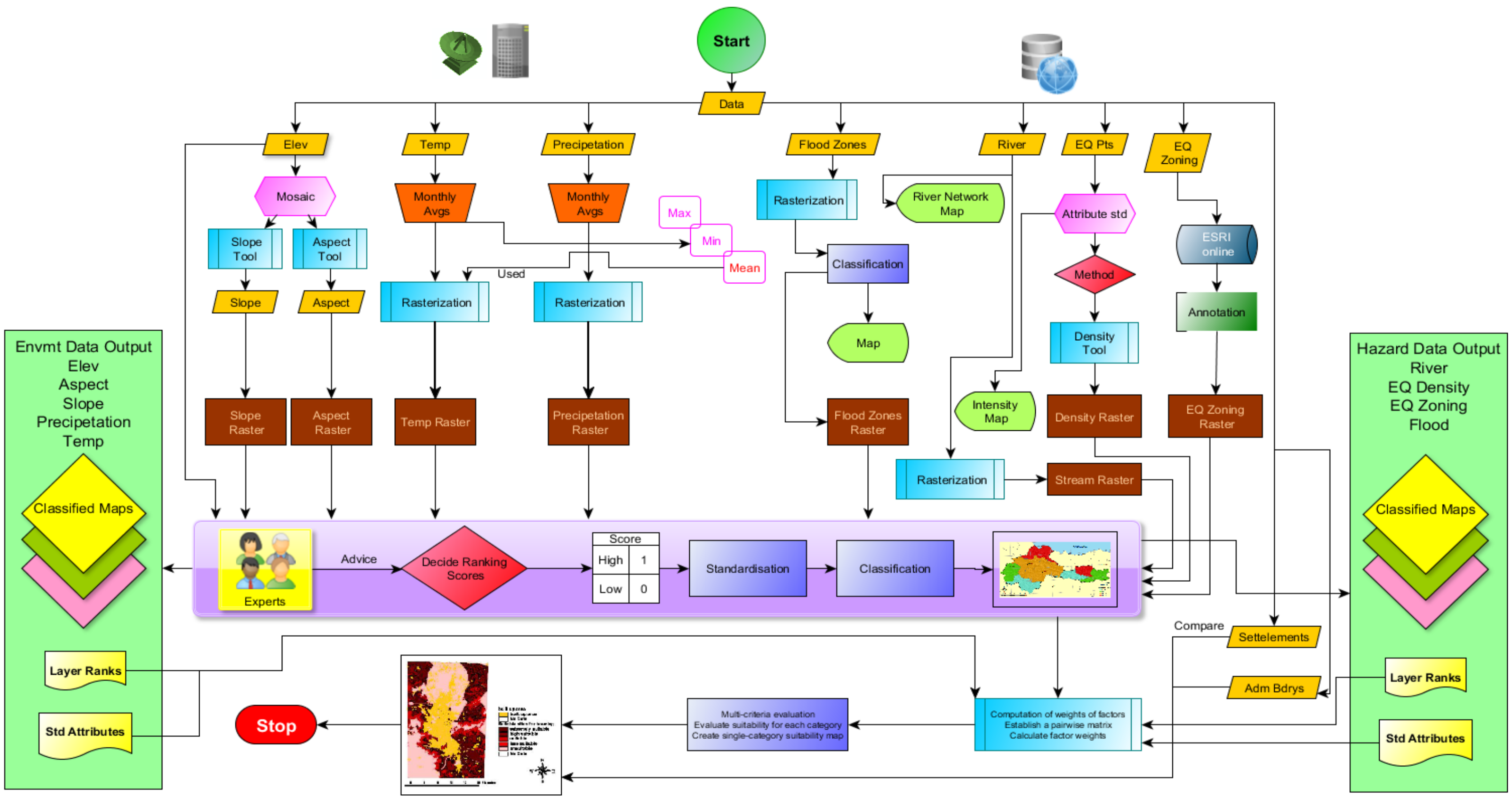

Figure 2. Methodology

3.6 Calculation of criteria scores

AHP was used to calculate the importance of each layer towards achieving the ultimate goal. There is a need to transform the different attribute values to a common scale in order for AHP to be used to obtain the contribution value of each layer. Therefore, after consulting experts in the teaching faculty of the School of Civil and Environmental Engineering (SCEE) in the National University of Science and Technology (NUST) in Pakistan and consulting similar studies conducted by researchers (Dai, Lee et al., 2001; Al-Shalabi, Mansor et al., 2006; Özgen, 