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The Development of a Geographic Information System (GIS) Database for Jiuzhaigou National Nature Reserve and Its Application

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Abstract: The objective of this paper is to develop a GIS (Geographic Information System) database for Jiuzhaigou National Nature Reserve (Jiuzhaigou, hereafter) in China and demonstrate its application as a research tool. A cost-effective procedure was developed to compile a variety of geographical and biological data of the study area in terms of popular GIS format such as shape files. These files were further calibrated and validated using field surveys data. The developed GIS database was used to quantify the distributions of the wildlife (amphibians, mammals, and birds) using the distances of the wildlife to the centerline of the bus-tour routes. The Pearson correlation coefficient was used to quantify the correlation in space between pairs of different wildlife using the number of habitats for given space contexts. An ArcObject-based macro was developed to perform the analysis. The results showed the majority of the habitats of wildlife are located in the proximity of the tour-bus routes with an average distance ranging from 564 to 894 m depending on types of wildlife. This indicates a possibility of the disturbance to the wildlife by human activities. The correlation coefficient of the wildlife ranged from 0.36 to 0.64 depending on pairs of wildlife, indicating some correlations in space. However, due to the limited sample size, the statistical significances need to be further investigated. This paper has successfully demonstrated the use of the GIS-based database as a research tool for environmental study.

Keywords: Geographic Information System (GIS); Database; Remote sensing; Wildlife; Correlation Coefficient; Jiuzhaigou

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Introduction

Located in the southeastern rim of Qinghai-Tibetan plateau (103°46' – 104°50' E, 32°55' – 33°20' N), Jiuzhaigou National Nature Reserve (Jiuzhaigou hereafter) is one of the most popular tourist destinations in China. Jiuzhaigou valley consists of three main watersheds (Zharu, Shuzheng-Zezhawa, and Riza), with an altitude ranging from 1,996 m to 4,764 m with lakes and waterfalls being the primary attraction for the tourists as shown in Figure 1.

Jiuzhaigou was recognized by UNESCO as a World Heritage Site in 1992 and a World Biosphere Reserve in 1997. Since Jiuzhaigou was open to the public in the early 1980s, the number of visitors

Figure 1 Tour-bus route and tour valleys in Jiuzhaigou National Nature Reserve

has grown quickly. More than two million people visit Jiuzhaigou each year since 2004 (Feng et al. 2010). Tourists in Jiuzhaigou usually are transported back and forth on fixed tour-bus routes of a road network of approximately 50 km along the bottom of the valley. The impact of tourism on the area is discernable both ecologically and environmentally in recent years, which has raised many questions: what are the key factors affecting ecosystems and how do these factors interact with each other? How do human activities affect ecosystem? How the economic development and ecosystem conservation can be balanced through efficient management? How will the ecosystem evolve and what is the trend? How will a sustainable development both ecologically and economically be promoted? In order to seek answers to these questions, a variety of studies had been carried out by many researchers (Zhang and Xu 1993; Liu et al. 1996; Winkler 1998; Li et al. 2005, 2006; Cui et al. et al. 2005; Cui et al. 2007; Feng et al. 2010; Gaulke et al. 2010; Henck et al. 2010; Xu et al. 2010; Gao et al. 2011; Chen et al 2011; Li et al. 2011). These studies have identified the scenic spots, hiking trails, mountain hazard events (debris flows and landslides), vegetation types, rock types, hilly terraces, and travertine flora in Jiuzhaigou. However, the usage of findings from these studies was limited due to several key shortcomings. Most of the data are qualitative. Each of the studies only represents a snap-shot of a particular area and individually cannot represent the whole reserve. In addition, the majority of the data are not in the format and projection comparable to the popular Geographic Information System (GIS) data formats, which may limit their full and effective use in management. This dilemma imposes great challenges in sharing information and data with others for a comprehensive environmental study without unnecessary waste of resources.

Therefore, the objectives of this study are to develop a GIS-based database to integrate information related to Jiuzhaigou from different researches and demonstrate the use of the database as a research tool for comprehensive environmental studies. In this paper, the database was used to evaluate the impact of the visitors and tour-bus routes on the wildlife in the area.

1 Methodology

The methodologies used for this study include: (1) the development of a GIS-based database; and (2) the application of the GIS-based database. The details are given in the following sections.

1.1 The development of a GIS-based database

The key steps in developing a GIS-based database include: (1) data acquisition; (2) data digitization; (3) data modeling; and (4) data quality assurance/quality control (QA/QC). The details for each step are given in the following.

