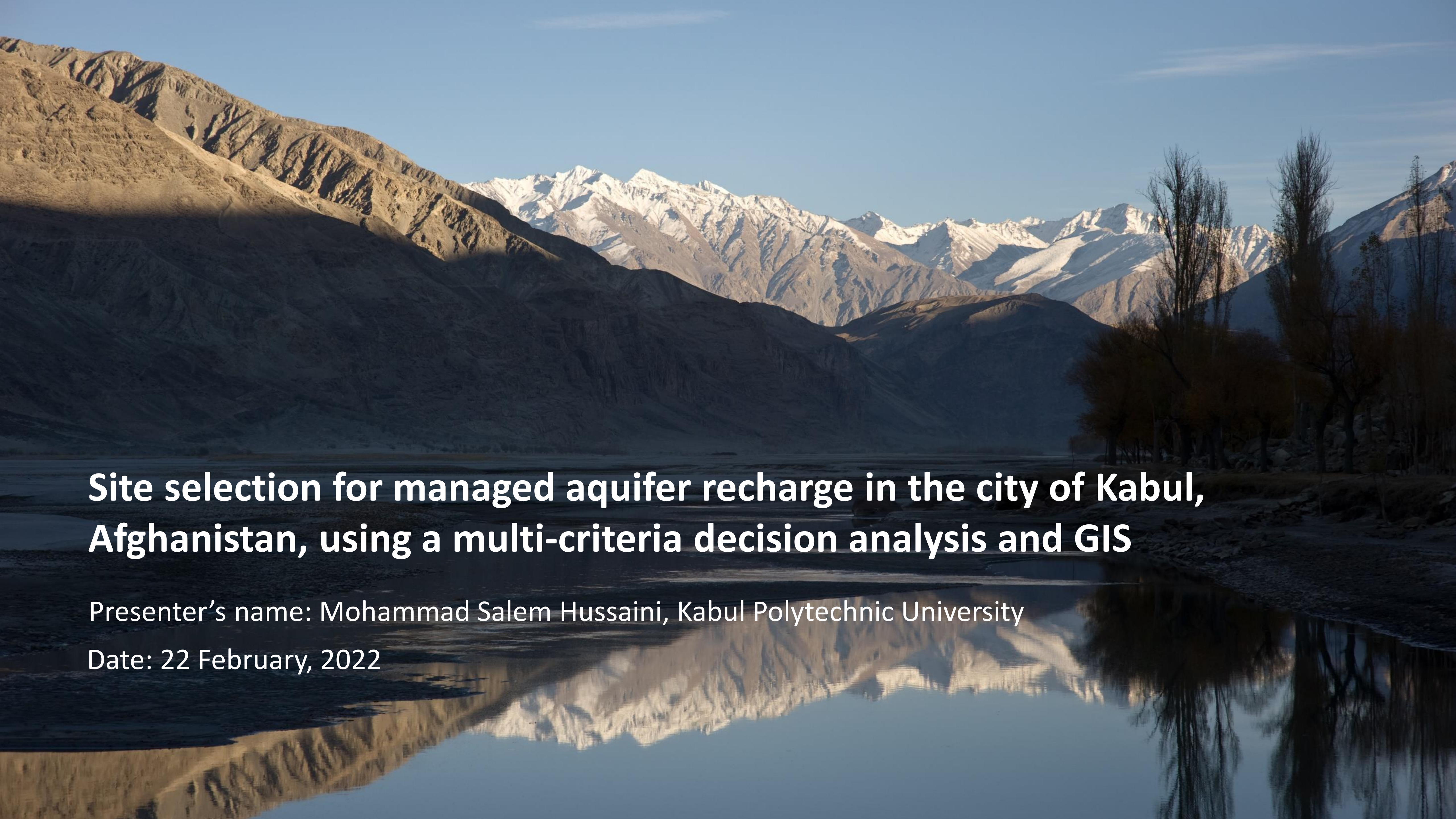

Site selection for managed aquifer recharge in the city of Kabul, Afghanistan, using a multi-criteria decision analysis and GIS

