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Integrating models to evaluate and map grassland fire risk zones in Hulunbuir of Inner Mongolia, China

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ABSTRACT

Grassland fire is a cause of major disturbance to ecosystems and economies throughout the world. This paper investigated the disruptive effects of grassland fire on the Hulunbuir grassland of the Inner Mongolia Autonomous Region of China. The study selected variables for fire risk assessment using a combination of data collection and evaluation methods: geographic information systems, remote sensing, and statistical yearbook data. The data evaluation resulted in eleven input variables, which were classified into five categories: fuel, fire climate, accessibility, human–social factors, and topography. All of the explanatory variables were integrated into a model and used to estimate the grassland fire risk index. Within the index, four categories were created, based on spatial statistics, to adequately assess respective fire risk: extreme, high, moderate, and low. Approximately half (54.33%) of the study area was predicted to fall within the extreme or high risk zones. The percentages of actual fires in each fire risk zone were as follows: extreme, 46.49%; high, 23.66%; moderate, 17.06%; and low, 12.79%. The mean correct prediction from the model was 76.30%. The model and results could aid in spatial decision making practices and in preventative grassland management strategies.

1. Introduction

Extensive grassland areas can be found on all continents of the world except Antarctica [1], and in these grass-dominated fuel areas, fire is a common occurrence [2]. These fires are of global significance, because the burning biomass constitutes one of the largest sources of global greenhouse gas emissions [3]. Grassland fires are also problematic for agricultural and livestock production; annual fires may result in increased soil erosion, soil degradation, loss of life and property, diminished grass resources, and decreased biodiversity [4].

In northern China, extensive areas are covered by grasslands, with nearly 1/6 of the total area experiencing frequent burns each year [5]. Grassland fires that recur frequently in a single area typically restrain grass growth, and can have devastating physical, biological, ecological, economical, and environmental consequences [6]. Zhang et al. [5] verified the occurrence of over 50,000 grassland fires in northern China from the 1950s to the 2000s.These fires affected 200 million ha, and resulted in an average annual loss of more than 1.5 million dollars mainly in herds, crops and grass. The two primary reasons for grassland fires in northern China are: (i) natural causes, primarily lightning, and (ii) unintentional human ignition. Over 80% of northern China grassland fires are of anthropogenic origin [7], as human activities of vehicular transport, stubble and grass burning on fields, smoking, cooking, arson, and sacrificial fire use are all significant sources of ignition [7].

With the number of livestock increases and the quality of grassland decreases, fire prevention is of high priority for breeding more herds in the Hulunbuir region. And fire risk evaluation is crucially important to fire prevention. Pre-fire planning resources require objective tools for the effective spatial prediction of fire occurrence likelihood [4]. Fire risk evaluation requires many tools to suit the complexity of fire occurrence, which includes both ignition and propagation. And the evaluation represents likelihood as fire ignition and propagation probabilities. Most fire risk evaluation to date has focused on sources of ignition, relying primarily on meteorological indices that are based on routinely measured weather station variables [4]. Some risk evaluation studies have also accounted for atmospheric conditions, human impacts, fuel loads, and moisture status [6,8].

Thus, this work argues for the utilization of grassland fire risk zone mapping which could support reduction of fire frequency and aversion of fire damage. This method could be particularly useful because most fires are caused by human activities, and

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could be prevented with proper management [9]. Fire risk zone mapping would be an excellent tool for aiding humans in fire prevention; many fire managers agree that fire prevention is a more cost-effective method than fire suppression, and prevention causes less damage to lives, personal property, and the environment [6,10]. So, the preparation of an effective grassland fire risk zone map is an economical and useful first step in the fire management planning and decision-making process, aiming to reduce or prevent the occurrence of grassland fires [6]. Previous studies on fire management planning and prevention focused on developing methods that could consistently assess fire risk via data integration [4,6,10].

The application of Remote Sensing (RS) and Geographic Information Systems (GIS) is a new trend in wildland fire studies, which involves the application of multi-scale spatial information at a tactical or strategic level. GIS in combination with satellite imagery has been used to map and monitor fire hotspots, fire perimeters, as well as variations in fuel mass and fuel moisture [11,12]. These methods have also been used to understand the ignition and propagation (behavior) of wildland fires, in addition to the factors that influence fire behavior [10,13]. Over the last few decades, explanatory factors that are measured using GIS, satellite imagery, and the like, have led to the development of several fire risk indices for fire risk evaluation and mapping [10,14].

