Handbook of Irrigation System Selection for Semi-Arid Regions

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Preface

Irrigation, the addition of water to lands via artificial means, is essential to profitable crop production in arid climates. Irrigated agriculture makes a major contribution to food security in the world. It uses more than 60%–70% of the water withdrawn from the world's water resources. The irrigated area at a global level represents around 20% of the total agricultural land and contributes 40% of the total food production. However, the performance of the majority of existing irrigation systems remains low. With increasing competition from other sectors, irrigation is under pressure to reduce its share of water use. The available world's water resources may not be able to meet various demands that will inevitably result in the irrigation of additional lands in order to achieve a sustainable food security. Due to the scarce water supply in the arid and semiarid climates, maximizing water use efficiency is critical. A shift from surface irrigation to high-tech irrigation technologies, e.g., sprinkle and drip irrigation systems, may yield significant water savings. Also, in lands where irrigation is introduced as a new practice, and in lands that currently irrigate, there must be irrigation method choices. Alternative irrigation methods may become more advantageous as the land organization, objectives, price, and cost change. The selection of irrigation methods will often be influenced by costs, energy, crop, soil texture, land topography, water supply, climate parameters, labor availability, etc. In other words, irrigation application method and system selection should result in optimum use of available water. The selection should be based on a full awareness of management considerations, such as water source and cost, water quantity and quality, irrigation effects on the environment, energy availability and cost, farm equipment, product marketability, and capital for irrigation system installation, operation, and maintenance. The purpose of this book is to bring together and integrate in a single text the subject matter that deals with the irrigation selection methods in arid and semiarid regions. The book is divided into four major sections dealing with the subject mentioned above and is intended for students, researchers, and professionals working on various aspects of irrigation method selection. Each section is composed of some chapters from various research groups and individuals working separately. Various case studies have been discussed in the chapters to present a general scenario of irrigation method selection management.

The first section highlights the parametric evaluation system for irrigation purposes. The parametric approach in the evaluation of land characteristics consists of a numeral rating of the different limitation levels of the land characteristics in a numerical scale from a maximum (normally 100) to a minimum value. If a land characteristic is optimal for the considered land utilization type, the maximum rating of 100 is attributed; if the same land characteristic is unfavorable, a minimal rating is applied. The aim of the parametric evaluation system is to provide a method that permits evaluation for irrigation purposes and that is based on the standard granulometrical and physicochemical characteristics of a soil profile. The section concludes with a review of the analytical hierarchy process integrated with GIS in an arid region for site selection of different irrigation systems.

Section two focuses on strategies for irrigation development and management. The deficit irrigation and partial root-zone drying irrigation systems are introduced in an arid area. Deficit irrigation (DI) and partial root-zone drying system (PRD) are strategies that involve this need that express irrigating the root zone with less water than the maximum evapotranspiration without loss in yield. Also, the solute leaching modeling under different irrigation regimes, soil moisture conditions, and organic fertilizer application in an arid area is introduced. This study examines the experimental and numerical modeling of soil solute leaching under different irrigation regimes, soil moisture conditions, and vermicompost application. Finally, this section concludes with an evaluation of the BUDGET model in simulating different strategies of irrigation in the west of Asia.

Section three highlights the multi-criteria decision-making for irrigation management in Europe. Decision-making related to irrigation management needs to be made in the context of multiple, usually conflicting, criteria that are coming from economic, environmental, and social domains. Multi-criteria decision analysis (MCDA) is the most often used approach for this type of decision-making, and different (MCDA) methods have been developed in the past. Hence, the first goal of this section was to make MCDA methods more intelligible (compared with the current level of understanding) to novice users within the field of irrigation management. Therefore, basic ideas as well as the main steps of selected (MCDA) methods are presented. Also, this section focuses on appraisal of agricultural lands for irrigation in the hot, subhumid region of Jayakwadi Command Area, Parbhani District, Maharashtra, India. The appraisal of basaltic clays soils under the hot, subhumid Marathwada region of Maharashtra is to tackle the recurring droughts and to explore answers to two vital questions such as water to every field and more crop per drop. The detailed land resource inventory is very essential for sustainable agriculture under irrigation with the help of the FAO and Sys parametric approach. This study showed the limits of soil–topography-yield variations in interpreting site-specific data for irrigation.

The final section starts with an evaluation of the soils delta of the Wadi Horan within the province of the Upper Euphrates, Iraq, for some technologies of irrigation systems. The results showed that drip irrigation proved more appropriate than the surface irrigation system in the study area. However, the main determinants of both methods were the characteristics of the physical environment and the topography of the study area. Drip irrigation research has proved that the conservation of soil and keeping it within the water field capacity will be more useful for application of the irrigation method, especially in climates and arid areas; therefore, it is recommended to exercise as the best way appropriate for the study area. Also, this section focuses on analysis and comparison of three irrigation systems (surface, sprinkle, and drip) in six major Iran watersheds by taking into account various soil and land characteristics. Details are given for the analysis of field data to compare the suitability of the land for surface, sprinkle, and drip irrigation systems. The analyzed parameters included soil and land characteristics. In this research, the land is not being "improved." The lands are just being ranked according to defined criteria to establish which irrigation method (surface, sprinkle, or drip) is best suited to the characteristics of the land. That is, the land suitability for irrigation methods (surface, sprinkle, or drip) is being compared while taking into consideration the characteristics of the land. The results obtained showed that sprinkle and drip irrigation methods are more suitable than a surface or gravity irrigation method for most of the soils tested. Moreover, because of the insufficiency of surface and groundwater resources, and the aridity and semiaridity of the climate in these areas, sprinkle and drip irrigation methods are highly recommended for a sustainable use of this natural resource; hence, the changing of current irrigation methods from gravity (surface) to pressurized (sprinkle and drip) in the study area are proposed.