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Date: 22 February, 2022

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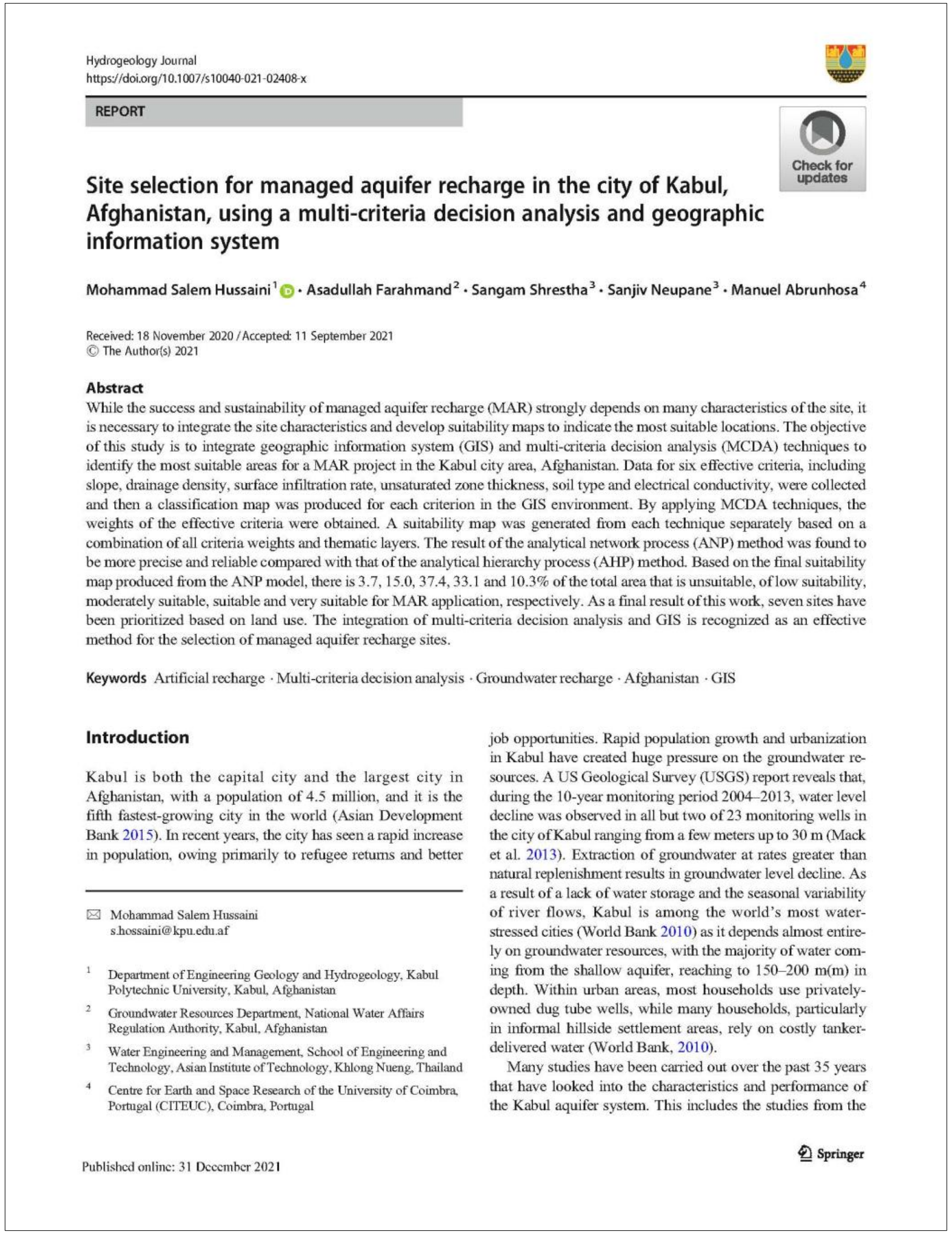

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REPORT

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Site selection for managed aquifer recharge in the city of Kabul, Afghanistan, using a multi-criteria decision analysis and geographic information system

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Abstract
While the success and sustainability of managed aquifer recharge (MAR) strongly depends on many characteristics of the site, it is necessary to integrate the site characteristics and develop suitability maps to indicate the most suitable locations. The objective of this study is to integrate geographic information system (GIS) and multi-criteria decision analysis (MCDA) techniques to identify the most suitable areas for a MAR project in the Kabul city area, Afghanistan. Data for six effective criteria, including slope, drainage density, surface infiltration rate, unsaturated zone thickness, soil type and electrical conductivity, were collected and then a classification map was produced for each criterion in the GIS environment. By applying MCDA techniques, the weights of the effective criteria were obtained. A suitability map was generated from each technique separately based on a combination of all criteria weights and thematic layers. The result of the analytical network process (ANP) method was found to be more precise and reliable compared with that of the analytical hierarchy process (AHP) method. Based on the final suitability map produced from the ANP model, there is 3.7, 15.0, 37.4, 33.1 and 10.3% of the total area that is unsuitable, of low suitability, moderately suitable, suitable and very suitable for MAR application, respectively. As a final result of this work, seven sites have been prioritized based on land use. The integration of multi-criteria decision analysis and GIS is recognized as an effective method for the selection of managed aquifer recharge sites.

Keywords Artificial recharge · Multi-criteria decision analysis · Groundwater recharge · Afghanistan · GIS

Introduction

Kabul is both the capital city and the largest city in Afghanistan, with a population of 4.5 million, and it is the fifth fastest-growing city in the world (Asian Development Bank 2015). In recent years, the city has seen a rapid increase in population, owing primarily to refugee returns and better job opportunities. Rapid population growth and urbanization in Kabul have created huge pressure on the groundwater resources. A US Geological Survey (USGS) report reveals that, during the 10-year monitoring period 2004–2013, water level decline was observed in all but two of 23 monitoring wells in the city of Kabul ranging from a few meters up to 30 m (Mack et al. 2013). Extraction of groundwater at rates greater than natural replenishment results in groundwater level decline. As a result of a lack of water storage and the seasonal variability of river flows, Kabul is among the world's most water-stressed cities (World Bank 2010) as it depends almost entirely on groundwater resources, with the majority of water coming from the shallow aquifer, reaching to 150–200 m(m) in depth. Within urban areas, most households use privately-owned dug tube wells, while many households, particularly in informal hillside settlement areas, rely on costly tanker-delivered water (World Bank, 2010).

