Dam Siting

Subjects: Engineering, Environmental
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Dam siting is the study of site selection, a branch of decision making, which has the characteristics of multidisciplinary integration, involving decision making, and coordination, geographic information science, computer science, etc. Siting decisions are constantly iterated and updated as the discipline evolves, and the dam siting process will inevitably face more challenges.

Keywords: dam siting ; multi-criteria decision-making ; geographic information systems ; machine learning ; siting factors

1. Introduction

Water is a basic human need [1], playing important roles in facilitating geophysical cycles [2], regulating microclimates and runoff cycles [3][4][5], regulating microclimates and runoff cycles [6][7]. Dams, on the other hand, regulate the hydrological environment of small areas at a small scale [8]. Dams are man-made structures or naturally occurring barriers that span rivers and raise water levels by controlling or impeding the flow of water. They provide effective regulation of the spatial distribution pattern of water resources [9], for purposes of soil and water conservation, water supply, irrigation, aquaculture, flood control, and power generation [10][11][12][13][14][15]. There are 58,713 registered dams in the world [16]. The economic value of dams far outweighs their disadvantages and costs, and they play significant roles in regulating the distribution of water resources and balancing water systems and ecosystems [17].

Dams are the key for hydraulic projects, but not all dam construction processes are based on a scientific and systematic approach to decision making. Due to anthropogenic and political factors, the neglect of the technical aspects of the problem is still present [18][19]. Reasonable siting solutions consider the balance between ecology and energy [20], reducing the associated damage to the environment [21]; poor siting can cause negative impacts, such as the risk of erosion leading to mudslides and landslides [22], serious impacts on runoff and sedimentation processes [23], and low or negative economic benefits [24]. Therefore, studying the spatial distribution of reservoirs and making decisions on dam siting are key steps in water resource management.

In the light of the scientific literature, many researchers have analyzed the optimal location for dam construction. These studies have specific factors to determine the appropriate location and show variability in different purposes of dams, for example: irrigation, power generation, water supply, and flood control. A search of English literature in existing databases (excluding other languages) shows that there are many research results on dam siting, but few review papers are available, making it difficult to grasp the progress of the existing research and the future direction of development in this field.

Sustainable development is an important global issue, in which the development of clean energy makes an essential contribution. Existing studies include systematic reviews of wind and solar power plant siting [25][26][27], as well as a review of hydroelectric plant siting [28], which similarly involve the selection and trade-off of a large number of factors. Hydroelectric power generation is one of the important uses of dams, and a comprehensive review on dam siting is highly informative. Meanwhile, dam siting can provide a strong support for future systematic reviews of hydraulic power plant siting. In this review, the existing research results on dam siting were analyzed and discussed in terms of three aspects—siting methods, siting decision factors, and the influence of use and siting factors—with the intention of providing more systematic and scientific theoretical support for future dam siting projects.

2. Factors Influencing Dam Siting

Factors are important elements in the siting process and affect the outcome of the site from different perspectives. A review of a large number of studies found that the selection of factors between dams showed certain similarities and characteristics, considering the differences that exist in the natural environment, social environment, and purpose. Analyzing the types and frequencies of factors in different articles can be useful in providing a reference for future site selection studies. It is essential to have advanced knowledge regarding the use of current study factors. For example, Othman [19] analyzed the factors in different papers before making a decision on the selection of factors, and concluded that 70% used land use, soil type, slope, sedimentation, and CN grid; 20–40% used elevation, drainage networks, distance to lineaments, lithology, distance to faults, tectonic zone, distance to villages, distance to roads, and distance to towns; and less than 10% of the articles used distance to materials, total dissolved solids (TDS), evapotranspiration, and depression volume. Nevertheless, rainfall, slope, land-use, geological lithology, and soil type are all important factors in different siting scenarios.

2.1. Criteria for Dam Siting

In this section, the 39 site selection criteria from the 25 sample papers are assessed and grouped into six categories: hydrological, geological, topographical, water quality, environmental, and socioeconomic. The first five categories of factors belong to the broad range of environmental influences, while the last—socioeconomic—falls under the category of humanities and social sciences.

2.2. The Influence of Dam Use on Criteria Selection

The objectives of decision makers vary widely, making it difficult to generalize a number of criteria for dam siting. Decision factors vary by purpose of the dam, from large hydroelectric power generation dams (e.g., the world-leading Three Gorges Dam) to small dams for irrigation and aquaculture.