It is evident but nevertheless worth mentioning that all the chapters have been prepared by individuals who are experts in their fields. The views expressed in the book are those of the authors, and they are responsible for their statements. An honest effort has been made to check the scientific validity and justification of each chapter through several iterations. We, the editors, publisher, and the authors of the chapters, have put together a comprehensive reference handbook on irrigation method selection in arid and semiarid regions with a belief that this book will be of immense use to present and future colleagues who teach, study, research, and/or practice in this particular field.

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Saeid Eslamian is a full professor of environmental hydrology and water resources engineering in the Department of Water Engineering at Isfahan University of Technology, where he has been since 1995. His research focuses mainly on statistical and environmental hydrology in a changing climate. In recent years, he has worked on modeling natural hazards, including floods, severe storms, wind, drought, pollution, water reuses, sustainable development and resiliency, etc. Formerly, he was a visiting professor at Princeton University, New Jersey, and ETH Zürich, Switzerland. On the research side, he started a research partnership in 2014 with McGill University, Canada. He has contributed to more than 600 publications in journals, books, and technical reports. He is the founder and chief editor of both the *International Journal of Hydrology Science and Techno*logy (IJHST) and the *Journal of Flood Engineering* (JFE). Professor Eslamian is now associate editor of four important publications: *Journal of Hydrology* (Elsevier), *Ecohydrology & Hydrobiology* (Elsevier), *Journal of Water Reuse and Desalination* (IWA), and *Journal of the Saudi Society of Agricultural Sciences* (Elsevier).

Professor Eslamian is the author of approximately 35 books and 180 chapter books. Dr. Eslamian's professional experience includes membership on editorial boards, and he is a reviewer of approximately 100 Web of Science (ISI) journals, including the ASCE *Journal of Hydrologic Engineering*, ASCE *Journal of Water Resources Planning and Management*, ASCE *Journal of Irrigation and Drainage Engineering*, *Advances in Water Resources*, *Groundwater*, *Hydrological Processes*, *Hydrological Sciences Journal*, *Global Planetary Changes*, *Water Resources Management*, *Water Science and Technology*, *Ecohydrology*, *Journal of American Water Resources Association*, *American Water Works Association Journal*, etc. UNESCO also nominated him for a special issue of the *Ecohydrology & Hydrobiology* journal in 2015. Professor Eslamian was selected as an outstanding reviewer for the *Journal of Hydrologic Engineering* in 2009 and received the EWRI/ASCE Visiting International Fellowship in Rhode Island (2010). He was also awarded outstanding prizes from the Iranian Hydraulics Association in 2005 and Iranian Petroleum and Oil Industry in 2011. Professor Eslamian has been chosen as a distinguished researcher of Isfahan University of

Technology (IUT) and Isfahan Province in 2012 and 2014, respectively. In 2016, he was a candidate for national distinguished researcher in Iran.

He has also been the referee of many international organizations and universities. Some examples include the U.S. Civilian Research and Development Foundation (USCRDF), the Swiss Network for International Studies, the Majesty Research Trust Fund of Sultan Qaboos University of Oman, the Royal Jordanian Geography Center College, and the Research Department of Swinburne University of Technology of Australia. He is also a member of the following associations: American Society of Civil Engineers (ASCE), International Association of Hydrologic Science (IAHS), World Conservation Union (IUCN), GC Network for Drylands Research and Development (NDRD), International Association for Urban Climate (IAUC), International Society for Agricultural Meteorology (ISAM), Association of Water and Environment Modeling (AWEM), International Hydrological Association (STAHS), and UK Drought National Center (UKDNC).

Professor Eslamian finished Hakimsanaei High School in Isfahan in 1979. After the Islamic Revolution, he was admitted to IUT for a BS in water engineering and graduated in 1986. After graduation, he was offered a scholarship for a master's degree program at Tarbiat Modares University, Tehran. He finished his studies in hydrology and water resources engineering in 1989. In 1991, he was awarded a scholarship for a PhD in civil engineering at the University of New South Wales, Australia. His supervisor was Professor David H. Pilgrim, who encouraged him to work on "Regional Flood Frequency Analysis Using a New Region of Influence Approach." He earned a PhD in 1995 and returned to his home country and IUT. In 2001, he was promoted to associate professor and in 2014 to full professor. For the past 24 years, he has been nominated for different positions at IUT, including university president consultant, faculty deputy of education, and head of the department. Professor Eslamian is now director for the Center of Excellence in Risk Management and Natural Hazards (RiMaNaH).

Professor Eslamian has made three scientific visits to the United States, Switzerland, and Canada in 2006, 2008, and 2015, respectively. In the first, he was offered the position of visiting professor by Princeton University and worked jointly with Professor Eric F. Wood at the School of Engineering and Applied Sciences for one year. The outcome was a contribution in hydrological and agricultural drought interaction knowledge by developing multivariate L-moments between soil moisture and low flows for northeastern U.S. streams. Recently, Professor Eslamian has published the editorship of 12 handbooks published by the Taylor & Francis Group (CRC Press): the three-volume *Handbook of Engineering Hydrology* in 2014, *Urban Water Reuse Handbook* in 2016, *Underground Aqueducts Handbook* (2017), the three-volume *Handbook of Drought and Water Scarcity* (2017), *Constructed Wetlands: Hydraulic Design* (2020), and the three-volume *Flood Handbook* (2020). He has also published the two-volume *Handbook of Water Harvesting and Conservation* (2020) by Wiley-Blackwell and the New York Academy of Sciences. In addition, *An Evaluation of Groundwater Storage Potentials in a Semiarid Climate* by Nova Science Publishers is also his joint book publication in 2019.