Many studies have been carried out over the past 35 years that have looked into the characteristics and performance of the Kabul aquifer system. This includes the studies from the

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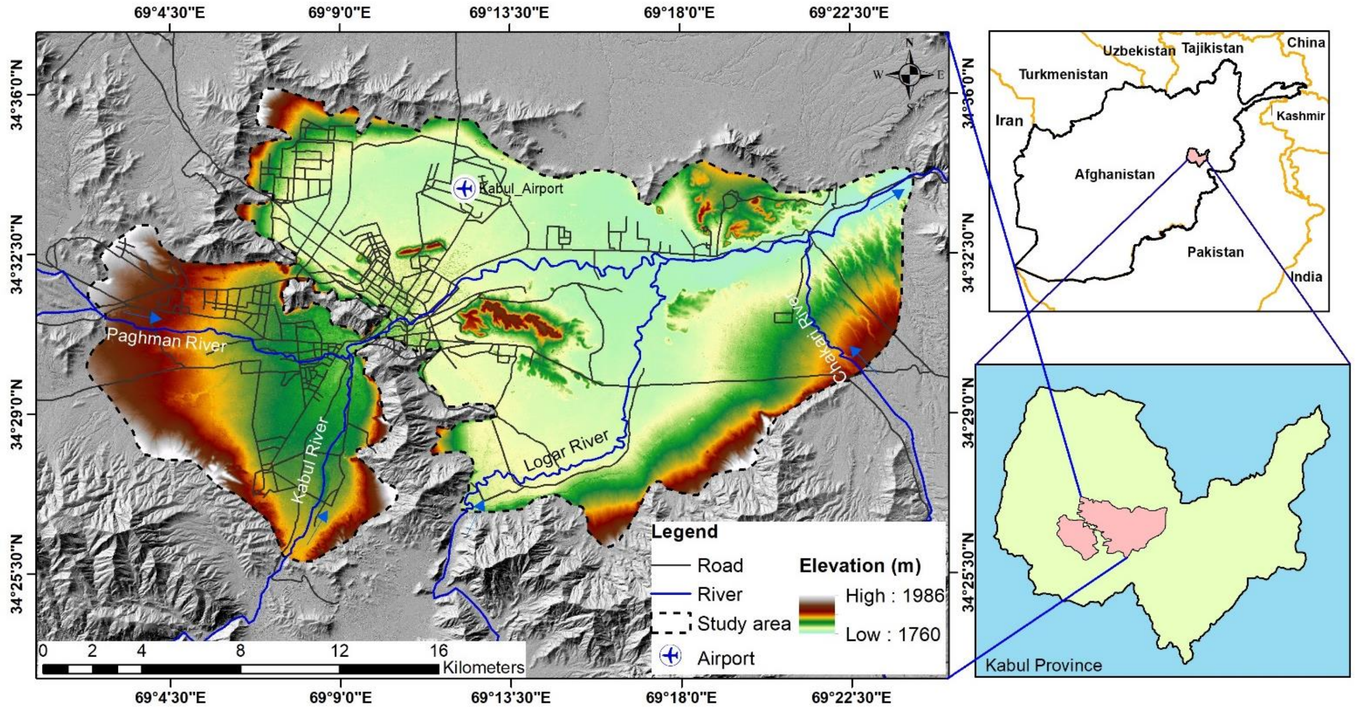
Published online: 31 December 2021

Introduction

- **Kabul** is both the capital city and the largest city in Afghanistan, with a population of 4.5 millions
- The fifth fastest-growing city in the world
- Rapid population growth and urbanization have created huge pressure on the **groundwater resources**
- From 2004-2013, **water level declined** from a few meters up to 30 m
- Lack of water storage and the seasonal variability of river flows, Kabul is among the world’s most water-stressed cities
- A key recommendation of a 5-year program funded by JICA (2011) was the need to use “**artificial recharge**” to strengthen sustainable groundwater yields
- The application of **managed aquifer recharge (MAR)** often provides the cheapest form of new and safe water supply in urban area
- Most of the previous studies used an integrated **GIS-MCDA approach** in order to determine the suitable areas for managed aquifer recharge.