1.1.1 Data acquisition

Data acquisition in this study refers to the GIS-related information acquired in the Jiuzhaigou area, including data of biology, geology, hydrology, land form, soil, and social-economy. The data were comprised of satellite images, hard copy maps, ground observations, and data obtained from the literatures.

Remote sensing images acquired in this study mainly refer to Quick Birds (QB) and Landsat

Images. Two different resolutions QB images, which were taken in 2004, were provided by JAB. One has a resolution of 0.6 m and the other has one of 2.4 m. The Landsat images include thematic mapper (TM), multiple-spectral scanner (MSS), and enhanced thematic mapper (ETM), which were downloaded from USGS website (http://glovis.usgs.gov/). Hard copy maps include soil, vegetation and geologic maps of the region. For the point events, data were collected from field survey and other studies. A summary of acquired data is listed in Table 1.

1.1.2 Data digitization

The data digitization here refers to the process of transforming acquired data from a variety of data formats (e.g., image, drawing) to a relatively standard data format such as vector and raster. Vector consists of features of point, line and polygon, and usually is stored as shape file. Raster consists of grid cells and pixels and can be stored as images and TIN (Triangulated Irregular Network) (Liu et al. 1996; Cui et al. 2005; Zhang and Xu 1993). The new data will have the same coordinates system, projection and datum, and can be readily used by GIS software for data analysis. The key procedures of this process include:

(a) Using the ERDAS IMAGINE 9.1 (Richards and Jia 2006) to process QB and Landsat images. For QB images, they were stacked, calibrated, and mosaic-generated as panchromatic (black & white) imageries with 0.6 m resolution and multispectral imagery with 2.4 m resolution, separately. The "stack" refers to combing different layers of original images into one image from multi-temporal change classifications (Richards and Jia

Table 1 A Summary of data collected and integrated in the GIS database

Category	Name	Data format		GIS feature type	Data sources
		Before	After		
Biology	Vegetation	Image	Vector	polygon	Cui 2005
	Amphibians	2-D events	Vector	point	SAF [a], JAB [b]
	Birds	2-D Events	Vector	point	
	Mammals	2-D Events	Vector	point	
Geology	Rock	Image	Vector	Polygon	Cui 2005
	Fault	Image	Vector	line	
Hydrology	River	Image	Vector	Line	Quick Birds JAB b
	Wetland	Image	Vector	Polygon	
	Watershed	n/a	Vector	Polygon	n/a
Land Form	Contour	Image	Vector	Line	SBSM [c]
	DEM	n/a	Raster	Grid	
	Slop	n/a	Raster	Grid	
	Aspect	n/a	Raster	Grid	
Soil	Soil	Image	Vector	Polygon	Zhang and Xu 1993
Socio-economic	Residents	Image	Vector	Points	JAB [b] Quick Birds
	Roads	Image	Vector	Line	
	Service	Image	Vector	Points	
	Scenery	Image	Vector	Points	
	Disturbance	Image	Vector	Polygon	
Miscellaneous	Biodiversity	Vector	Vector	Polygon	JAB [b]
	Regions of Forest fire prevention	Vector	Vector	Polygon	JAB [b]
	Land Use Type	image	Vector	Polygon	USGS [d]

Notes: [a] SAF – Sichuan Academy of Forest; [b] JAB – Jiuzhaigou Administrative Bureau; [c] SBSM – State Bureau of Surveying and Cartography; [d] USGS – United States Geographic Service

2006). The "calibrate" refers to establishing a scale or cell size (for a raster) for a specified object. Only after a raster or vector object has been calibrated, accurate measurements can be determined and displayed (Meyer et al. 1993). The "mosaic-generate" refers to creating a variety of spectral gradients within a file, which is subsequently useful only as a mosaicked unit (Homer et al. 2004). In order to obtain a high resolution image, the QB images were also masked and radiometrically corrected. The "mask" refers to clipping images in terms of the boundary of study area (a separate layer) (Markus et al. 2005). The "Radiometric correction" refers to converting absolute radiance values to Digital Numbers reflectance values, which is the digital count of the target in the raw overpass image (Furby and Campbell 2001; Schroeder et al. 2006). The operation of "Radiometric correction" is intended to remove systematic or random noise affecting the amplitude of the QB image (Meyer et al. 1993; Blaschke et al. 2000; Kleinod et al. 2005). The details on how the tasks during image processing in ERDAS IMAGINE 9.1 (ERDAS 2011) were achieved are given elsewhere (Radiarta et al. 2008). Similarly, Landsat images were also stacked, calibrated, masked. Since the images already contain coordinates system and georeference information, the information keeps the same after this process.