2010), new score values were assigned at a common scale of 0 to 10 and resultant layer maps are shown in Figure 3. AHP consists of three steps. In the first step, the problem was defined and broken down into simple understandable parts, known as structural hierarchy (shown in Figure 4). The goal is to develop a hierarchy with the top level as the goal (suitable site selection for urban development) and ladders down from general to specific levels ending with nine attributes. Each level in the network must be linked with the next one (Şener, Süzen et al., 2006).

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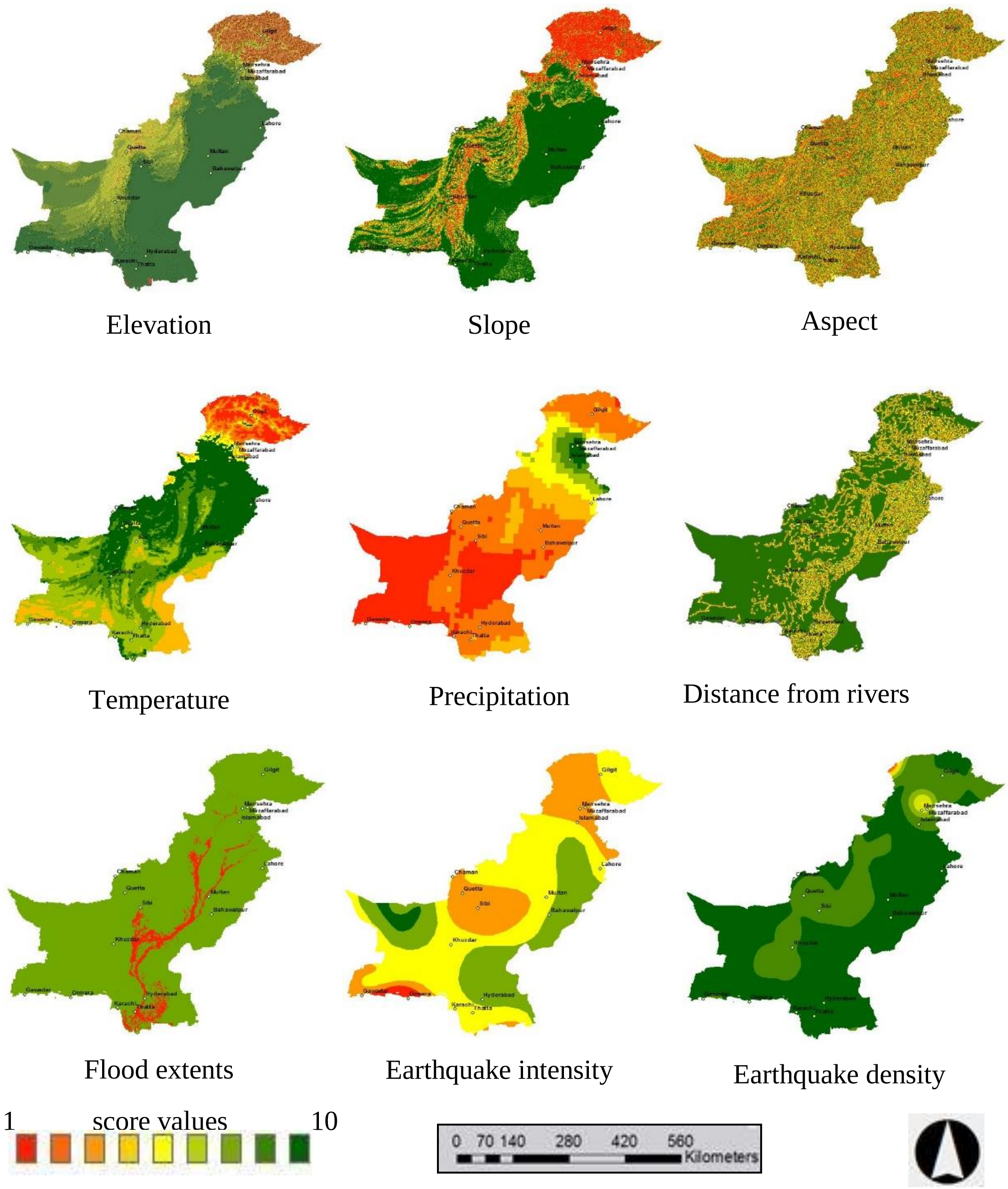

