Pinpointing Source of Mekong and Measuring Its Length Through Analysis of Satellite Imagery and Field Investigations

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Abstract  For centuries, explorers and scientists from different countries had made their own conclusions on the source of the Mekong. However, the geographic source of the Mekong is still arguable because of the complexity of the Mekong source water system, inaccessible environment and the varied technologies used by those explorers and scientists. The satellite remote sensing technology has been used to pinpoint the source of the Mekong, associated with the on-the-spot investigations made by the authors in June 1999 and September 2002. The actual length of the Mekong has also been calculated.

Keywords  source of Mekong; satellite imagery; field investigation

CLC number  P237.9

Introduction

The Mekong is the one of the most important rivers in Asia. It runs to the South China Sea, passing through China, Burma, Thailand, Cambodia, Laos PDR and Vietnam (See Fig.1). More than 61 million people depend on the Mekong and its tributaries for food, water, transport, and many other aspects of their daily lives. It supports both, one of the world’s most diverse fisheries and, one of the most biologically diverse river systems in the world. The source of the Mekong has however not been pinpointed precisely to date. Associated with this, the exact length of the Mekong has also not been calculated. Its length is reported as 4 000 km to 4 880 km, as published in various encyclopaedias, magazines, textbooks and technical reports etc\textsuperscript{[1-8]}. As a result of the various reported lengths, there is no confirmation on the correctness of the length.

In general, the length of a river depends on the position of the geographic source, the identification of the mouth, and the precise measurement of the river length between source and mouth. Locating the mouth of a river is rather straightforward. It is commonly defined as the intersection of the tangential line of two sides of the outlet with the central line of the river. Nevertheless, searching for the source in the most inaccessible reaches of the earth has intrigued explorers for centuries and is an important event in the field of geography even today. According to the widely accepted convention, the spring or glacier in

Received on January 13, 2007.

Supported by the National 863 Program of China (No.2003AA131170); the Special Funds of Director of Institute of Remote Sensing Applications, Chinese Academy of Sciences; the Funds of State Key Laboratory of Remote Sensing Sciences; and the Funds of State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing.

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the drainage basin that is farthest away from the mouth is considered as the geographical source of the river, thus giving a maximal river length. The source of the Mekong is located approximately on the highest and most remote part of the world’s highest plateau: the Qinghai-Tibetan Plateau. From the mid-nineteenth century, some expeditions that were separately supported by the Mekong Committee of the French Société de Géographie, National Geographic Society and China Scientific Exploration Association have been undertaken to locate the source of the Mekong\(^{[1-8]}\). As a result of the limited technologies, the complexity of the Mekong source region water system and inaccessible environment, they could not identify the source of the Mekong precisely. This is resulted in the diversity on the source of the Mekong in many literatures\(^{[1-8]}\).

Fig.1 Course of Mekong

The upstream of the Mekong is the Zha River and the uppermost portion of Zha River is the Zhana River and Zhaa River, two main branches of the upper Mekong. The Zhana River and Zhaa River are confluence at Ganasongduo. There are nearly 400 tributaries in the Mekong sources region. Among them, the branches that originated at Rup-sa La Pass, Zhanahuohuozhudi (the sacred source), Mountain Zhanarigen, Lungmo Pass and Mountain Chajiarima in the Zhana River drainage basin are believed to be the source of the Mekong by some scientists, explorers and local nomads and the Lake Zhaxiqiwa (the sacred source) and Mountain Lasaigongma or Mountain Guozongmucha in the Zhaa River drainage basin are believed to be the sources of the Mekong by others\(^{[1-8]}\). But the details such as length, latitude, longitude and name of the mountains have not been provided to various conclusions. While in some cases, different names were given to the same source. To pinpoint the geographic source of the Mekong and calculate its accurate length, the satellite remote sensing images analysis associated with the on-the-spot investigations is proposed in this paper.