(b) Using the Windows Photo Gallery (Dufaux et al. 2009) and a scanner to scan the currently available paper-based maps and save as JPEG (Joint Photographic Experts Group) files. The resolutions for these JEPG files were 300 dpi (dots per inch). An Epson Expression 1640XL A3 full color scanner was used for this process. Since the scanned JPEG files do not contain any coordinates system and georeference information, these files have to be further processed, as described in the following process.

(c) Using the ArcInfo 9.3 (ESRI 2011), a GIS software to digitize the JPEG files with proper projections and coordinates systems. Firstly, all the JPEG files were projected using the Universal Transverse Mercator (UTM) approach; then were georeferenced with preselected control points using the Georeferencing function. The JPEG files were rubber sheeted to match ground control points which produced relative coordinate errors of less than a pixel. The selection of the control points were based on the following criteria: (I) easily identifiable landmarks on both maps and fields; (II) intersections of rivers, and major roadways; and (III) localities lying in different directions and geographic areas. Seven control points were selected for this study and are shown in Figure 2.

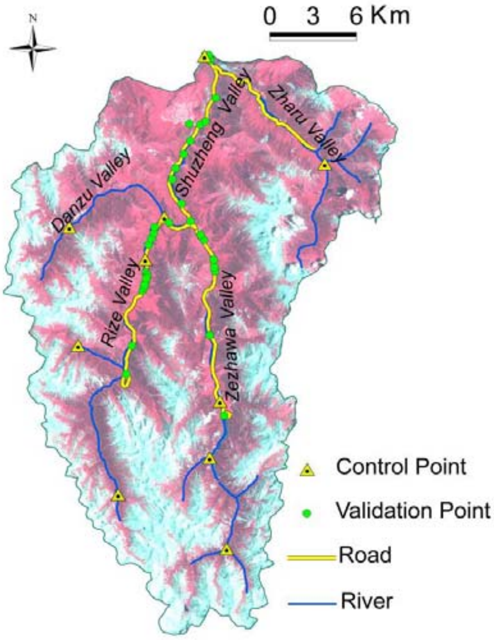

Figure 2 Selected geological locations for database validation during field surveys

The geographic coordinates of these control points were obtained during several field surveys. The georeferencing process was done as follows: The QB images of the study area were rectified by adding control points coordinates. All the scanned JEPG maps were then rectified based on the QB images by selecting several easily identifiable landmarks on both QB images and JPEG maps.

In order to obtain a digitized product with better accuracies, a line shape file of the study area is created and used as a bench mark before all JEPG files being digitized. The line shape file is projected with UTM method and polygonized using a topographic map of the study area. All digitized maps were clipped in terms of the benchmark layer before projection and georeferencing. The attribute tables for all digitized maps (shape files) were created and edited at the end.

1.1.3 Data modeling

Data modeling here refers to the process of using the available data to derive other types of interested data. For example, the Digital Elevation Model (DEM) and river shape files were used to derive slope, aspect and watershed. This process includes some ArcGIS basic operations such as the conversion of raster data to vector features and extraction of map with smaller extent from existing maps. The software used to perform the above tasks is ArcGIS Desktop 9.3. The watershed map, which consists of 24 small watersheds, was automatically delineated using the GIS Hydrology module built in the ArcGIS software with details given elsewhere (Wolock and Price 1994; Wu et al. 2008). The digital contour map of the study area was digitized by using a scanned topographic map at a scale of 1:100,000 obtained from the Sichuan Bureau of Surveying and Mapping (SBSM), and then projected, rectified based on the QB images and clipped by using the boundary map of the study area. By using ArcGIS model of "Create TIN From Features", TIN map has been created automatically. The TIN map was then used to: (a) derive a DEM map with grid cell sizes of 30 m; (b) identify the direction of water flow (flow direction), the number of cells flowing into each cell (flow accumulation), and the cells comprising a basin (area draining to a single coastal point). These tasks were achieved by using the spatial analyst module of the ArcGIS. The 30 m grid cell with the maximum flow accumulation in each basin was identified as the "pour point," or point of discharge to the lakes.

1.1.4 Data QA/QC

Data QA/QC refers to the process of validating the GIS data transformed from different sources. Transformed data were validated by comparing the geographic coordinates of predetermined locations to the field survey results. The process is performed automatically using ArcPad 7.1, which built in a GPS handheld. The GPS used for this study is a GeoExplorer ® 2008 Trimble® GeoXTTM, which has an accuracy of 1-3 meters (Edmonds 2011). In order to validate a specific data, the data has to be uploaded onto the storage card of the GeoXTTM GPS. Then, the ArcPad can be programmed to collect the coordinates of the selected locations and update the original coordinates. These processes can be repeated several times in order for better precision and accuracies.