This use of spatial data and technology has been coupled with increased attention to the role of human activities in wildland fire ignition. The first studies involving human impact on fire risk were based largely on census and statistical data, with no application of spatial methods [15]. More recently, however, researchers have expanded their work to include the spatialization of human factors, the likes of which include the relationship between fire occurrence and the distance to roads and settlements, or to specific land uses [16,17]. Researchers have also argued for the inclusion of socio-economic factors in fire risk evaluation, such as population density, rural population, and workforce numbers [6]. Despite the documented improvement of fire risk studies resulting from inclusion of human factors data, the impact of human and social factors on the spatial and temporal patterns of wildland fire occurrence is still not well understood [18]. Human behavior is complex, and requires data collection and evaluation strategies to match its multi-dimensionality. To make prevention efforts more efficient, enhanced knowledge of the spatial patterns of wildland fire risk, as well as their spatial relationships with underlying human–social factors is essential.

In this paper, we examine anthropogenic grassland fires risk in the northeast of Inner Mongolia, China, with the goal of improving on previous methods of fire risk assessment. Previous work on grassland fires in northern China has largely been qualitative and rarely includes spatial analysis [19]. With this in mind, this paper aims to build an integrated fire risk model that is supported by GIS and remote sensing methods; we develop a model for grassland fire risk zone assessment with which to map the grassland fire risk zones. A grassland fire risk zone map, which integrates fuel, fire climate, and human–social factors data, help grassland managers design fire management plans strategically for the prevention and reduction of fire risk activities. Further, the final product is useful in directing managers toward proper action for fire management when fires do occur.

2. Study area

The Hulunbuer study area is located in the Inner Mongolia Autonomous Region in northeastern China, between 47.08–53.23°N and 115.22–126.06°E (Fig. 1). It is approximately 681 km long and 703 km wide, and covers a total area of 252,948 km^2.

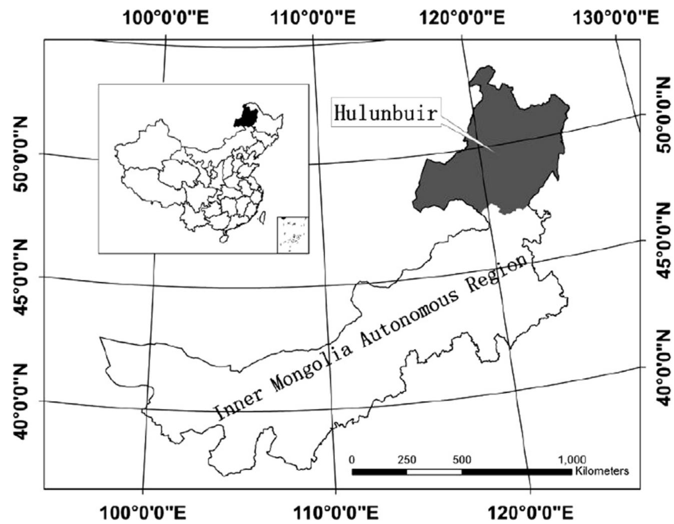

Fig. 1. The location of the Hulunbuir study area in the Inner Mongolia Autonomous Region, northeast China.

On average, 340 wildfires occur in this region every year, consequently burning an average of 1,111,717 ha per year. The study area climate is typical temperate continental monsoon, with low irregular rainfall and extreme changes in temperature between summer and winter. The annual mean air temperature and precipitation are approximately −2.3 °C and 320 mm respectively. Over half of annual precipitation (55%) occurs during the summer months. The vegetation in the Hulunbuir grassland region is made up of diverse plant communities, which are dominated by *Stipa baicalensis*, *Filifolium sibiricum*, and *Leymus chinensis*. The elevation ranges between 200 and 1500 m; the central region is dominated by the Daxing'An Mountains, stretching from the center of the region toward the east and west, the elevation gradually decreases and topography gradually becomes flatter. Approximately 3000 villages and towns are contained within the study area, and the practices of the inhabitants lead to accidental fires. Paved roads, dirt roads, and railroads are common in the region; they are distributed throughout the area with a high density of 67.64 km/km^2. Fields make up the main land cover components, and 65% of grassland areas are adjacent to fields.

3. Data and methods

The grassland fire risk assessment method developed in this study used fuel, fire climate, and human–social factors data, in combination with spatial and statistical analysis to provide an accurate prediction of fire occurrence. Lightning-ignited fires were excluded from this study because they have occurred with far less frequency than have human-caused fires [20]. Previous studies that included human factor variables focused on accessibility (distance from roads or residential areas) and meteorological variables [9]. In an attempt to improve on the scope of human factor variables, this study also considered the human activities and socio-economic factors that contribute to high fire risk [6]. We used these seven variable groups in the definition of useful human factor variables including: socio-economic transformations in rural areas; human presence and socio-economic transformations in urban areas; persistence or transformation of traditional activities linked to fire in rural areas; accidental or negligent events related to electric lines, hunting reserves, road transit, railways, and military exercises; landscape structure and housing patterns; indirect factors leading to intentional fires; and related policy. The study also