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Faezeh Eslamian holds a PhD in Bioresource Engineering from McGill University. Her research focuses on the development of a novel lime-based product to mitigate phosphorus loss from agricultural fields. Faezeh completed her bachelor's and master's degrees in Civil and Environmental Engineering from Isfahan University of Technology, Iran, where she evaluated natural and low-cost absorbents for the removal of pollutants such as textile dyes and heavy metals. Furthermore, she has conducted research on the worldwide water quality standards and wastewater reuse guidelines. She is an experienced multidisciplinary researcher with interest in soil and water quality, environmental remediation, water reuse, and drought management.

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Section I

Introduction

1 Introduction of Parametric Evaluation System for Irrigation Purposes

Mohammad Albaji, Saeid Eslamian, Abd Ali Naseri, and Faezeh Eslamian

CONTENTS

1.1 INTRODUCTION

In arid and semiarid climates, where the study area has been carried out, according to the results of the climate classification, the most relevant method to improve agriculture production is irrigation. An adequate supply of water is important for plant growth. When rainfall is not sufficient, crops must be provided with additional water from other sources. To decide where to apply irrigation and to choose the appropriate method, natural conditions, previous experience with irrigation, required labor inputs, type of crops and technology, costs and benefits, and other factors should be considered. As a matter of fact, irrigation practices can be very expensive and may cause negative phenomena, such as soil erosion and salinization. For this reason, evaluation systems for irrigation purposes must be developed. The prevailing semiarid climatic conditions and an insufficient amount of precipitation are a major limitation to crop yields in the study area. Agricultural fields are often required to be irrigated if food security is to be ensured, especially with vegetable crops. The purpose of land suitability for irrigation was therefore aimed at visualizing parcels of land that may be conveniently irrigated for agricultural production based on the physical and chemical parameters of the underlying soil (IAO 2007).

On the other hand, food security and stability in the world greatly depend on the management of natural resources. Due to the depletion of water resources and an increase in population, the extent of irrigated area per capita is declining, and irrigated lands now produce 40% of the food supply (Hargreaves and Mekley 1998). Consequently, available water resources will not be able to meet various demands in the near future, and this will inevitably result in the seeking of newer lands for irrigation in order to achieve sustainable global food security. Land suitability, by definition, is the natural capability of a given land to support a defined use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for a defined use.

According to FAO methodology (1976), land suitability is strongly related to “land qualities” including erosion resistance, water availability, and flood hazards, which are in themselves immeasurable qualities. Since these qualities are derived from “land characteristics,” such as slope angle and length, rainfall, and soil texture—which are measurable or estimable—it is advantageous to use the latter indicators in the land suitability studies and then use the land parameters for determining the land suitability for irrigation purposes. Sys et al. (1991a) suggested a parametric evaluation system for irrigation methods that was primarily based upon physical and chemical soil properties (Dengiz 2006; Liu et al. 2006; Naseri et al. 2009; Albaji 2010; Albaji et al. 2012).

1.2 INTRODUCTION OF PARAMETRIC EVALUATION SYSTEM FOR IRRIGATION PURPOSES

1.2.1 General Principles

The parametric approach in the evaluation of land characteristics consists of a numeral rating of the different limitation levels of the land characteristics in a numerical scale from a maximum (normally 100) to a minimum value. If a land characteristic is optimal for the considered land utilization type, the maximum rating of 100 is attributed; if the same land characteristic is unfavorable, a minimal rating is applied.

The successful application of the system implies the respect of the following rules:

1. The number of land characteristics to consider has to be reduced to a strict minimum to avoid repetition of related characteristics in the formula, leading to a depression of the land index. Therefore, all land qualities expressed by one characteristic should be rated together. As such, the single rating of texture should be done with regard to the capacity to retain nutrients, water availability, permeability, and one should avoid introducing separate ratings for these single qualities.
2. An important characteristic is rated in a wide scale (100–25), a less important characteristic in a narrower scale (100–60). This introduces the concept of a weighting factor. Example: studying the suitability for irrigation the very important factor of texture is rated from 100 to 25, the less important factor of calcium carbonate content from 100 to 80.
3. The rating of 100 is applied for optimal development or maximum appearance of a characteristic. If, however, some characteristics are better than the usual optimal, the maximum rating can be chosen higher than 100. Example: if the most common organic carbon content of the top 15 cm in a specific area varies from 1% to 1.5%, the rating of 100 is applied for that carbon level. Soils with more than 1.5% O.C are attributed a rating of more than 100 for organic matter.
4. The depth to which the land index has to be calculated must be defined for each land utilization type. If one considers that for a specific land utilization type all horizons have a similar importance, the weighted average of the profile section until the considered depth is calculated for each characteristic. If, on the other hand, one considers that the importance of a horizon becomes greater when this position is nearer to the surface, a different proportional rating can be given to the depth sections of the profile in such a way that they increase when approaching the surface. Therefore, the profile can be subdivided into equal sections; to each of these sections one attributes a “depth correction index” (weighting factor) starting with a minimum value in depth and becoming gradually greater when approaching the surface section.

The depth to be considered should coincide with the normal depth of the root system in a deep soil. The weighting factors or depth correction indices suggested are given in Table 1.1.