Similar to the preselected control points as mentioned previously in this paper, easily identified geographical features were selected for field surveys as shown in Figure 2. The geological features include intersections of rivers, roadways, lake boundaries, wetland boundary lines, buildings, and others. Typically, the locations were chosen along the edge of some features such as line and polygon in the map.

1.2 The application of the GIS-based database

In order to demonstrate the GIS-based database as a research tool, the ArcObject functions (ESRI 2011) was used to quantify the wildlife's spatial distributions and their spatial correlations in Jiuzhaigou. The ArcObject is a powerful tool that could be used for environmental study in a variety of ways, such as road grade estimation (Zhang and Frey 2006) and other types of spatial analysis (ESRI 2001; Souleyrette et al. 2003; Ager et al. 2011). In order to quantify the spatial distribution, the distance of the point features to the tour-bus routes for each tour valley were calculated. This distance is also regarded as that to the scenic trails since the scenic trails are very close to the tour-bus routes as described before. In order to quantify the correlations, the Pearson' sample correlation coefficient (Casella and Berger 2001) was used. The details are given in the following:

1.2.1 Spatial distributions

A VBA (Visual Basic for Application) based macro using ArcObject functions was developed to calculate each point feature to the roadway. There are two key steps to perform the task, including (1) Buffer the roadways with a two-kilometer zone (both sides); (2) Calculate the distances of the point features fallen within the buffer to the center of the roadways using ArcObject functions. The cumulative distribution function (CDF) of the distances was used to define the spatial distribution. Figure 3 shows the schematics of how the distances were calculated.

1.2.2 Spatial correlation

The Pearson's sample correlation coefficient is generally used to quantify the correlation between

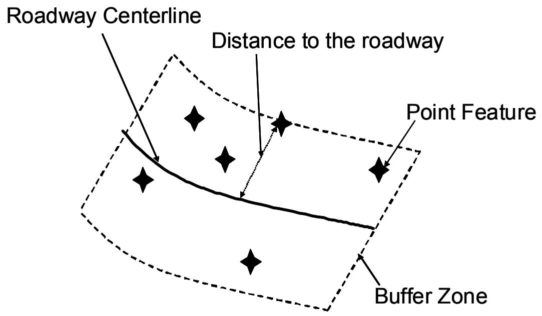

Figure 3 Schematics of calculation of distances of habitats to the roadway

two variables, especially when they are linearly correlated. The significances of correlations were quantified and justified based on the sample size using an Inverse Fisher Transformation (IFT) (Fisher 1915). The IFT was used to construct a 95% confidence interval (CI) of a zero correlation coefficient for different sample sizes. If the calculated correlation coefficient falls within the 95% CI of the zero correlation coefficient for a given sample size, then the correlation between two variables is deemed not to be statistically significant. For example, given a sample size of 20, a zero correlation coefficient has a 95% CI of -0.4 to 0.4. The absolute value of the correlation coefficient of two variables has to be greater than 0.4 in order for being deemed statistically significant.

In order to quantify the correlation coefficient of any two types of animals, in this paper, the numbers of point features of different types of wildlife within each predefined buffer zone were used as a measure of statistics. For this study, the three tour-bus routes were further divided into nine segments based on the geographic locations of vista points. Each segment will have a buffer zone of two-kilometers. Therefore, the sample size for calculating correlation coefficient is nine. The reason why a two-kilometer of buffer zone was chosen will be discussed later.

2 Results and Discussions

The development of a GIS-based database using approaches discussed above, including the key components of the database and its validation was given in this section. Spatial distributions of the wildlife habitats and the spatial correlations in locations of habitats between pairs of species are also presented as well. The details are given as following:

2.1 Development of a GIS-based database and its validation

A variety of data sources were acquired and post-processed, including data digitization and data modeling to develop a GIS-based database. As shown in Table 1, this GIS database includes two types of data, i.e., vector and raster. The vector data includes information of biology, geology, hydrology, soil, and socio-economic and contours. The raster data includes the DEM, slope and aspects of the study area, which were derived from the contours and other shape files. These data can be directly used for further analysis. In order to validate the developed dataset, several field surveys were done to collect geographic coordinate information for selected geographical locations. The information of these location coordinates was used to validate the developed GIS database using the data QA/QC procedure discussed above.