Lempérière [29] considered the dams of the future as being multipurpose, while Abushandi [30] dentified five major purposes of modern hydraulic facilities: regulation and flood control under an extremely uneven spatial distribution of water resources, soil erosion and sediment control, drought control, irrigation, and hydropower generation. According to the latest data from the ICOLD 2020 statistics (**Table 1**) [16], irrigation is the major purpose, accounting for 47% and 24% of the sole-purpose and multiple-purpose statistics of dams, respectively. The next three major purposes are hydropower, water supply, and flood control.

Table 1. Purposes of dams.

Description	Sole-Purpose	Percentage	Multiple-Purpose	Percentage
flood control	**2539**	**8.82%**	**4911**	**0.19%**
fish farming	**42**	**0.15%**	**1487**	**0.06%**
hydropower	**6115**	**21.24%**	**4135**	**0.16%**
irrigation	**13580**	**47.17%**	**6278**	**0.24%**
navigation	**96**	**0.33%**	**579**	**0.02%**
recreation	**1361**	**4.73%**	**3035**	**0.11%**
water supply	**3376**	**11.73%**	**4587**	**0.17%**
tailing	**103**	**0.36%**	**12**	**0**
others	**1579**	**5.48%**	**1385**	**0.05%**

Source from [16].

The purpose determines the siting of different water collection structures and hydraulic facilities, such as retention basins, reservoirs, check dams, and rainwater harvesting structures (RWH), in order to achieve the spatial regulation of water resources. Check dams are built on seasonal streams, in order to intercept runoff from catchment-contributing areas and store it to optimize water utilization. RWH are important technologies for storing fresh water or recharging groundwater resources, for purposes such as water supply and agricultural irrigation. Singh [31] pointed out the differences between four types of catchment structures—RWH, check dams, percolation tanks, and farm ponds—in the process of determining sites (**Table 2**).

Table 2. Siting differences of catchment structures.

Type	Slope	Permeability	Land Use	Soil
RWH	<15%	low	near agricultural land	silt loam
check dams	<15%	less	barren, shrub, riverbed	sandy clay loam
percolation tank	<10%	high	barren, shrub	silt loam
farm ponds	<10%	moderate	barren, shrub	sandy clay loam

Source organized from [31].

In order to clarify the link between the siting factors and purposes of dams, information was collated from 25 sample papers, selected for the four main types of dam purposes: irrigation, hydropower, water supply, and flood control. **Table 3** reflects the frequencies (in percentage) of criteria used in different types of dams, where the total percentages of sub-criteria under each type of criteria in the four types of uses is 100%.

Table 3. Share of criteria in different purposes.

Criteria	Sub-Criteria	Irrigation	Hydropower	Water Supply	Flood Control	Total
topographical	slope	9%	15%	6%	16%	46%
	elevation/hypsometry	12%	8%	2%	3%	25%
	TWI	7%	-	-	-	7%
	TPI	-	-	4%	-	4%
	STI	-	-	4%	-	4%
	SPI	-	-	4%	-	4%
	TRI	-	-	4%	-	4%
	plan curvature	-	-	3%	-	3%
	profile curvature	-	-	3%	-	3%
hydrological	rainfall/precipitation	8%	2%	4%	9%	23%
	run-off/discharge	9%	-	8%	6%	23%
	drainage network order	5%	2%	5%	6%	18%
	drainage density	4%	2%	8%	-	14%
	catchment size	-	5%	4%	-	9%
	curve number grid	3%	-	5%	-	8%
	stream width	-	-	3%	2%	5%
geological	geology/lithology	9%	26%	6%	16%	57%
	distance to faults	-	18%	-	6%	24%
	distance to lineaments	-	9%	-	4%	13%
	tectonic zones	-	6%	-	-	6%
environmental	land cover	12%	8%	10%	10%	40%
	soil type	18%	-	5%	-	23%
	distance to the streams/river	6%	-	8%	-	14%
	groundwater	5%	-	12%	-	17%
	soil erosion	6%	-	-	-	6%