TABLE 1.1
Number of Sections and Weighting Factors for Different Depths

Depth (cm)	Number of Equal Sections	Weighting Factors
125–150	6	2.00,1.50,1.00,0.75,0.50,0.25
100–125	5	1.75,1.50,1.00,0.50,0.25
75–100	4	1.75,1.25,0.75,0.25
50–75	3	1.50,1.00,0.50
25–50	2	1.25,0.75
0–25	1	1.00

A land suitability classification for surface, sprinkler, and drip irrigation was provided. It was carried out by a parametric system according to the methodology proposed by Sys et al. (1991a). The aim of this parametric evaluation system (Sys et al. 1991a) is to provide a method that permits evaluation for irrigation purposes, and that is based on the standard granulometrical and physico-chemical characteristics of a soil profile. It has been estimated that the soil as a medium for plant growth under irrigation should in the first place provide the necessary water and plant nutrients in an available form, and in the most economic way. A method to improve the agriculture production can be the application of irrigation; the decision regarding if it is possible, how and in which area, should be taken according to economic and agronomic factors. In order to avoid bad effects such as salinization or water stagnating and in order to estimate the impact of agronomic parameters, an evaluation of irrigation suitability has to be applied (IAO 2002).

In the system proposed by Sys et al. (1991b), the factors affecting soil suitability for irrigation purposes can be subdivided into four groups:

1. PHYSICAL PROPERTIES determine the soil-water relationship in the solum such as permeability and available water content both related to texture, structure, and soil depth; also, $CaCO_3$ status could be considered here.
2. CHEMICAL PROPERTIES interfere in the salinity/alkalinity status, such as soluble salts and exchangeable Na.
3. DRAINAGE PROPERTIES.
4. ENVIRONMENTAL FACTORS, such as slope.

The soil drainage, depth, slope, texture, electric conductivity, and $CaCO_3$ content were the considered parameters. The parametric method is based on the concept that index rating (capability index for irrigation) is obtained by multiplying all the parameters involved in the evaluation. Thus, any factor may dominate or control the final rating. Recall that according to the specific suitability evaluation, this multiplication is applied considering all parameters involved in the evaluation.

The different land characteristics that influence the soil suitability for irrigation are rated, and a capability index for irrigation (Ci) is calculated according to the formula:

$$Ci = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100} \tag{1.1}$$

where:

Ci = Capability index for irrigation
A = Soil texture rating
B = Soil depth rating
C = Calcium carbonate content rating
D = Electrical conductivity rating
E = Drainage rating
F = Slope rating.

TABLE 1.2
Suitability Classes for the Irrigation Capability Indices (Ci) Classes

Capability Index	Definition	Symbol
>80	Highly suitable	S_1
60–80	Moderately suitable	S_2
45–59	Marginally suitable	S_3
30–44	Currently not suitable	N_1
<29	Permanently not suitable	N_2

The suitability classes are defined according to the value of the capability (or suitability) index (Ci) (Table 1.2).

The classes S_2 to N_2 can have the following subclasses with regard to the nature of the limiting factors:

s = Limitations due to physical soil properties (A, B, C)
n = Limitations due to salinity/alkalinity (D)
w = Wetness limitations (E)
t = Topographic limitations (F).

The land suitability classification consists of assessing and grouping the land types in orders and classes according to their aptitude (FAO methodology 1976). The order defines the suitability and is expressed by:

- S (suitable) characterizes a land were sustainable use giving good benefits is expected.
- N (not suitable) indicates a land with qualities that do not allow the considered type of use or are not enough for sustainable outcomes.

The classes (S_1, S_2 and S_3 for suitable order; N_1 and N_2 for unsuitable order) express the degrees of suitability or unsuitability. Thus, there are five classes according to Table 1.3 for irrigation.

1.2.2 Factors Influencing the Soil Suitability for Irrigation

1.2.2.1 Texture (A)

Texture is rated (Table 1.4) with regard to permeability and available water content, and weighted average is calculated for the upper 1.5 m.

TABLE 1.3
Land Suitability Classes

Order	Class	Description
Suitable	S_1 (Highly suitable)	Land having no or insignificant limitations for irrigation
	S_2 (Moderately suitable)	Land having minor limitations for irrigation
	S_3 (Marginally suitable)	Land having moderate limitations for irrigation
Not Suitable	N_1 (Currently not suitable)	Land having severe limitations for irrigation but can be improved by specific management
	N_2 (Permanently not suitable)	Land having such severe limitations for irrigation that are very difficult to overcome

TABLE 1.4
Rating of Textural Classes for Irrigation

	Rating for Surface Irrigation					Rating for Sprinkler Irrigation					Rating for Drip Irrigation				
	Fine Gravel (%)			Coarse Gravel (%)		Fine Gravel (%)			Coarse Gravel (%)		Fine Gravel (%)			Coarse Gravel (%)	
Tex[a]	**<15**	**15–40**	**40–75**	**15–40**	**40–75**	**<15**	**15–40**	**40–75**	**15–40**	**40–75**	**<15**	**15–40**	**40–75**	**15–40**	**40–75**
CL[b]	100	90	80	80	50	100	90	80	80	50	100	90	80	80	50
SiL	100	90	80	80	50	100	90	80	80	50	100	90	80	80	50
SCL	95	85	75	75	45	95	85	75	75	45	95	85	75	75	45
L	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
SiL	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
Si	90	80	70	70	45	90	80	70	70	45	90	80	70	70	45
SiC	85	95	80	80	40	85	95	80	80	40	85	95	80	80	40
C	85	95	80	80	40	85	95	80	80	40	85	95	80	80	40
SC	80	90	75	75	35	95	90	80	75	35	95	90	85	80	35
SL	75	65	60	60	35	90	75	70	70	35	95	85	80	75	35
LS	55	50	45	45	25	70	65	50	55	30	85	75	55	60	35
S	30	25	25	25	25	50	45	40	30	30	70	65	50	35	35

[a] Tex: Textural Classes.
[b] CL: Clay Loam; SiL: Silty Loam; SCL: Sandy Clay Loam; L: Loam; SiL: Silty Loam; Si: Silty; SiC: Silty Clay; C: Clay; SC: Sandy Clay; SL: Sandy Loam; LS: Loamy Sand; S: Sandy.