Figure 4 shows a panel of figures representing these data in the context of spatial distribution, including vegetation, soil, rock and main faults, wildlife, rivers and wetlands. For the vegetation, as shown in Figure 4 (a), the dominating types are *Kobresia* meadow, Bashan fir forest, *Rubus amabilis* shrubland, *Abies faxoniana* forest, and *Rhododendron rufum* shrubland, each accounting for 50.9%, 12.1%, 7.3%, 5.3%, and 3.9% of the study area, respectively. The Kobresia meadow is mainly found in places with high altitude and is continuously distributed in space; Both the Bashan fir forest and the *Rubus amabilis* shrubland are mainly found in both sides of the rivers with the former evenly being distributed across the entire park while the latter being clustered in the north; The *Abies faxoniana* forest is found clustering in between *Kobresia* meadow and Bashan fir forest; The *Rhododendron rufum* shrubland mainly lie in the valley areas in the south; For the soil type, as shown in Figure 4 (b), the Subalpine meadow soil, alpine meadow soil, dark brown forest soil, alpine frost desert soil are the dominating types, accounting for 34.4%, 31.3%, 23.4%, and 8.1% of the study area, respectively. The alpine meadow soil dominates in the south while the dark brown

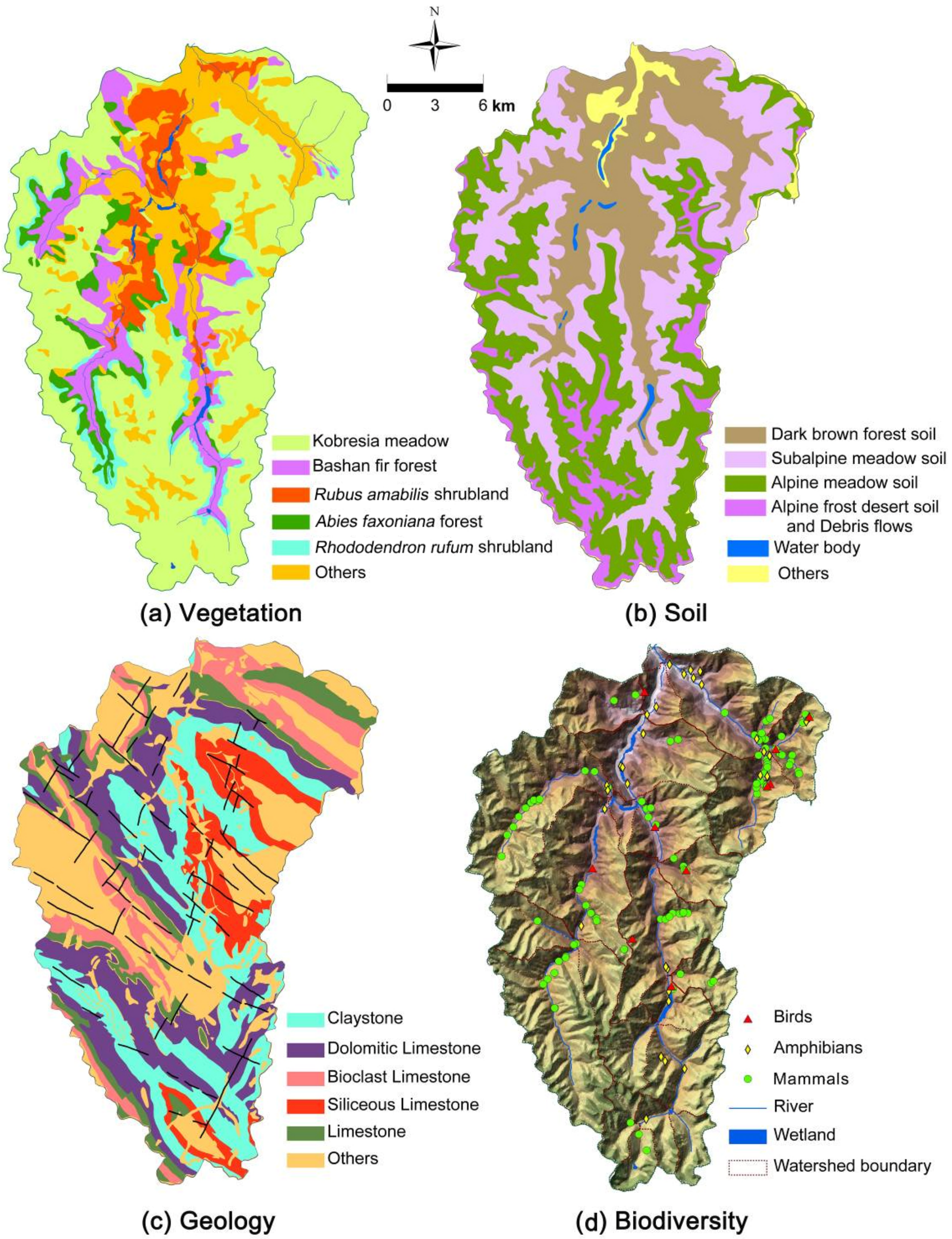

Figure 4 Several key GIS data of Jiuzhaigou National Nature Reserve: (a) Vegetation type; (b) Soil types; (c) Rocks types and main faults; (d) Distributions of birds, amphibians, mammals, rivers, and wetlands

