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Spatial distribution and temporal variation of high fluoride contents in groundwater and prevalence of fluorosis in humans in Yuanmou County, Southwest China

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HIGHLIGHTS

- ► High F contents in water and fluorosis in humans occurred in lowland Yuanmou County.
- ► Fluoride levels and fluorosis prevalence dropped due to a supply of safe water.
- ► Fluorosis is positively associated with high fluoride levels in drinking water.
- ► Supply of safe drinking water is an effective way to reduce fluorosis.
- ► It is essential to enhance awareness of health risks posed by high F levels in water.

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ABSTRACT

Successive surveys conducted in 1984, 2006 and 2007, of all villages in Yuanmou County, China, highlighted 40 villages with groundwater fluoride levels higher than 1.0 mg/L and related cases of human fluorosis. Using the data from these surveys and by employing geographic information system (GIS) techniques, high fluoride levels and fluorosis cases were mapped. The results show high fluoride concentrations and fluorosis hotspots were found to be predominately located in the lowlands of central Yuanmou County. Spatial distribution of high fluoride levels was found to be primarily determined by geology, arid climate, and topography. Both dental and skeletal fluorosis had dramatically decreased due to a program of low-fluoride drinking water supply supported by local governments. The prevalence of dental fluorosis in children had dropped from 43.26% in 1984 to 21.97% in 2006, and the number of skeletal fluorosis cases had decreased from 327 in 1984 to 148 in 2006, respectively. Despite a decline in fluorosis cases, the emergence of fluorosis in new areas indicates the need for both continuous monitoring of drinking water in affected areas and increased public awareness.

1. Introduction

Fluorine in the form of fluoride is a natural component of geochemical processes. Fluoride occurs in rocks, soil, air, water, plants, and animals as well as in the human body. While low intake of fluoride by humans can benefit teeth (e.g. caries prevention) and bone growth [1–4], long-term excessive absorption of fluoride can lead to fluorosis of teeth and bones, and to a multitude of other health problems including negative impacts on the intellectual development of children [5–8]. High fluoride levels in humans result from exposure to numerous sources such as fluoride-emitting industries, burning of coal, volcanic ash, excessive fluoride in brick tea (tea compressed into block form), and fluoride contaminated drinking water [9–12]. Fluorosis is becoming a global environmental toxicological problem in a number of parts of the world [13], and is most commonly found in water-stressed regions [14,15]. India and China have the highest fluorosis prevalence in humans in Asia [16–22]. Fluorosis is a serious public health problem throughout most of China. In 2010 there were 41.76 million fluorosis cases in 1325 different counties,

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out of which 58.2% were caused by chronic exposure to high levels of fluoride in drinking water [23].

Dental fluorosis mostly involves visual change in enamel opacity caused by hypomineralization associated with fluoride ingested during tooth development (in humans, generally from birth to the age of 7 or 8) [24]. Severe fluorosis can affect tooth structure [25]. Skeletal fluorosis is caused by continuous, excessive exposure to fluoride and is characterized by axial osteosclerosis, joint pain, ligamentous ossification and fractures [26]. Fluoride enters the human body mainly through food and water intake. Studies indicate that soluble fluoride in drinking water is the highest contributor to daily fluoride intake [27], and that drinking water is thus the most significant source of human fluoride ingestion [25,28].

Yuanmou County in Yunnan Province, China, has been identified by the Center for Disease Control and Prevention (CDC) as an area where endemic fluorosis caused by using groundwater high in fluoride content for drinking purposes, prevails. In the past 30 years, the CDC of Yuanmou County has put great efforts into surveillance and monitoring of fluoride concentration in groundwater and of fluorosis in humans, as well as introducing safe drinking water supply at the village level in order to reduce fluorosis. However, as the large quantity of data that was generated through these efforts has never been sufficiently analyzed with reference to environmental factors, the linkages of high fluoride concentrations in groundwater with fluorosis in humans were never explored, and the distribution of fluorosis hotspots in this county was not well understood. A spatial fluoride risk assessment had previously been carried out in Durango, Mexico where concentrations in tap water were used to categorize the city into different risk zones, with exposure risk calculated for different age groups based on body weight and water consumption [29]. Zhang et al. assessed spatial fluoride risk distribution in the West Plain of Jilin Province, northeast China [30], and Fordyce et al. mapped high fluoride hotspots for the purpose of more effectively applying water fluoride removal technology in central Europe [31]. The distribution of fluoride from different water sources was mapped in Ethiopia by Kloos and Haimanot [32]. Even though these fluoride risk assessments have focused on potential risks and on exposures to such risks, or have mapped the distribution of these risks, very few studies have taken into account both the change of fluoride levels in the environment, and the change of human fluorosis over a long period [33,34]. In this study, we therefore not only explore the geographical distribution pattern of high fluoride contents in groundwater and fluorosis affected villages, and of the main factors responsible for high fluoride concentration, but also the variation of fluoride contents in groundwater and fluorosis in 3 years, i.e. 1984, 2006 and 2007, based on substantial surveillance data from the CDC of Yuanmou County, using spatial analysis function of geographic information system (GIS). Although there have been studies using fluoride contents in some mammalian species to indicate changes of fluoride contents in the environment over decades [35,36], this is the first time that both temporal and spatial variations of fluoride contents in groundwater and fluorosis in humans are investigated for selected years during a period from the 1980s to 2000s. The main purpose of this exercise is to show how important it is to continue monitoring fluoride contents in groundwater and fluorosis in affected areas, as more and more attention is being paid to endemic fluorosis by governments and international organizations.