1.2.2.2 Soil Depth (B)

Soil depth is defined as the thickness of the loose soil above a limiting layer, which is impenetrable for roots or percolating water. The most common types of such limiting layers are:

- An unconsolidated gravelly or stony horizon with at least 75% coarse fragments (by weight)
- A continuous, more or less consolidated, calcium carbonate or gypsiferous layer with a minimum thickness of 30 cm, and containing at least 75% calcium carbonate or gypsum (or both together)
- A continuous hard rock or hardpan more than 10 cm thick.

Table 1.5 gives the soil depth ratings used for the suitability classification for irrigation.

1.2.2.3 Calcium Carbonate Status (C)

The presence of free lime in the soil has not only an effect on the structural arrangement of the soil mass, interfering thus directly in water infiltration rate and evaporation processes, but also plays a role in the soil reaction and the physicochemical constitution of the solum as a whole. Thus, the calcium carbonate status influences at the same time the soil-water relationship of the soil and its available nutrient supply for plant growth.

A moderate $CaCO_3$ content has a favorable effect on soil suitability for irrigation. Table 1.6 gives the $CaCO_3$ ratings used in the system. The $CaCO_3$ content of the profile represents the weighted average over the superficial 150 cm.

1.2.2.4 Soil Salinity (D)

The unfavorable effect of salinity hazards depends on soil texture. Ratings are given in Table 1.7. The values for electrical conductivity (Ec) are weighted averages for the upper 150 cm.

1.2.2.5 Drainage (E)

Imperfect or poor drainage is an evident limiting factor. The drainage problems for irrigation are related to soil texture and to the depth and salinity status of the groundwater. Ratings are given in Table 1.8.

TABLE 1.5
Rating of Soil Depth for Irrigation

Soil Depth (cm)	Rating for Surface Irrigation	Rating for Sprinkler Irrigation	Rating for Drip Irrigation
<20	25	30	35
20–50	60	65	70
50–80	80	85	90
80–100	90	95	100
>100	100	100	100

TABLE 1.6
Rating of $CaCO_3$ for Irrigation

$CaCO_3$ (%)	Rating for Surface Irrigation	Rating for Sprinkler Irrigation	Rating for Drip Irrigation
<0.3	90	90	90
0.3–10	95	95	95
10–25	100	100	95
25–50	90	90	80
>50	80	80	70

TABLE 1.7
Rating of Salinity for Irrigation

	Rating for Surface Irrigation		Rating for Sprinkler Irrigation		Rating for Drip Irrigation	
EC (ds. m^{-1})	C, SiC, SiCL, S, SC Textures[a]	Other Textures	C, SiC, SiCL, S, SC Textures	Other Textures	C, SiC, SiCL, S, SC Textures	Other Textures
<4	100	100	100	100	100	100
4–8	90	95	95	95	95	95
8–16	80	50	85	50	85	50
16–30	70	30	75	35	75	35
>30	60	20	65	25	65	25

[a] C: Clay; SiC: Silty Clay; SiCL: Silty Clay Loam; S: Sand; SC: Sandy Clay.

TABLE 1.8
Rating of Drainage Classes for Irrigation

	Rating for Surface Irrigation		Rating for Sprinkler Irrigation		Rating for Drip Irrigation	
Drainage Classes	C, SiC, SiCL, S, SC Textures[a]	Other Textures	C, SiC, SiCL, S, SC Textures	Other Textures	C, SiC, SiCL, S, SC Textures	Other Textures
Well Drained	100	100	100	100	100	100
Moderately Drained	80	90	90	95	100	100
Imperfectly Drained	70	80	75	85	80	90
Poorly Drained	60	65	65	70	70	80
Very Poorly Drained	40	65	45	65	50	65
Drainage Status Not Known	70	80	70	80	70	80

[a] C: Clay; SiC: Silty Clay; SiCL: Silty Clay Loam; S: Sand; SC: Sandy Clay.

TABLE 1.9
Rating of Slope for Irrigation

	Rating for Surface Irrigation		Rating for Sprinkler Irrigation		Rating for Drip Irrigation	
Slope Classes (%)	Non-terraced	Terraced	Non-terraced	Terraced	Non-terraced	Terraced
0–1	100	100	100	100	100	100
1–3	95	95	100	100	100	100
3–5	90	95	95	100	100	100
5–8	80	90	85	95	90	100
8–16	70	80	75	85	80	90
16–30	50	65	55	70	60	75
>30	30	45	35	50	40	55

1.2.2.6 Slope (F)

The dominant topographic factor that influences the irrigation suitability concerns the slope. Rating the overall slope can be considered as sufficient. It is also estimated that a difference should be made between terraced and nonterraced slopes. Ratings are given in Table 1.9.

TABLE 1.10
Some of Physicochemical Characteristics for Reference Profiles of Soil Series Coded 1

Soil Depth (cm)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	ECe ($ds.m^{-1}$)	Drainage Classes	Slope (%)
0–15	20	64	16	40.50	1.00	Moderately Drained	2–5
15–52	18	55	27	44.30	1.30	Moderately Drained	2–5
52–150	15	54	31	43.60	1.50	Moderately Drained	2–5

Example

Calculating the Ci and land suitability classes of different irrigation methods based on the parametric evaluation in Dasht Bozorg Plain, Soil series coded 1.

Some of the physicochemical characteristics for reference profiles of soil series coded 1 are shown in Table 1.10.