forest soil dominates in the north. Furthermore, the altitudinal distribution of these soil types from valleys upwards is the dark brown forest soil, subalpine meadow soil, and alpine meadow soil in sequences. The Alpine frost desert soil is mainly seen in the peak areas of the mountains in the south, where granular flows often occur; For the rocks and main faults, as shown in Figure 4 (c), the dominating types are Claystone, Dolomitic Limestone, Bioclast Limestone, Siliceous Limestone, and Limestone, accounting for 20.7%, 20.0%, 10.2%, 9.0% and 8.7% of the study area, respectively. The main directions of the faults in Jiuzhaigou are northwest-southeast and Northeast-southwest. These two directional faults are overlapped for most of the areas. Furthermore, the majority of the faults are located in the north central part of the park. For rivers and wetlands, as shown in Figure 4 (d), there are three main rivers/valleys that have been open to the public in Jiuzhaigou, i.e., the Zezhawa river/valley, the Zharu river/valley, and the Rize river/valley. The Zezhawa River flows from the north to south crossing the entire park. The Zharu River is located in the north-east of the park and flows from north-west to south-east. The Rize River is located in the west of the park and flows from north to south. These valleys are well spatially distributed across the entire park, and the wetlands are also evenly distributed in the south and north.

As expected and shown in the Figure 4 (d), these valleys are the habitats of many wildlife, such as amphibians, mammals, and birds because the food and water resources are usually abundant in the valley areas. Although mammals are found in other valleys, they appear to be most populous in the Zharu valley. However, what are the spatial distributions of these habitats across the entire park? Will the habitats are being impacted by the tourism development? Whether or not these habitats are spatially correlated? The answers to these questions are important for tourism management and ecological system preservation. This serves as motivations for the second paper of this series of study, which has a focus on the spatial analysis of wildlife distribution and demonstration of the established GIS database application.

Since the GIS database were validated using field surveys with a handheld GPS, the accuracy and precision of the GIS database is largely affected and determined by the performance of the selected GPS. The accuracy and precision of the GPS are within several meters and may be adequate for environmental study in the context of ecological conservation and tourism management. In addition, as discussed in the methodology section, highly accurate QB images were also used to define the boundary of the digitized JPEG images. This has greatly assured the accuracy of these JPEG files, thus the GIS database.

2.2 Spatial distributions of the habitats

Table 2 shows the spatial distribution of the wildlife habitats identified in this study. Since the habitats were shown in the GIS database as point features, each point feature represents an event of existence of the wildlife. The spatial distributions shown in this table only indicates the number of the wildlife habitats but not the actual population.

Table 2 Spatial distribution of wildlife by visiting areas

Visiting area	Spatial distribution of animals (%)[a]		
	Amphibians	Mammal	Birds
Shuzheng	61.5	31.3	47.2
Zharu	30.8	32.0	41.7
Changhai	0.0	8.8	5.6
Others	7.7	27.9	5.6

Note: [a] The spatial distribution percentage was calculated based on the number of point features fallen within each tour valley area.

For amphibians, the majority of the habitats are in the Zharu and Shuzheng-Zezhawa valley areas (more than 92% together). There are a few in the Danzu valley. However, there are no habitats observed in the Rize valley. This could be due to the following reasons: There are more open areas around the tour-bus route in the Rize valley. Visitors could access to the vista points more easily compared to other valleys, and also spend more time here to explore around. This may disturb the amphibians, at least make them feel uncomfortable and force them to leave temporarily or permanently. In addition, the altitude might also be a limiting factor because the altitude in the Rize valley is much higher than the other valleys.

For mammals, the habitats are relatively evenly distributed compared to other species in Zharu, Shuzheng-Zezhawa, and Danzu valley areas with the Rize valley having the least.

For birds, similar to amphibians, the majority of habitats are in the Zharu and Shuzheng-Zezhawa valley areas. For the Rize and Danzu valley areas, each only has 5.6% of the habitats. The reason for scarcity of habitats for all species for the Rize valley area could be due to easy accessibility to scenic points in this area. Thus, the activities will disturb the animals and force them to migrate to other places.