Figure 3. Transformed criteria map layers

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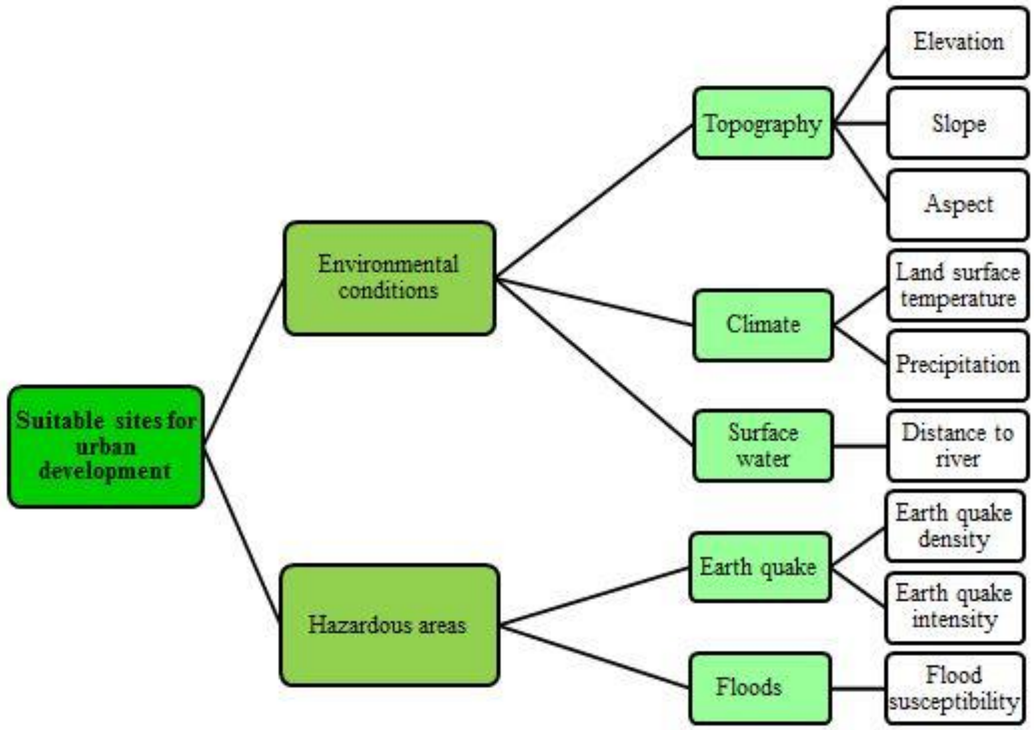