1. The textural rating of the profile calculates as follows:

First section (0–25 cm)	15 × 2 × 20	= 600
	10 × 2 × 18	= 360
Second section (25–50 cm)	25 × 1.5 × 18	= 675
Third section (50–75 cm)	2 × 1 × 18	= 36
	23 × 1 × 15	= 345
Fourth section (75–100 cm)	25 × 0.75 × 15	= 281.25
Fifth section (100–125 cm)	25 × 0.5 × 15	= 187.50
Sixth section (125–150 cm)	25 × 0.25 × 15	= 93.75
	Sum	= 2,578.50

Use six sections of 25 cm with weighting factors: 2.00, 1.50, 1.00, 0.75, 0.50, and 0.25.
The amount of sand particle in the profile calculates as follows:
The amount of sand particle in the profile: (2,578.5)/(150) = 17/19%
The amount of silt particle in the profile calculates as follows:

First section (0–25 cm)	15 × 2 × 64	= 1,920
	10 × 2 × 55	= 1100
Second section (25–50 cm)	25 × 1.5 × 55	= 2,062.50
Third section (50–75 cm)	2 × 1 × 55	= 110
	23 × 1 × 54	= 1,242
Fourth section (75–100 cm)	25 × 0.75 × 54	= 1,012.50
Fifth section (100–125 cm)	25 × 0.5 × 54	= 675
Sixth section (125–150 cm)	25 × 0.25 × 54	= 337.50
	Sum	= 8,459.50

The amount of silt particle in the profile: (8,459.5)/(150) = 56.39%
The amount of sand particle and silt particle in the profile are 17/19% and 56.39%, respectively; therefore, by referring to the triangular soil texture, the soil texture of profile is **silty loam**.
The rating of silty loam textures for different irrigation systems are as follows (Refer to Table 1.4):

Soil Texture	Rating for Surface Irrigation	Rating for Sprinkler Irrigation	Rating for Drip Irrigation
Silty Loam	100	100	100

2. The soil depth ratings for different irrigation systems are as follows (Refer to Table 1.5):

Soil Depth (cm)	Rating for Surface Irrigation	Rating for Sprinkler Irrigation	Rating for Drip Irrigation
150	100	100	100

3. The $CaCO_3$ (%) in the profile calculates as follows:

First section (0–25 cm)	15 × 2 × 40.50	= 1215
	10 × 2 × 44.30	= 886
Second section (25–50 cm)	25 × 1.5 × 44.30	= 1661.25
Third section (50–75 cm)	2 × 1 × 44.30	= 88.60
	23 × 1 × 43.60	= 1002.80
Fourth section (75–100 cm)	25 × 0.75 × 43.60	= 817.50
Fifth section (100–125 cm)	25 × 0.5 × 43.60	= 545
Sixth section (125–150 cm)	25 × 0.25 × 43.60	= 272.50
	Sum	= 6488.65

The $CaCO_3$ (%) in the profile: (6488.65)/(150) = 43.25%
The ratings of $CaCO_3$ (%) for different irrigation systems are as follows (Refer to Table 1.6):

$CaCO_3$ (%)	Rating for Surface Irrigation	Rating for Sprinkler Irrigation	Rating for Drip Irrigation
43.25	90	90	80

4. The electrical conductivity ($ds.m^{-1}$) in the profile calculates as follows:

First section (0–25 cm)	15 × 2 × 1.00	= 30
	10 × 2 × 1.30	= 26
Second section (25–50 cm)	25 × 1.5 × 1.30	= 48.75
Third section (50–75 cm)	2 × 1 × 1.30	= 2.60
	23 × 1 × 1.50	= 34.50
Fourth section (75–100 cm)	25 × 0.75 × 1.50	= 28.12
Fifth section (100–125 cm)	25 × 0.5 × 1.50	= 18.75
Sixth section (125–150 cm)	25 × 0.25 × 1.50	= 9.37
	Sum	= 198.10

The electrical conductivity ($ds.m^{-1}$) in the profile: (198.10)/(150) = 1.32%
The ratings of electrical conductivity ($ds.m^{-1}$) for different irrigation systems are as follows (Refer to Table 1.7):

ECe ($ds.m^{-1}$)	Rating for Surface Irrigation	Rating for Sprinkler Irrigation	Rating for Drip Irrigation
1.32	100	100	100

5. The ratings of drainage classes for different irrigation systems are as follows (Refer to Table 1.8):

Drainage Classes	Rating for Surface Irrigation	Rating for Sprinkler Irrigation	Rating for Drip Irrigation
Moderately Drained	90	95	100

6. The ratings of slope for different irrigation systems are as follows (Refer to Table 1.9):

Slope (%)	Rating for Surface Irrigation	Rating for Sprinkler Irrigation	Rating for Drip Irrigation
2–5	97.50	97.50	100

7. Capability index for surface, sprinkler, and drip irrigation systems is calculated according to the formula:

$$Ci = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100}$$

7.1. The capability index for surface irrigation system is:

$$Ci = 100 \times (100/100) \times (90/100) \times (100/100) \times (90/100) \times (97.5/100) = 74.92$$

The suitability class for surface irrigation system is (Refer to Table 1.2): S_2
The subclasses for surface irrigation system are:
s = Limitations due to $CaCO_3$ (%) content
w = Drainage limitations.
Finally, the land suitability class for surface irrigation system is: S_{2sw}

7.2. The capability index for sprinkler irrigation system is:

$$Ci = 100 \times (100/100) \times (90/100) \times (100/100) \times (95/100) \times (97.5/100) = 83.36$$

The suitability class for sprinkler irrigation system is (Refer to Table 1.2): S_1

7.3. The capability index for drip irrigation system is:

$$Ci = 100 \times (100/100) \times (80/100) \times (100/100) \times (100/100) \times (100/100) = 80.00$$

The suitability class for drip irrigation system is (Refer to Table 1.2): S_1

1.3 LAND SUITABILITY MAPS

In order to develop land suitability maps for different irrigation methods, a semi-detailed soil map (for all plains) was used, and all the data for soil characteristics were analyzed and incorporated into the map using ArcGIS 9.2 software.