As discussed before, since the scenic trails usually are located closely to the tour-bus routes, the locations of the tour-bus routes could also be regarded as those of the scenic trails. Due to the existences of the scenic trails and tour-bus routes, the disturbance to the wildlife is of a concern for natural preservation. It is assumed that the wildlife will not be disturbed if the noises/sound made by the visitors and tour buses cannot be heard by the wildlife. Thus, the distances from the habitats to the roadways/scenic trails are critical in evaluating this impact. Based on the noise transmission theory (NOISH 1975), the sound loudness level is proportional to the inverse of the squared distances to the sound source. Therefore, a two-kilometer was deemed to be sufficient for keeping the wildlife from disturbances to their habitats. This is because a 75 dB of noise will become less than 4 dB after two kilometers travel, a level much less than the environmental background. This is why a 2-km buffer zone was created along the roadways for this study.

As shown in Figure 5, the point features outside each visiting areas are 30%, 49%, and 23% for amphibians, mammals, and birds, respectively.

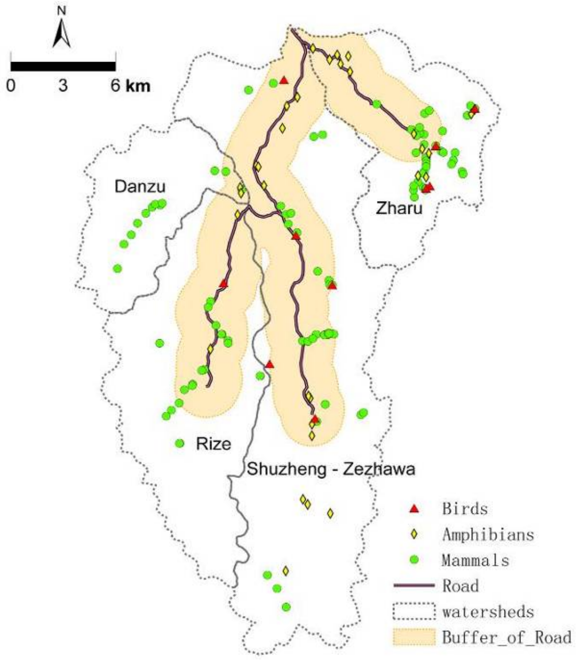

Figure 5 Spatial Distributions of Amphibian, Mammals and Birds of Jiuzhaigou National Nature Reserve (the buffer size for the roads is two kilometers for each side)

There are still significant amount (51-77%, depending on species) of point features fallen within each visiting areas. This indicates that there are possibilities the habitats might be disturbed by the existing roadways.

In order to quantify the spatial distribution of the habitats of these animals, the distances of these habitats to the roadway within the defined 2-km buffer zone were calculated using the ArcObject based macro developed for this study. The averages of the habitats to the roadway are 564 m, 894 m, and 888 m for amphibians, mammals, and birds, respectively. Figures 6-8 show the empirical CDF of the distances of the habitats to the roadways for amphibian, mammals, and birds, respectively.

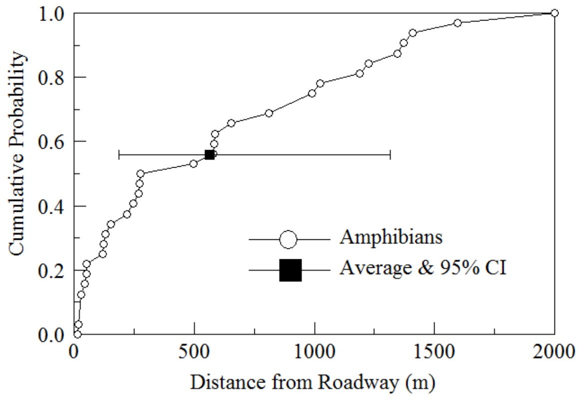

Figure 6 Empirical CDF of the Distances of Amphibian Habitats to the Roadways in Jiuzhaigou

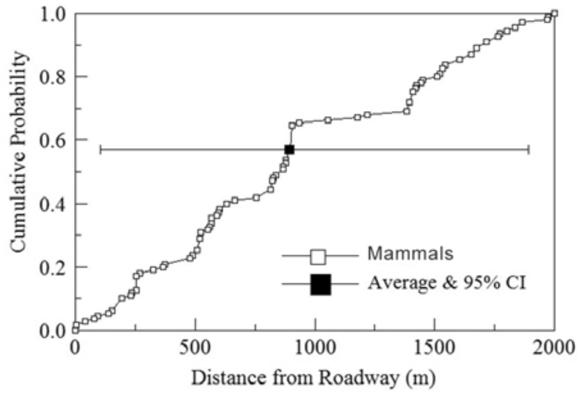

Figure 7 Empirical CDF of the Distances of Mammals Habitats to the Roadways in Jiuzhaigou