Criteria	Sub-Criteria	Irrigation	Hydropower	Water Supply	Flood Control	Total
water quality criteria	TDS	16%	-	16%	-	32%
	EC	8%	-	9%	-	17%
	SSP	8%	-	9%	-	17%
	PH	8%	-	9%	-	17%
	sediment	8%	-	9%	-	17%
socioeconomic	distance to roads	14%	2%	8%	4%	28%
	distance to materials/facilities	-	12%	-	5%	17%
	distance to cities/community	8%	6%	-	4%	18%
	distance to villages	3%	-	12%	3%	18%
	cost of construction	-	6%	-	3%	9%
	welfare	-	2%	-	-	2%
	culture	-	2%	-	-	2%
	people incorporation	-	6%	-	-	6%

The preferred factors in topography are slope and elevation, which highly influence the construction of irrigation, hydropower, and flood control dams, and which together account for 21%, 23%, and 19% of these three types of uses, respectively. Runoff and rainfall are important hydrological factors, which are more important in irrigation, water supply, and flood control, accounting for 17%, 12%, and 15% respectively. Geological factors are significantly more prominent in hydropower dams than for the other three purposes, up to 22%. The most important of the environmental factors are land-use and soil type, with higher percentages for irrigation and water supply, accounting for 30% and 15% respectively. Water quality indicators are concentrated in dam siting studies for water supply and irrigation purposes, hydropower and flood control types of dams are usually not involved in water quality standards. Finally, socioeconomic factors maintained relative importance in all purposes.

In the irrigation of crops and domestic water supply, water quality standards are important factors in the siting of surface and underground dams and rainwater harvesting structures [17][32]. To ensure crop safety and food security, water quality standards are important factors in dams for irrigation and water supply purposes. Poor water quality can negatively affect crop productivity, crop quality, and the public health of consumers and farmers, who are in direct contact with the irrigation water [33]. Globally, at least 20 million hectares of agricultural land are irrigated with treated or untreated wastewater [34], often containing excess sodium, magnesium, chloride, and boron, which affect soil alkalinity, phytotoxicity, and heavy metal content. However, geological factors play a dominant role in underground dams for such purposes, including sub-factors such as geological lithology, distance to faults, and distance to lineaments [35][36][37].

Hydroelectric power plants are dams designed to generate electricity by impounding rivers and converting the kinetic and potential energy of water into electrical energy using hydraulic turbines. According to the ICOLD, there will be 6115 dams for the purpose of power generation by 2020, of which 4135 will be multi-purpose dams [16]. The Three Gorges Dam, one of the world’s 10 largest dams, is a multi-purpose dam that not only provides a huge supply of electricity, but also provides excellent flood control [38]. The hydrological index [39], installed hydroelectric capacity [40], and potential power generation [41] are the main considerations in the siting design of hydropower dams. Rojanamon [42] proposed four directions of consideration for the siting factors of power stations—engineering, economic, environmental standards, and social impacts—and integrated the sub-factors of each direction, using GIS analysis to process to obtain the best potential siting area. Jafar [43], on the other hand, based on GIS and combined with the best-worst method (BWM) in MCDM, determined the optimal location model for hydropower dams, in terms of four aspects: physical, environmental, socioeconomic, and technological.

Floods and other water-related disasters account for 70% of all deaths associated with natural hazards [44], and flood control is one of the most important elements of sustainable water resource management [45]. Flood control dams can largely mitigate the catastrophic effects of floods. There are 2539 sole-purpose flood control dams and 4911 multi-purpose flood control dams worldwide [16]. In Egypt, which suffers from frequent seasonal flooding and droughts, as well as water demand for agricultural irrigation, the Aswan Dam largely regulates the extremely uneven distribution of water resources and achieves spatial and temporal deployment of the multi-year runoff from the Nile [46]. The critical factors for the siting of flood control dams include the design height of the dam, which is limited by topographic conditions, hydrological characteristics, and technology, where the height of the dam directly affects the possibility of flooding and, indirectly, the possibility of dam failure [47]. Sumi [48] also pointed out that the relationship between dam height and storage capacity varies greatly between countries, due to differences in geographic conditions; for example, the ratio of storage capacity to dam height is particularly large for dams in the United States, as these dams are often built in gently sloping rivers and wide river valleys. Patel [49] considered the good soil and water conservation functions of check dams to moderate flooding and soil erosion in small watersheds.

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