The digital soil map base preparation was the first step toward the presentation of a GIS module for land suitability maps for different irrigation systems (Albaji et al. 2010, 2014). The soil map was then digitized and a database prepared. The total different polygons or soil series were determined in the base map. Soil characteristics were also given for each soil series. These values were used to generate the land suitability maps for surface, sprinkle, and drip irrigation systems using geographic information systems (Albaji et al. 2008; Landi et al. 2008; Rezania et al. 2009; Jovzi et al. 2012).

Suitability classes are defined by considering the value of the capability indices and presented in Table 1.2. Each of the land and soil characteristics with associated attribute data are digitally encoded in a GIS database to eventually generate six thematic layers.

Data are digitally encoded in a GIS database to eventually generate six thematic layers. The diagnostic factors of each thematic layer were assigned values of factor rating identified in Tables 1.3 through 1.8. The parametric model is defined using the value of factor rating as formula (1.1). These six layers were then spatially overlaid to produce resultant layers. In Figure 1.1, a schematic chart of GIS application for land suitability map for different irrigation methods is shown.

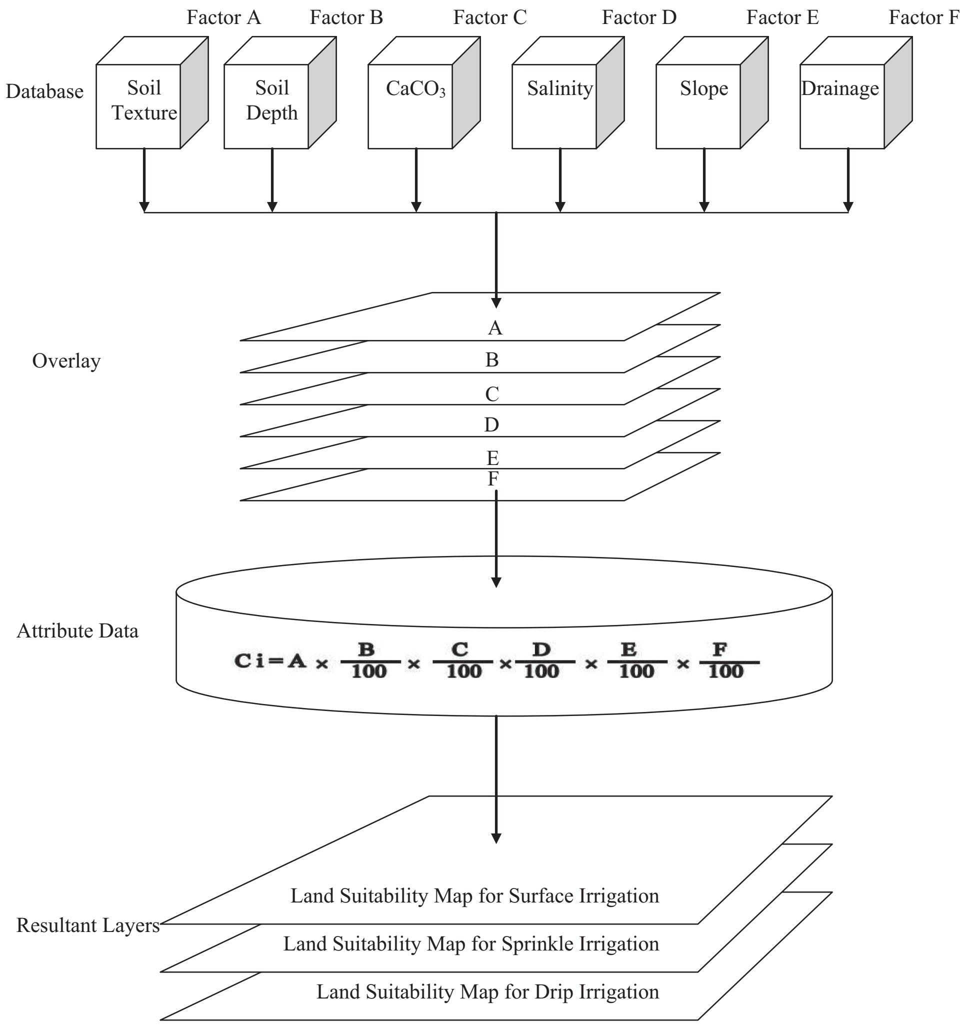

FIGURE 1.1 Schematic chart of GIS application for land suitability map for different irrigation methods.

1.4 CONCLUSIONS

The parametric approach in the evaluation of land characteristics consists of a numeral rating of the different limitation levels of the land characteristics in a numerical scale from a maximum (normally 100) to a minimum value. If a land characteristic is optimal for the considered land utilization type, the maximum rating of 100 is attributed; if the same land characteristic is unfavorable, a minimal rating is applied. The successful application of the system implies the respect of the following rules: (a) The number of land characteristics to consider has to be reduced to a strict minimum to avoid repetition of related characteristics in the related formula; (b) An important characteristic is rated in a wide scale (100–25), a less important characteristic in a narrower scale (100–60); (c) The rating of 100 is applied for optimal development or maximum appearance of a characteristic; (d) The depth to which the land index has to be calculated must be defined for each land utilization type; and (e) The depth to be considered should coincide with the normal depth of the root system in a deep soil.