1 Methodology

The common data sources for measuring the lengths of the rivers are the topographic maps with adequate scale. However, the large scales topographic maps are considered as confidential information by many countries and are not available for purchase from market sources. In addition, for some regions of the rivers traversed, the large scale topographic maps are not readily available although the small or medium scale maps can be obtained from atlases in different languages. It is well-known that the measured length of a river depends on the scale of the map on which the measurement is based on; in general, due to the fractal quality of a river, the smaller the scale, the shorter the resulting length measurement. This is because some details of the river’s channels are generalized according to various mapping specifications. This is the reason for large variation in the lengths of the Mekong in various literatures\(^{[1-8]}\).

Remote sensing imagery is capable of covering large areas with quantitative observational parameters such as spectral radiance. It is therefore a potentially rich data source for locating the source and calculating the length of the rivers. Governments and commercial agencies of many countries support a series of satellites for long-term global observations of the land surface, biosphere, solid earth, atmosphere and oceans\(^{[9,10]}\). Although there are many remote sensing satellite series in operations, such as Ikonos, QuickBird, SPOT, ERS, RADARSAT, IRS, CBERS, Landsat and others, not all is suitable for measuring the length of rivers on the earth. The images are selected on the bases of converges, resolution, availability and cost. Among all the remote sensing satellites, Landsat series satellite data are the only record of global land-surface conditions at the scale of tenths of meters over the last 30 years.
Data at these spatial resolutions can provide acceptable accuracy in measuring the rivers and are also available in the market. In this paper, the Landsat TM and ETM+ image are chosen as the data source for measuring the length of the Mekong.

Raw remotely sensed data acquired by the satellites are representations of the irregular surfaces of the earth. Images of seemingly flat areas are even distorted by both the curvature of the earth and the sensor used. When satellite remote sensing imagery is incorporated into a geographic information system (GIS) and/or remote sensing image processing package for further analysis, the rectification must be undertaken according to some mathematical models so that the rectified image can be represented on a planar surface, conforms to other images to obtain an integrated map.

Satellite image rectification is the process of transforming data from one grid system into another by using a geometric transformation. Polynomial transformation and triangle-based methods are the more popular techniques for satellite image rectifications. Since the pixels of the new grid may not align with the pixels of the original grid, the pixels must be resampled. Resampling is the process of interpolation or extrapolation of data values for the pixels on the new grid from the values of the source pixels. Three methods are used in resampling, namely nearest neighbour, bilinear interpolation and cubic convolution. When high accuracy is required, orthorectification is needed. Orthorectification is a form of rectification that corrects terrain displacement and can be used if a digital terrain model (DEM) of the study area is available. It is based on the collinearity equations, which can be derived by using 3-dimensional ground control points (GCPs). The result is an image that appears as if the satellite or the viewer is looking normal to the earth at every location. In such orthogonal views, the horizontal position of any feature directly beneath the viewer would not be affected by local terrain variations. Once images were orthorectified and geodetic coordinates assigned, it can used for various purposes.

Any topographic map must be associated with some ellipsoid and datum, projection and coordinate system, as well as the map scale. The map projection system is the system designed to represent the surface of a sphere or spheroid on a plane. Since flattening a sphere to a plane results in distortions to the properties, such as conservation of distance, angle or area, there are several map coordinate systems for determining the location of an image. These coordinate systems conform to a grid, and are expressed as $X, Y$ (column, row) pairs of number. Each map projection system is associated with a map coordinate system. Due to historical reasons, each country has its own geodetic network and national geodetic reference frame. Many different coordinate systems, based on a variety of geodetic datum, units, projections and reference systems are in use today. Most of the national reference frames are not identical and are not a global coordinate system designed for use anywhere in the world. For measuring the exact length of Mekong, it is necessary to choose one coordinate and projection system that is suitable for high-accuracy application.