Figure 4. Structural hierarchy of the problem

Criteria are compared with each other to determine relative importance of each in accomplishing the objective in the second step of AHP. This was achieved through a pairwise comparison matrix which was built by assigning numerical values to each pair of constraints using guidelines given by Saaty (Table 2). Separate matrices were built for environmental and hazard groups and are shown in Tables 3 and 4 respectively. Then the weights of layers were calculated by normalizing values in each column of the matrix and calculating the row mean. Consistency of judgment in assigning the priority values was checked by a consistency ratio (CR) which was 4%, thus being well within the specified limit of 10% discussed by Saaty. After multiplying the weights with score values, weighted layers were obtained. Standardized scores and weighted layer values are shown in Table 5. The weighted layers in each group were added to obtain the environmental and hazard maps (Figure 5). In the third and final step, results were synthesized. In order to combine the two resultant maps in order to obtain the final suitability index map, each was classified into four classes. An environmental suitability map was classified using values of 1 to 4, and a hazard suitability map was assigned with values of 10, 20, 30 and 40. The higher the score the 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 6). 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 2
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 3
Pairwise comparison matrix for environmental group

	Elevation	**Slope**	**Distance to river**	**Average precipitation**	**Average temperature**	**Aspect**	**Weight of Layer (%)**
Elevation	1	2	3	5	6	8	**39**
Slope	1/2	1	3	4	5	8	**29**
Distance to river	1/3	1/3	1	2	4	7	**15**
Average precipitation	1/5	1/4	1/2	1	2	4	**8**
Average temperature	1/6	1/5	1/4	1/2	1	3	**6**
Aspect	1/8	1/8	1/7	1/4	1/3	1	**3**

Consistency Ratio = 3%

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Table 4
Pairwise comparison matrix for hazard group

	Flood	**Earthquake Zones**	**Earthquake Density**	**Weight of Layer (%)**
Flood	1	3	5	**64**
Earthquake Zones	1/3	1	3	**26**
Earthquake Density	1/5	1/3	1	**10**
Consistency Ratio = 4%				

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Table 5
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
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
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

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		400-500 500-689	8 10	68.80 86.00
Hazard group				
Earthquake density	10.47	IV-Less Richter Scale IV-VI VI-VII VII-VIII VIII-<	1 4 6 8 10	10.47 41.88 62.82 83.76 104.7
Earthquake intensity	25.83	0-5 events / 100 sq. km 50-100 100-200 200-300 300-400 400-500 500-635	10 8 6 5 3 2 1	258.3 206.64 154.98 129.15 77.49 51.66 25.83
Flood extents	63.70	0 1	1 10	63.70 637