In the proposed system, the factors affecting soil suitability for irrigation purposes can be subdivided into four groups: physical properties, chemical properties, drainage properties, and environmental properties. The soil drainage, depth, slope, texture, electric conductivity, and $CaCO_3$ content were the considered parameters. The different land characteristics that influence the soil suitability for irrigation are rated, and a capability index for irrigation (Ci) is calculated according to the formula.

In order to develop land suitability maps for different irrigation methods, a semi-detailed soil map was used, and all the data for soil characteristics were analyzed and incorporated into the map using ArcGIS 9.2 software. The soil map was then digitized and a database prepared. The total different polygons or soil series were determined in the base map. Soil characteristics were also given for each soil series. These values were used to generate the land suitability maps for surface, sprinkle, and drip irrigation systems using geographic information systems.

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2 Using Analytical Hierarchy Process Integrated with GIS in an Arid Region for Site Selection of Different Irrigation Systems

Lamya Neissi, Saeed Boroomand Nasab, and Mohammad Albaji

CONTENTS

2.1 INTRODUCTION

Multi-criteria decision-making combines technically feasible, economically viable, socially acceptable, and environmental friendly criteria with respect to their importance of suitability. Then these criteria are analyzed by using GIS and treated spatially to generate regions susceptibility maps (Anane et al. 2012).

Multi-criteria decision-making (MCDM) methods are recommended for considering different parameters that can affect the appropriate irrigation system site selection. Integrating MCDM with a geographical information system (GIS) has been used in site selection assessment for proper decision-making to increase the potential of environmental resources in arid and semiarid regions.

Saaty (1997) defined analytical hierarchy process (AHP) as one of the MCDM methods that changes a complex multi-criteria decision problem into a simple hierarchy.

AHP has several advantages including overspecification of judgment, built-in consistency tests, and use of appropriate measurement scales and applicability in elicitation of utility functions (Chen and Huang 2004).

Site selection by using AHP integrated with GIS has been applied for many environmental resources (Assefa et al. 2018; Pan and Xu 2018; Garcia et al. 2014; Akinci et al. 2013; Anane et al. 2012; Chandio et al. 2011; Montazar and Zadbagher 2010; Gilliams et al. 2005). AHP solved a variety of complex environmental problems including land suitability (Feizizadeh and Blaschke 2013; Mendas and Delali 2012; Cengiz and Akbulak 2009), selecting strategies (Abdollahzadeh et al. 2016), ranking different alternatives (Baffoe 2019; Sharma et al. 2018), selecting best crop pattern (Dekamin et al. 2018; Werner et al. 2014), and flood hazard assessment (Phonphoton and Pharino 2019; Seejata et al. 2018). Due to the successful application of AHP in solving environmental and agricultural problems, this method was adopted to evaluate different irrigation systems for the most suitable regions for water-saving and higher irrigation system efficiency in the context of this study.

Maps contain valuable spatial information from a general point of view. In the case of water management for best irrigation system site selection in arid regions, using AHP integrated with GIS can be helpful. AHP assigns appropriate weight to each irrigation system according to considered criteria under drought conditions in arid regions; then GIS maps show the most suitable sites for each irrigation system due to assigned weights calculated by AHP.

The present study aims to select the most suitable sites for different traditional and modernized irrigation systems according to analytical hierarchy process and GIS maps in arid regions. The methodology uses easy-to-get data from the official institution of the Khuzestan Water and Power Authority (KWPA) and available satellite images.

2.2 MATERIALS AND METHOD

2.2.1 Characterization of the Study Area

The Izeh Plain is located in Khuzestan Province at the southwestern part of Iran, 49°45′ to 49°59′ E and 31°46′ to 31°57′ N with 11,080.5 km^2 area (Figure 2.1). The climate is arid with 1,685 mm as annual average evaporation at Izeh (city). The average temperature is 30°C. The Izeh Plain is considered a flat area with a slope that varies from 2% to 5% and loamy soil texture. Agriculture is the basic economic activity in the Izeh Plain. Over much of the Izeh Plain, the use of surface irrigation systems has been applied specifically for field crops to meet the water demand of both summer and winter crops. The major irrigated broad-acre crops grown in this area are wheat, barley, and maize, in addition to fruits, melons, watermelons, and vegetables such as tomatoes and cucumbers. But like other plains in Khuzstan Province, the important major crops in the Izeh Plain are wheat and barley (Albaji and Alboshokeh 2017; Behzad et al. 2009a, 2009b; Naseri et al. 2009; Albaji et al. 2012b).

Surface water used for irrigation is classified in the C3S1 water quality class (Anonymous 2017). Surface irrigation is the most important irrigation in the Izeh Plain, as well as other plains in Khuzstan Province; there are very few instances of sprinkle and drip irrigation on large area farms in this area (Albaji et al. 2008, 2012a, 2014a, 2014b, 2016; Boroomand Nasab et al. 2010; Rezania et al. 2009; Landi et al. 2008). For this research, irrigation systems such as solid set irrigation system, wheel move irrigation system, low-pressure irrigation system, surface irrigation system, and drip irrigation system were considered in selecting the most suitable sites for different irrigation systems in the Izeh Plain.

Two wetlands, Miangaran and Bondoun, are located in the Izeh Plain. The Miangaran wetland is located 1.5 km north of Izeh City with a 2,500 ha area, and the Bondoun wetland is located 3 km south of Izeh City with a 1,300 ha area. These two wetlands have important role in environmental conservation and surface water saving. Drought conditions of the Izeh Plain caused these wetlands to become dry over the years.

The Zagros Mountains are located in the north and south parts of the Izeh Plain. Highest elevation of the plain is 342 m in the mountainous area, which can affect site selection of the best irrigation system.