Study area

- The study area (Kabul city) is located nearly 1800 meters above sea level (masl) within Kabul province in north-eastern Afghanistan.
- Three main rivers flow through Kabul: the **Kabul River**, the **Logar River**, and the **Paghman River**.
- **Shallow groundwater** represents the main source of water supply
- It comprises three interconnected aquifers, consisting of **coarse sandy to gravely detritus** originating from the surrounding mountains
- The main groundwater recharge occurs after the snowmelt from **direct infiltration from the rivers**

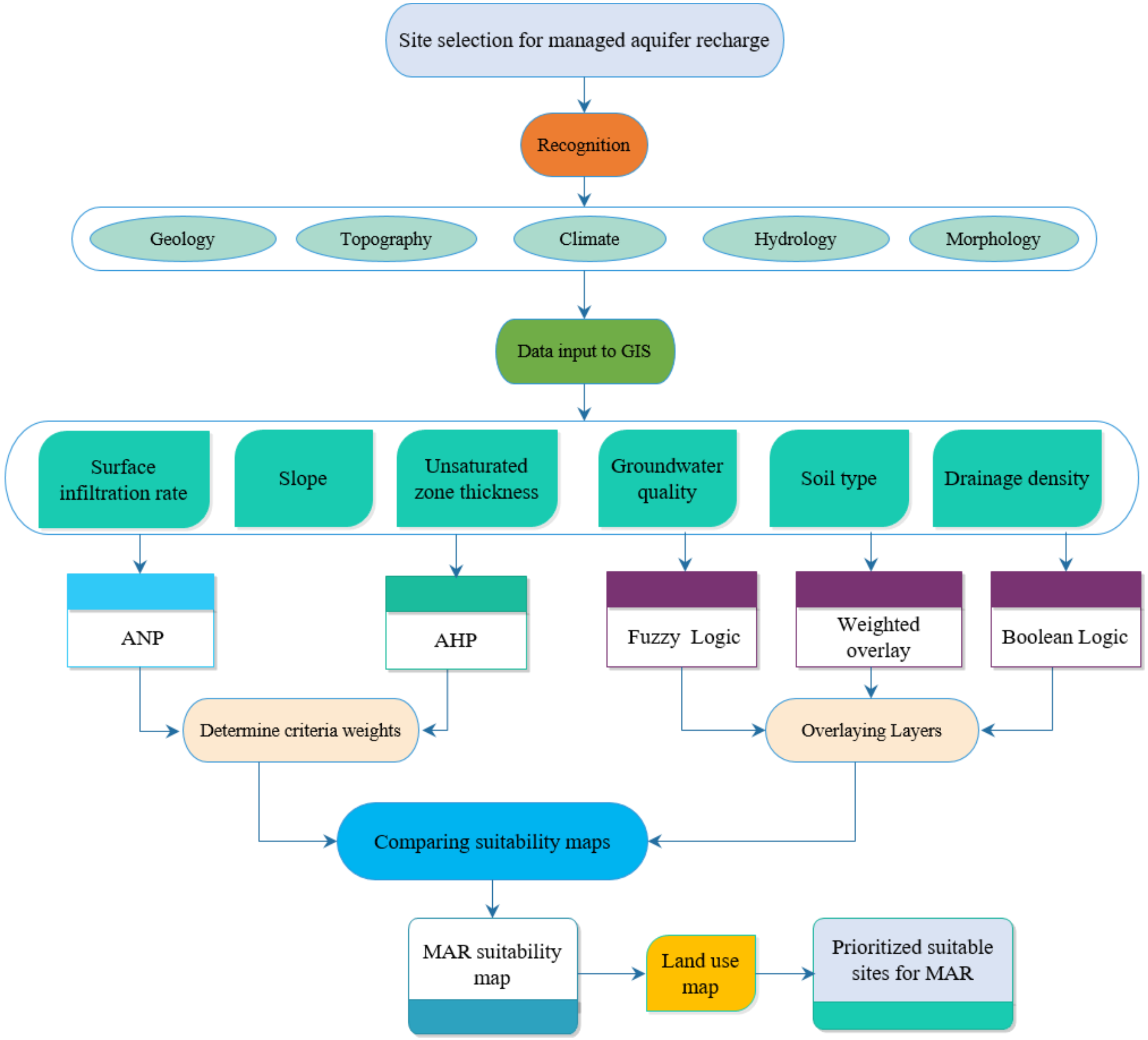


Location map of the study area

Data and Methods

Data set used in this study

Data	Source	Period
Slope	SRTM data (USGS website)	2020
Surface infiltration rate	DACAAR, MEW, MRRD, BGR, FAO & private companies	2020
Soil type	MEW, JICA & Private companies	2020
Unsaturated zone thickness	MEW, LM	2020
Water quality	MEW, DACAAR	2016
Land use/Land cover	UN-Habitat, MUDL	2016
Drainage density	SRTM data (USGS website)	2020



Flow diagram of methodology

1- **Drainage density** (km/km^2):
0-0.5 (very suitable), 0.5-1.5 (suitable), 1.5-2 (moderate) and >2 (unsuitable)