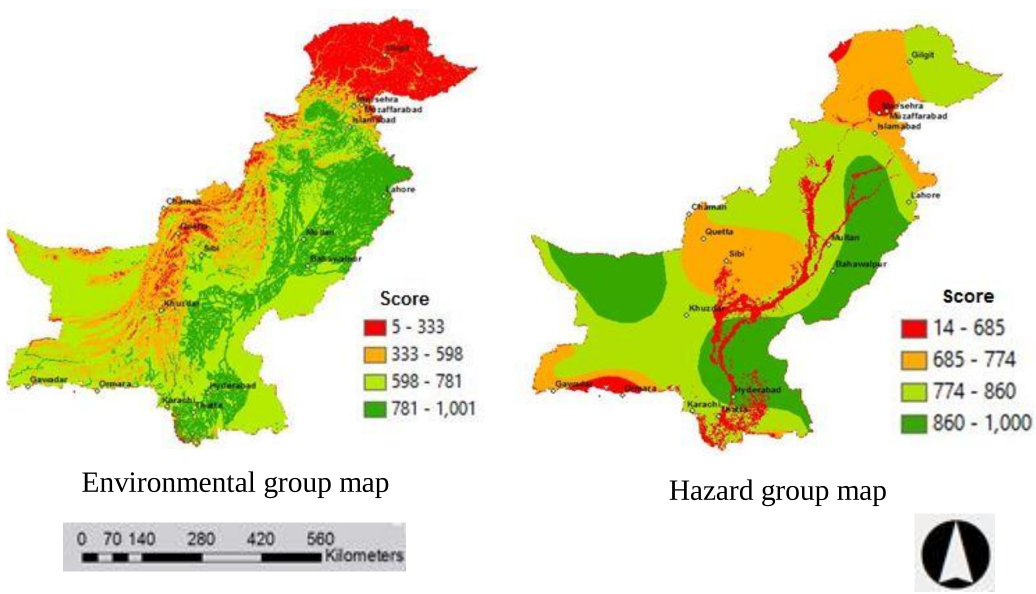

Figure 5. Environmental and hazard group maps

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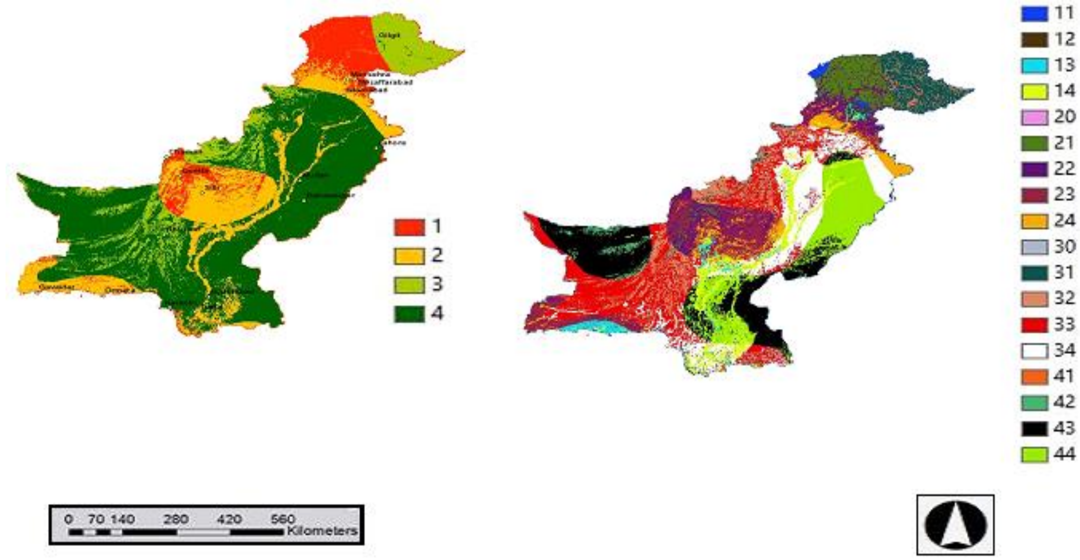

Figure 6. Final suitability index map

4. Findings and discussion

The study was performed in a manner that the ancient 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 suitability 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 in three kinds of suitability maps i.e. environmental, hazard and aggregated final score map. The scores of the 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 the final suitability map need to be decoded keeping in view the score values in the two contributing group maps. A combination of higher values in both represents suitability while the union of lower values shows lesser suitability.

4.1 Environmental group map

The environmental group map encompassed the contribution of six factors namely elevation, slope, aspect, distance to rivers, mean temperatures and precipitation since the year 2000 onwards. The percentage of emphasis each criterion had on this group map is described in Table 5 above. After a detailed consultative and cyclic process of evaluation the analyst found elevation to be the biggest contributor, or in other words it had the highest priority, of the people who settled in Pakistan throughout history with the weight of this layer being 39%. On the other hand, aspect remained the lowest, having the least priority of the people who settled in Pakistan despite being a mountainous country all along its reach; the weight of this layer was just 3%. This shows that the people in Pakistan almost completely disregarded the importance of the availability of sunlight for their agricultural crops and settlement purposes as compared to other important factors.

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Aggregated results of all six weighted layers showed scores from 5 to 1001. Higher score values showed higher suitability for settlement and vice versa. This means that the combined effect of all six layers when analysed collectively showed distinct results for every 100 sq. M. which is the spatial resolution of the analysis. The area of Pakistan was divided into four zones. The first zone contained scores from 5 to 333 which represented the least priority area for settlement and are shown in red in Figure 5 above. The second zone contained score values from 333 to 598 which represented less suitable areas for settlement and are shown in yellow in Figure 5 above. The third zone contained score values from 598 to 781 which represented suitable areas for settlement and are shown in light green in Figure 5 above. The fourth zone contained score values from 781 to 1001 which represented the most suitable areas for settlement and are shown in dark green in Figure 5 above. While comparing the map of the environmental group and population shown above in Figures 5 and 7 respectively, it is evident that the areas of the most suitable zone in the first map shown in dark green generally conform to the areas of high density population in darker shades of brown in the second map. This is because the masses choose environmentally better places due to their awareness of the conditions.