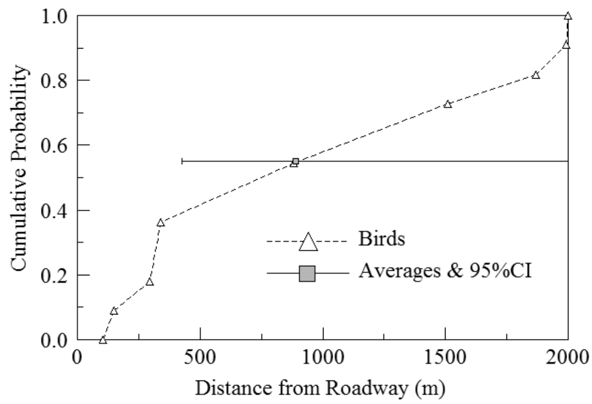

Figure 8 Empirical CDF of the Distances of Birds Habitats to the Roadways in Jiuzhaigou

For amphibian, as shown in Figure 6, 60% of the habitats are located within a distance of 650 m to the roadway. The CDF curve is slightly skewed to the left, indicating that more habitats are located closer to the roadway. This implies that the amphibians are likely to be disturbed by the tourists/visitors. Because the habitats were observed almost everywhere across the entire buffer zone, and the limited number of observations, a relatively large 95% CI of the average distances were observed. In this case, the 95% CI ranges from 377 to 750 m.

For mammals, as shown in Figure 7, more than 65% of the habitats are within one kilometer to the roadway. Except for the habitats lying between 1.0 km and 1.5 km to the roadway, the CDF curve is relatively straight, indicating the habitats are normally distributed at the average distances. Similar to that of amphibians, the 95% CI of the average distance is large due to the limited observations.

For birds, as shown in Figure 8, more than 60% of the distances are within one kilometer from the roadway. Since there were only a few habitats observed in this study, a large 95% CI of the average distance is expected. The 95% CI of the average distance from the roadway ranges from 461 m to 1.3 km.

2.3 Spatial correlations of the habitats

The correlation coefficients in spatial locations of the habitats between types of wildlife are given in Table 3. The correlation coefficients range from 0.36 to 0.64, depending on the pair of wildlife. The habitats of the mammal are more correlated with that of birds than with that of amphibians. This might be because the birds usually nest in the trees and mammals usually live on the ground, thus there are few conflicts in the territory occupation.

Table 3 The correlation coefficients between Species in Locations of Habitat

Species	Correlation coefficients matrix[a]		
	Amphibian	Mammal	Birds
Amphibian	1	0.36	0.61
Mammal	0.36	1	0.64
Birds	0.61	0.64	1

Note: [a] The sample size for calculating the correlation coefficients is 9.

However, amphibian might have some conflicts with mammals since their territory areas could overlap.

Since only nine areas of locations were studied, the sample size could be too small to indicate significance for the correlation between different pair of wildlife. The 95% CI for a zero correlation coefficient for a sample size of nine ranges from -0.6 to 0.6 using the IFT. For future work, there is a need for survey and more divisions of road segments to study the spatial correlation of habitats.

3 Conclusions

This paper developed a procedure to transform different sources of data to a GIS-based database. The developed GIS-based database was validated by several field surveys. The procedure used commonly seen hardware and software, thus is feasible and cost-effective. Although this paper only uses the results for Jiuzhaigou as an example, the procedure can also be used to other areas for similar purposes.

The GIS-based database of Jiuzhaigou consists of data in biology, geology, hydrology, land form, soil, and social-economy in formats of vector and raster. As being developed as a tool, the GIS-based database in this paper was only presented and demonstrated descriptively. However, this definitely will not restrain the use of the database quantitatively. In the meanwhile, this paper has also successfully demonstrated the use of a developed GIS-based database as a research tool for environmental study. The focus of this study is on the quantification of the spatial distribution of the wildlife habitats in the Jiuzhaigou. The results showed that the majority of the habitats are located in the proximity of the tour-bus routes, which indicates a possibility of the disturbance to the wildlife by human activities. Possible measures to mitigate the disturbances include changes of bus-stop locations, bus-tour rescheduling and roadway rerouting. Warning signs of not making noise might be helpful since the majority of the scenic trails are near roads and the noises will scare the animals, especially for those primitive areas such as Shuzheng Lake area. However, in order to make a decision as to whether or not a measure should be taken or what measure should be taken, the population of the wildlife at each habitat should be further investigated. Furthermore, the impact of these routes on the activities of the wildlife should be further evaluated by successive studies. However, this is out of the scope of this study and will not be further discussed.

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