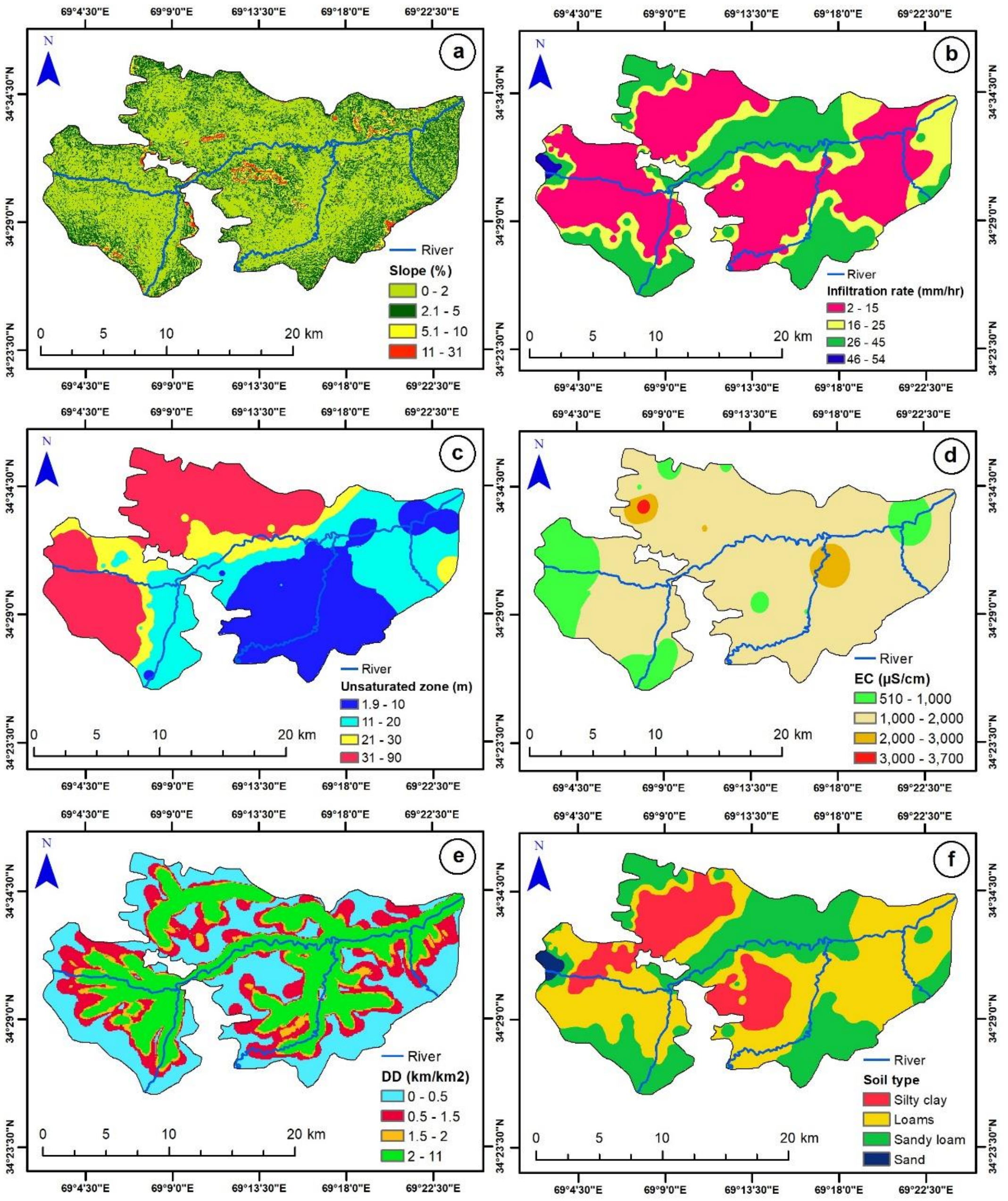
2- **Slope** varies from 0 to 31%: 0-10% (suitable area) and more than 10% (unsuitable area)

3- **Unsaturated zone thickness**:
very suitable (>30 m), suitable (20-30 m), moderate (10-20 m) and unsuitable (0-10 m)

4- **Surface infiltration rate** (mm/hr):
0-15 (unsuitable), 15-25 (moderate), 25-45 (suitable) and >45 (very suitable)

5- **Electrical conductivity** (μS/cm):
<1000 (very suitable), 1000-2000 (suitable), 2000-3000 (moderate), >3000 (unsuitable)

6- **Soil types**: Silty-clay, Loam, Sandy Loam, and Sand.