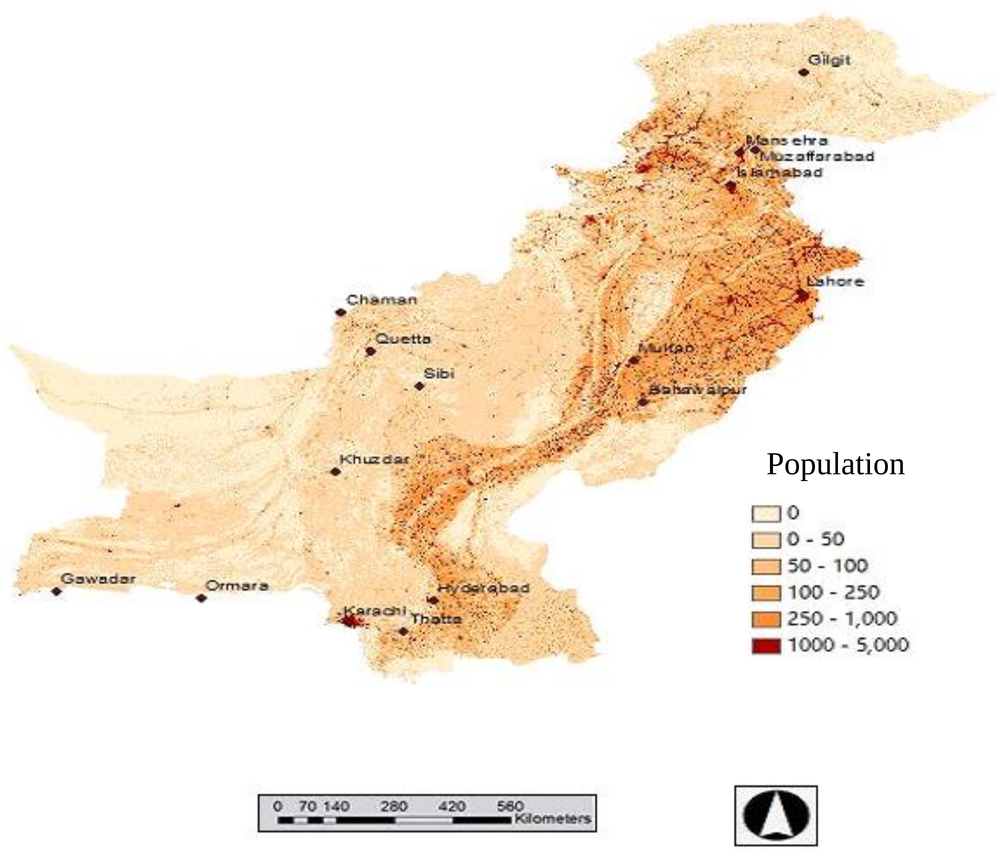

Figure 7. Population density map

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4.2 Hazard group map

The hazard group map encompassed the contribution of three factors namely flood occurrence of major events, earthquake density and earthquake intensity from the year 2000 onwards. The percentage of emphasis each criterion had on this group map is described in Table 5 above. After a detailed consultative and cyclic process of evaluation, the analyst found flood areas as the highest contributor with the weight of this layer being 64%. On the other hand, earthquake density remained the lowest, being the least priority, 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%. This shows that the importance of a greater number of events is less important for settlement purposes as compared to the greater intensity of similar events i.e. earthquakes.