Universal transverse Mercator (UTM) is a widely used map projection that employs a series of identical projections around the world in the mid-latitude areas, each spanning six degrees of longitude and oriented to a meridian. In UTM projection system, the area between $84^\circ N$ and $80^\circ S$ latitude is divided into north-south columns 6° of longitude wide called zones. This projection is conformal, that is, it preserves angular relationships and scale. It also easily allows a rectangular grid to be superimposed on it. This grid system and the projection on which it is based have been widely adopted for topographic maps, georeferencing of satellite imagery, natural resources data bases, and other applications that require precise positioning. Principal rivers in this world that distribute in the inhabited continents are valid for UTM projection. There are various coordinate systems that are associated with this projection system. Among them, WGS 84 (World Geodetic System of 1984) is considered to be one of the best mathematical models of the earth. WGS 84 is an earth fixed global reference frame of the earth, including an earth model. It is defined by a set of primary and secondary parameters: the primary parameters define the shape of an earth ellipsoid, its angular velocity, and the earth mass which is included in the ellipsoid reference; the secondary parameters define a detailed gravity model of the earth.

NASA has sponsored the creation of an orthorectified and geodetically accurate global data set of
Landsat MSS (multi-spectral scanner), TM (thematic mapper) and ETM+ enhanced thematic mapper) to support a variety of scientific studies and educational purpose\[11\]. These images are precision orthorectified Landsat scenes delivered in the standard Landsat individual scene coverage (approximately 180 km × 180 km) and are available for the whole globe in either the two epochs of circa 2000 or earlier base-line coverage of circa 1990. In this project, orthorectified Landsat ETM+ scenes of circa 2000 are selected as the main data source for measuring the length of the rivers. Precision orthorectified Landsat ETM+ scenes were acquired from 1999 to 2002 with a spatial pixel resolution of 14.25 m, 28.5 m, and 57.0 m for the panchromatic, reflective and thermal bands respectively. Nearest neighbour resampling method was used in the orthorectification. These data sets are comprised of all nine Landsat ETM+ spectral bands and are in a UTM (universal transverse Mercator) map projection and WGS-84 coordinate system with a geodetic accuracy of better than 50 m RMSE (root means square error). For some regions that ETM+ images are not available, the orthorectified Landsat TM images acquired in circa 1990 are used. Landsat ETM+ and TM bands are generally made into colour images for the interpretation purpose. In principle, any three of the visible and reflected IR bands may be combined in blue, green and red channels to produce a colour image. Band assignments are often expressed in R, G and B order. For example, the assignment 4, 2, 1 means that band 4 was assigned to red, band 2 to green and band one to blue. There are over one hundred possible colour combinations, which is an excessive number for practical use. Theory and experience show that a small number of colour combinations are suitable for most applications. The optimum band combination is determined by terrain, climate and nature of the interpretation projects. In this project, the water has the spectral characteristics significantly different from the other objects of the earth surfaces and is very easily recognized by the interpreters. The band assignment is 5 (R), 4 (G), 3 (B) for all the scenes of the Landsat scenes.

Remote sensing image processing package, ERDAS IMAGINE 8.5, is selected as the platform for measuring the length of the Mekong. The length was measured along the central line of the river’s mainstream, from its geographical source to the mouth. Prior to or during measurement, the channels can be recognized from images by processing the satellite images, e.g. contrast enhancement, intensity, hue and saturation transformation, filtering of random noise, atmospheric correction and others. Based on the orthorectified satellite images mentioned above, the measured length of river with accuracy between 2:1 000 and 3:1 000 of the length can be achieved.

2 Conclusions

The Mekong originates from the foot of Mountain Jifu. The geographic position of the source of the Mekong is latitude 33°45′48″N and longitude 94°40′52″E, in which the elevation is 5 200 m, on the boundary of Zaduo County and Zhiduo County, Qinghai Province, China. In summer, the melted snow and ice gather into a stream that is named the Guyong-Pudigao Creek (see Figs.2-4). In Fig.3, triangle markes the position of the source of the Mekong. It is the spring furthest away from the sea and the end of the branch with the greatest flow of the water. This conclusion is attained by the interpretation of the satellite imagery and thorough investigations on-the-spot in June 1999 and September 2002. The Guyong Creek merge with the Gaoshanguxi Creek, which originates from Guozongmucha(also called as Lasaiongma), to form the Guoyong River at Yeyongsongduo. The Guoyong River gathers five main headwaters to form the Zhaa River. As comparison, the lengths and geographic positions of the Zhaa River with other headwaters that were considered as the sources of the Mekong by other explorers are listed in Table 1 and shown in Fig.2.