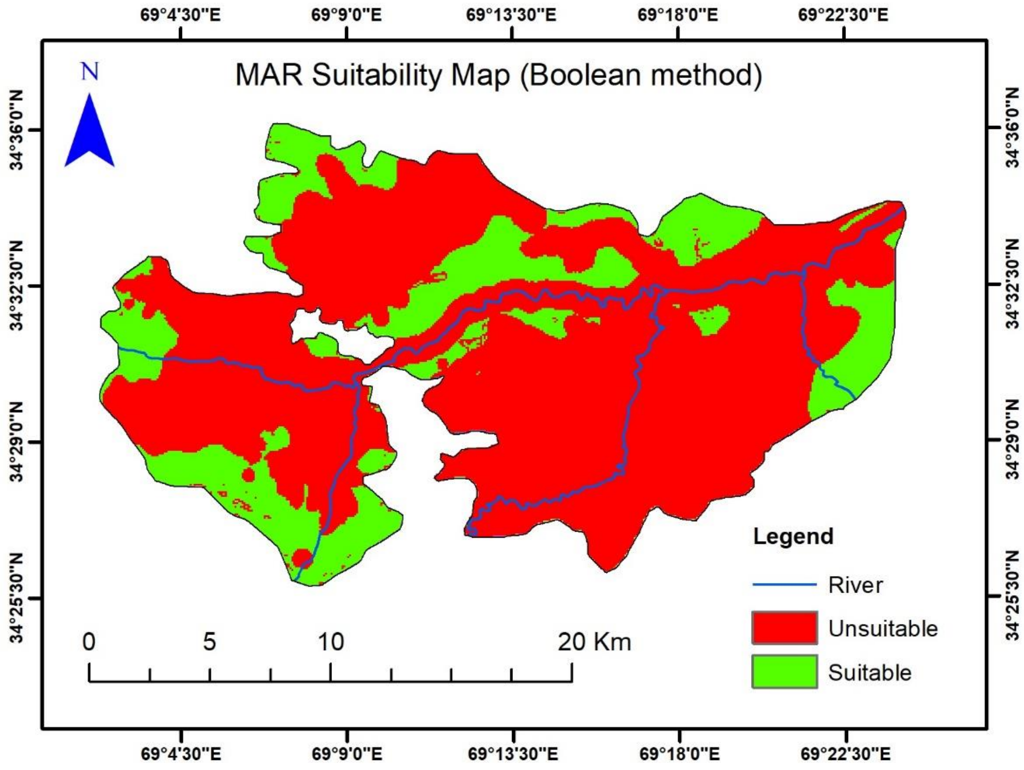
Thematic map for six effective criteria: (a) slope, (b) surface infiltration rate, (c) unsaturated zone thickness, (d) electrical conductivity, (e) drainage density, (f) soil type

Multi-Criteria Decision Analysis

- Boolean logic
- Weighted overlay
- Fuzzy logic method
- Analytical hierarchy process (AHP)
- Analytical network process (ANP)

Software used:

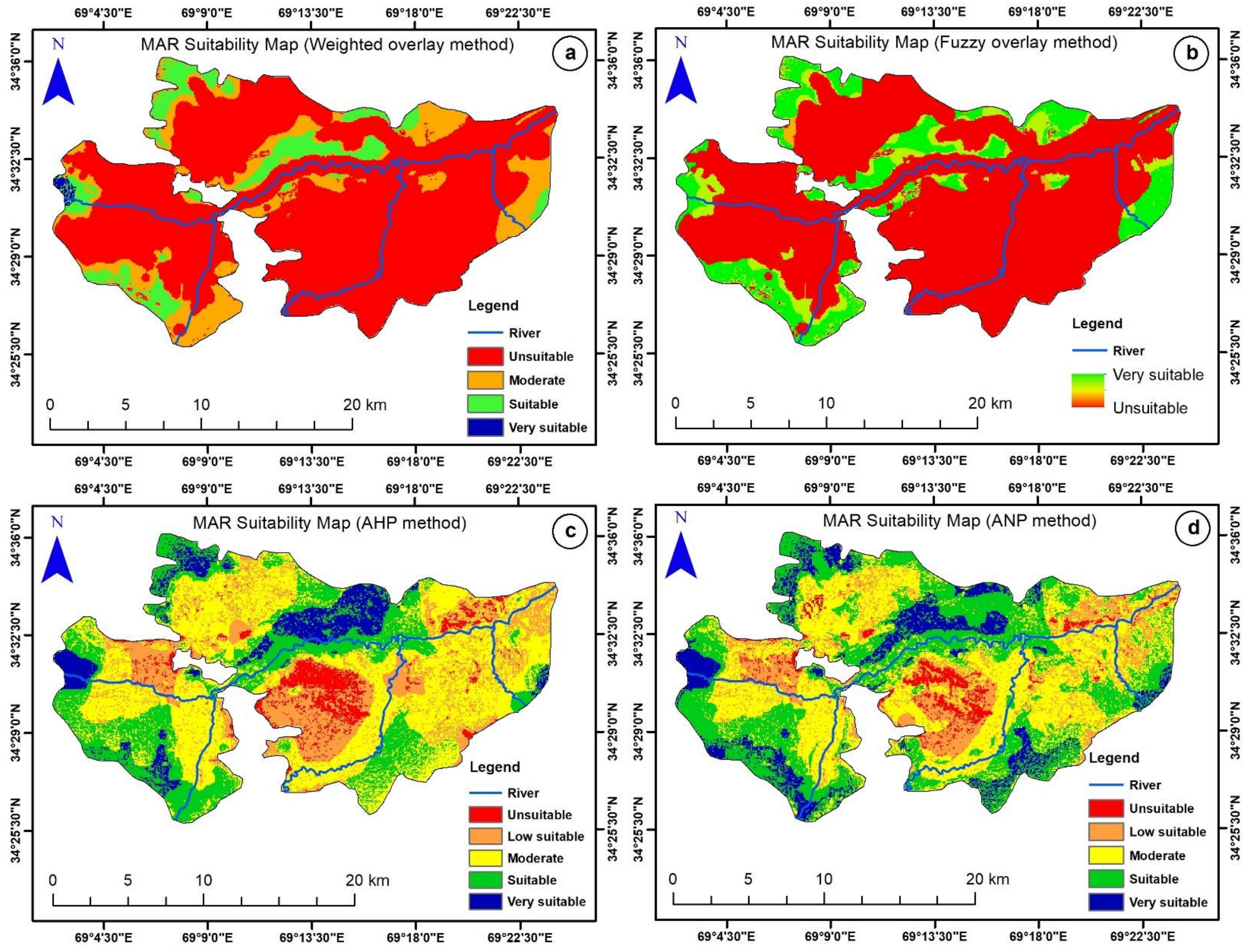
ArcGIS, ArcMap, Expert Choice, Super Decision