Aggregated results of all three weighted layers showed scores from 14 to 1000. As before, higher score values showed higher suitability for settlement and vice versa. This means that the combined effect of all three layers when analysed collectively showed distinct results for every 100 sq. M. which is spatial resolution of the analysis. The area of Pakistan was divided into four zones. The first zone contained scores from 5 to 685 and represented the least priority areas for settlement and are shown in red in Figure 5 above. The second zone contained score values from 685 to 774 and represented less suitable areas for settlement; these areas are shown in yellow in Figure 5. The third zone contained score values from 774 to 860 and represented suitable areas for settlement; these areas are shown in light green in Figure 5. The fourth zone contained score values from 860 to 1000 representing the most suitable areas for settlement and are shown in dark green in Figure 5.

While comparing the map of the hazard group and population shown above in Figures 5 and 7 respectively, it is evident that the areas of the most suitable zone in the first map shown in dark green generally do not conform to the areas of high density population in darker shades of brown in second map. This is because the masses were not aware of the hazardous conditions surrounding them.

4.3 Synthesis of environmental and hazard group layers

In order to combine the two group layers and maintain the sovereignty of individual groups; first each one was classified into four classes and allocated separate series numbers. Series 1, 2, 3 and 4 was allotted to the environmental group, and series 10, 20, 30 and 40 was allotted to hazard group. After reclassifying and simply adding the two groups a 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 (shown in Figure 6 above). Generally, the higher scores represented higher suitability and vice versa. But a critical review of the score values showed that the combination of higher score values in both the contributing maps i.e. environmental and hazard groups actually represent more suitability and not a numerically higher 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,

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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.

4.4 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 6. The first zone having values of 11, 12, 21 and 22 were assigned the colour red representing areas which were worst for living or future urban development. The second zone having values of 13, 14, 23 and 24 were assigned the colour yellow and represented areas which were less suitable for living. The third zone having values of 31, 32, 41 and 42 were assigned the colour light green and represented areas which were suitable for living. The fourth zone having values of 33, 34, 43 and 44 were assigned the colour dark green colour and represented areas which were most suitable for living.

A visual comparison of the final classified map (Figure 6) and population density map (Figure 7) showed that most of the settlement areas in Pakistan are within the highest suitability zone i.e. zone 1 in green, however, a few settlement areas in the northern, middle west and southern parts of the country lay in lower suitability areas i.e. zone 2 in yellow.

4.5 Statistical Analysis

4.5.1 Statistical analysis of area and population conformity

Statistical analysis of area and population conformity to suitability zones show that 72% of the 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 with an increased population in less suitable zones as compared to suitable zones. The worst zone is thinly populated. The details are shown in Figure 8.

4.5.2 Statistical analysis of roads and rails

Statistical analysis of linear features also shows a similar trend as that of the population. The most suitable zone comprises the bulk i.e. 66% metaled roads, 60% tracks and 78% rail roads. The details are shown in Figure 9.

4.5.3 District risk index analysis

A district risk index analysis resulted in two kinds of outputs. One was the high population density districts, and the second was high risk districts where the less suitable and worst zones overlapped. 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 6 and include Islamabad, Sialkot, Narowal, Muzaffarabad and Quetta.