Begin from Mountain Jifu, the Mekong flows westward over 22.6 km before it merges with the Gaoshanguxi Creek at Yeyongsongduo to form the Guoyong River. The Gaoshanguxi Creek is one of the main headwaters of the Mekong with a length of 21.0 km, which is originated from Mountain Guozongmucha and was previously believed to be the source of the Mekong by other researchers. In comparing the length of two tributaries, the Guyong-Pudigao Creek is longer than the Gaoshanguxi Creek by 1.7 km.
From Yeyongsongduo, the River changes its name to the Guoyong River and then the Zha River, and flows 76.7 km southward to merge with the Zhana River in Ganasongduo. From Ganasongduo, it flows 513.8 km southeast to Changdu City with the name of Zha River. From Changdu City to the border of China, it flows 1,584.8 km with the name of Lancang River (Turbulent River). Out of China, 2,711.0 km of it passes through Myanmar, Thailand, Laos, Cambodia and Vietnam to its mouth in South China Sea with the name of the Mekong. It splits into several branches at the Mekong Delta in Vietnam before it enters the

![Fig.2 Tributaries of Mekong up Ganasongduo of Zaduo County, Qinghai, China](image)

![Fig.3 Landsat 7 ETM+ image (30 November 1999) of source of Mekong](image)

| Name of source | Drainage     | Latitude (N) | Longitude (E) | Elevation (m) | Length (km) |
|----------------|--------------|--------------|---------------|---------------|-------------|
| Mt. Jifu       | Zha River    | 33°45'48"    | 94°40'52"     | 5,200         | 99.4        |
| Mt. Guozongmucha| Zha River    | 33°42'39"    | 94°41'37"     | 5,160         | 97.7        |
| Lake Zhaxiqiwa | Zha River    | 33°37'20"    | 94°25'40"     | 4,840         | 76.7        |
| Mt. Zhanarigen | Zhana River  | 33°20'24"    | 94°11'50"     | 4,790         | 67.2        |
| Mt Chajiarima   | Zhana River  | 33°21'08"    | 93°55'20"     | 5,080         | 97.3        |
| Rupsa-la Pass   | Zhana River  | 33°16'32"    | 93°52'56"     | 4,975         | 90.5        |
| Lungmo Pass     | Zhana River  | 33°03'24"    | 93°59'25"     | 4,920         | 83.5        |
South China Sea. Considering the consistency with the mainstream of the river, the amount of water that enters into the sea, especially the lengths of each channel, the Tieng River are selected as the mouth of the Mekong. The intersection of the central line of river with the tangential line of two sides of the outlet is defined as the end of the Mekong. The geographical position of the end of the Mekong is latitude 9°55′42″N and longitude 106°42′45″E. The end point is shown in Fig.5. The calculated length of the Mekong from the source to the mouth is 4 909 km and the lengths of each sections of the Mekong listed in Table 2. Compared with the new measured lengths of other principal rivers of the world, the Mekong is the 10th longest river of the world.

| Section                              | Length /km |
|--------------------------------------|------------|
| Mt. Jifu — Yeyongsongduo (Guyong-Pudigao Creek) | 22.7       |
| Yeyongsongduo — Ganasongduo (Zha River) | 76.7       |
| Ganasongduo — Changdu (Zha River)     | 513.8      |
| Changdu — Bordor of China (Lancang River) | 1 584.8   |
| Border of China — Mekong Delta (Mekong River) | 2 711.0   |

Acknowledgement

The authors gratefully acknowledges Prof. Guo Huadong, Prof. Huang Bingwei, Prof. Wang Zhizhuo, Prof. Chen Shupeng, Prof. Li Deren, Prof. Wu Yirong, Prof. Niu Zheng, Dr. Wang Wen, Dr. Di Kai-chang, Dr. Wu Xiaoliang, Mr. Xiwu Duojie, Mr. Zheng Ming, Mr. Ye Yan and Mr. Peng Yi for their generosity, kind assistances and encouragements.

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