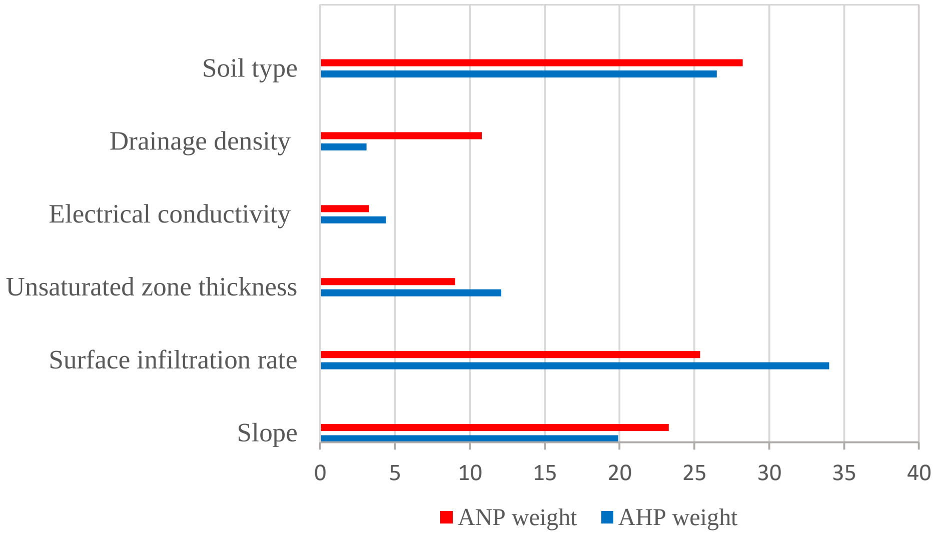
Suitability map based on Boolean logic

Major Results

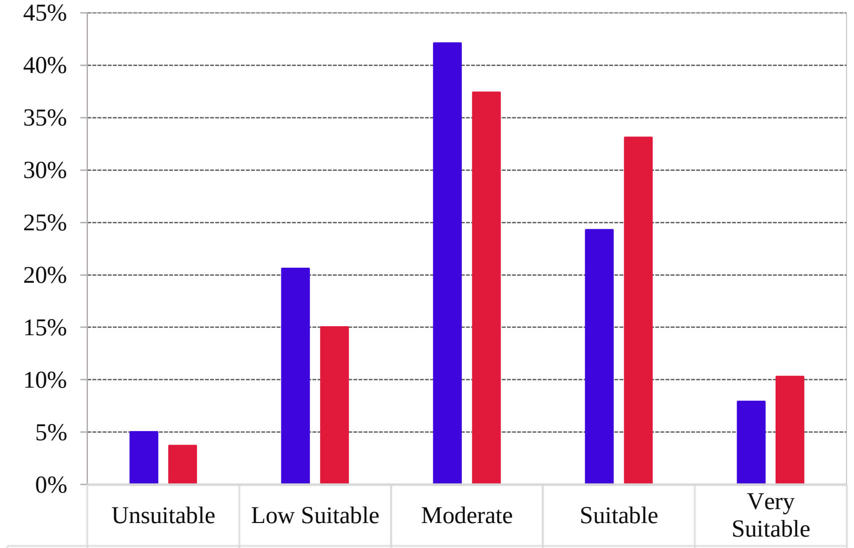
- **Boolean logic** analysis was the **simplest** and best-known method and presents an **overall approach** to the site's suitability of MAR.
- The map prepared from the **fuzzy overlay method** has a significant **similarity** to the generated map from the **weighted overlay method**.
- According to **AHP** suitability map, 5%, 20.6%, 42.1%, and 24.3% of the total area are unsuitable, low suitable, moderately suitable and suitable, and 7.9% are very suitable.
- According to **ANP** method, 3.7% of the total area is unsuitable, 15% is of low suitability, 37.4% is moderately suitable, 33.1% is suitable and 10.3% is very suitable for MAR.
- The **highest weight** in the **AHP** method is assigned to the **surface infiltration rate** but the highest weight in the **ANP** method belongs to the **soil type**.
- When criteria have **interdependency**, the **ANP** method gives a more **accurate and reliable result** in comparison to AHP for site selection purposes.
- To find the final suitable areas for MAR application, **seven prioritized sites**, named A, B, C, D, E, F and J, were assigned considering **appropriate land use** types.