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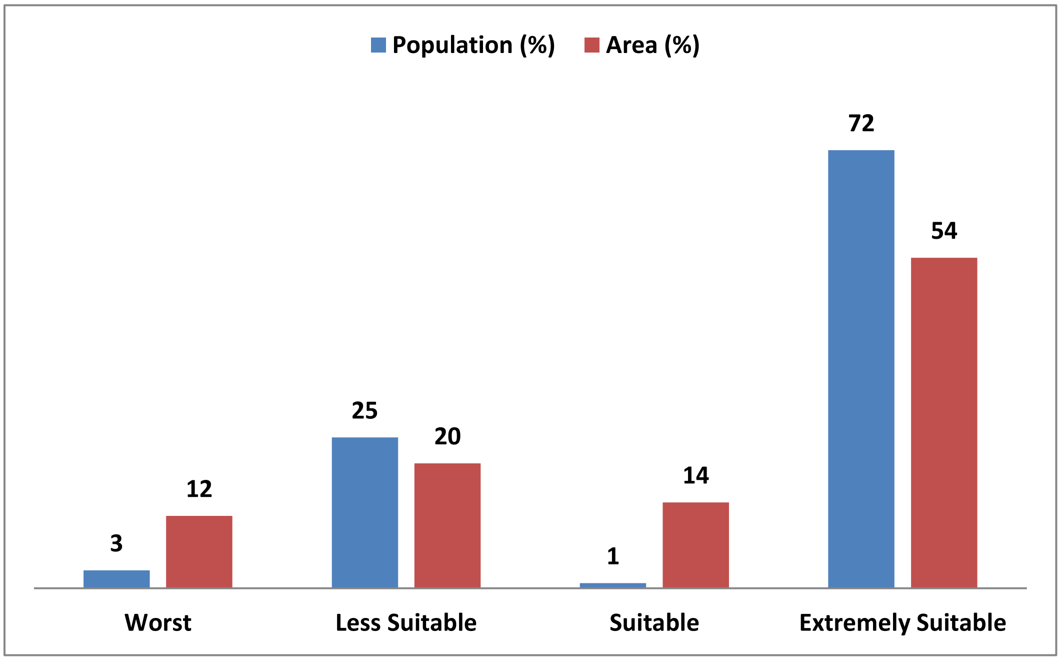

Figure 8. Area and population conformity to suitability zones

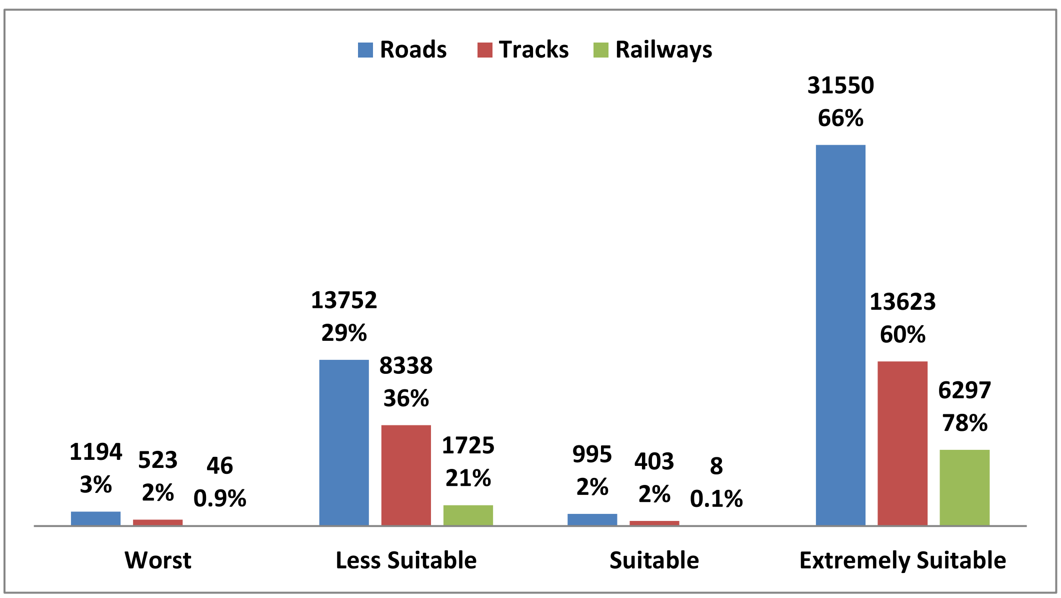

Figure 1. Roads, tracks and rail vs. suitability zones

Table 6
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

5. Conclusion

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 to achieve the objective through the integration of the multicriteria decision analysis (MCDA) framework using the 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 in the regionalization of the territory of Pakistan according to the level of suitability for future urban development, thus achieving its goal.

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

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