2. Materials and methods

2.1. Site specification

Yuanmou County is located in north-central Yunnan Province, Southwest China (Fig. 1), along the Yangtze River, with a total area of 2036 km^2. The Longchuan River, a tributary of the Yangtze River, runs from south to the north. The predominantly mountainous terrain ranges in elevation from 845 to 2808 m above sea level (masl). Characteristic of Yuanmou County are the dry-hot valleys of the Hengduan Mountains. Yuanmou County has a monsoon climate with an annual average temperature of 21.6 °C. The average temperature of the hottest month is 26.4 °C, and the average temperature of the coldest month is 14.3 °C. The annual rainfall is 637 mm, most of it occurring between the months of May to October. The annual evaporation of 3507 mm is 5.6 times the annual rainfall [37].

Because dense populations and historical migrations have led to deforestation and land degradation, Yuanmou County is now an area of high poverty and resource scarcity. The total population is 215,795 (year 2010) in 10 townships, with 30% minorities mainly Yi, Lisu, Miao and Muslim. Many people live in remote mountain areas with poor access to roads, markets and basic water resources. The economy is predominantly agricultural, the basin area of the Longchuan River has the highest population density and the most intensive agriculture. Common health issues in Yuanmou are associated with endemic fluoride from drinking water, and with water sanitation due to water scarcity in the uplands.

2.2. Collection of data on fluoride concentrations and fluorosis

The WHO guideline value for fluoride in drinking water is 1.5 mg/L, with a target of 0.8–1.2 mg/L to prevent tooth decay and to maintain adequate skeletal strength. Acceptable levels depend on climate, amount of water intake, and intake of fluoride from other sources. In this study, we used the Chinese national standard for fluoride of 1.0 mg/L as a guideline. Fluoride levels in drinking water exceeding the state criteria are classified into three categories: 1.0–2.0 mg/L as moderately high, 2.0–4.0 mg/L as high and >4.0 mg/L as dangerously high, respectively.

Village-level fluoride concentration in groundwater from 1984, 2006 and 2007 and fluorosis data from 1984 and 2006 were obtained from the CDC of Yuanmou County. Fluoride concentration in groundwater and the occurrence of fluorosis in humans were investigated by the CDC in 1983 and 1984. In order to determine the fluoride concentration, samples of all drinking water sources were collected in villages with less than five sources. In villages with more sources, only five source were sampled in the north, east, south, west, and at the center of the village. The average of all sources was calculated to represent the fluoride concentration in groundwater at village level. For each water source, a 250 ml water sample was collected for laboratory testing, and the fluoride concentration of water was determined using the fluoride ion selective electrode method [38]. Both water sample collecting and F ion testing were conducted following the Chinese national standard for drinking water tests (GB/T 5750). Between 1983 and 1984, a total of 860 drinking water supply sources were investigated in 613 villages of Yuanmou County. A total of 41 villages were then identified as high-fluoride areas. From these 41 villages, the CDC collected an additional total of 304 water samples in 2006. An overall survey of fluoride levels in the drinking water was conducted again by the CDC from 2007 to 2009, which yielded an additional 10 fluorosis affected villages, fluoride concentrations in groundwater were recorded in 47 fluorosis affected villages but no survey was conducted for the total number of fluorosis cases in all fluorosis affected villages. Though the data is from 3 years (1984, 2006 and 2007), the period under observation is representative of overall trends as it covers the situation before and after the agency's intervention.

The number of cases of dental fluorosis in 8- to 12-year olds was selected as a key indicator of dental fluorosis prevalence.