Suitability maps for managed aquifer recharge: (a) weighted overlay, (b) fuzzy overlay, (c) AHP, (d) ANP

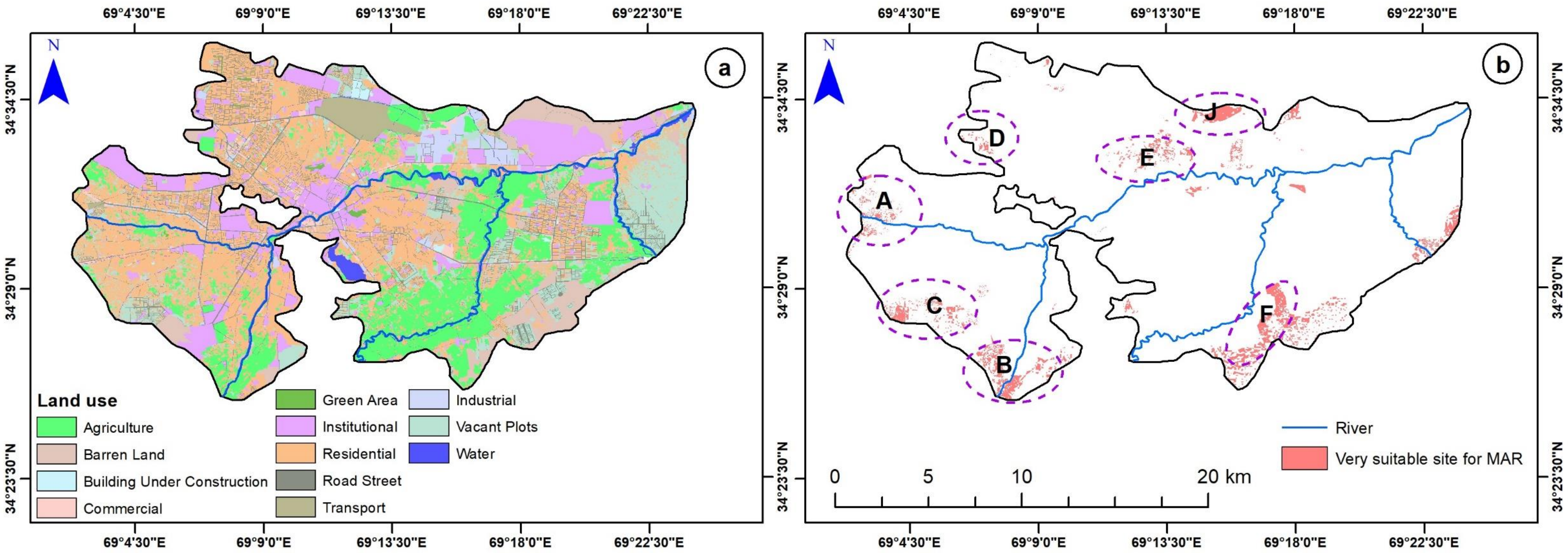


Weightage of effective criteria based on AHP and ANP



	Unsuitable	Low Suitable	Moderate	Suitable	Very Suitable
AHP	5.0%	20.6%	42.1%	24.3%	7.9%
ANP	3.70%	15.0%	37.40%	33.10%	10.30%

Suitability classes based on AHP and ANP methods



a) Land-use/land-cover map, b) prioritized sites for managed aquifer recharge (MAR)

Conclusions

- Generally, a **very suitable area** for MAR is located in the **western part** of the study area in the upper Kabul sub-basin close to the upstream of Paghman River.
- **Suitable areas** for application of **MAR** are located in the **southwest, western, northern**, and **central** parts of the study area but the **larger portion** of suitable areas are in the **western and central** parts.
- The results of the present study can serve as **guidelines for planners, decision makers and hydrogeologists** for planning future artificial recharge projects in the study area.
- The databases and the results obtained can also be useful in developing a **conceptual model** of the study area for future modeling studies.
- The integration of **multi-criteria decision analysis and GIS** is an **effective method** for modeling the uncertainties and reducing the errors that are associated with data classification in GIS for selection of MAR sites.
- The findings of the study can be used to gain **good knowledge and insight** into the various **multi-criteria decision analysis methods** used in locating the most suitable sites for **MAR** in an **urban area**.
- It is recommended that applying **GIS-MCDA** for site selection of groundwater recharge, flood spreading and groundwater potential zones for **other major cities** located at the **Upper Indus River Basin.** This can be a very good interest for **future collaboration** with other country chapters.


THANK YOU