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GIS-based sites selection methodology for efficient hydrogen fuel deployment

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DEDICATION

I dedicate this study to God Almighty my creator, my strong pillar, my source of inspiration, wisdom, knowledge and understanding. He has been the source of my strength throughout this study;

Our great teacher and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life;

Our great parents, who leads us through the valley of darkness

with light of hope and support,

Our beloved brothers and sisters;

Our homeland algeria, the warmest womb;

The great martyrs, the symbol of sacrifice;

To all our family, the symbol of love and giving,

Our friends who encourage and support us,

All the people in our life who touch our hearts,

to teacher alaa bakkur thank you for teaching and guiding us we really appreciate your effort ,

we dedicate this research to love ones.

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Dr. Cherrad Noureddine Lecturer professor at university of ouargla

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GIS-based sites selection methodology for efficient hydrogen fuel deployment

Abstract

Hydrogen is an energy carrier that can transform our fossil-fuel dependent economy into a hydrogen economy, which can provide an emissions-free transportation fuel. The integration of hydrogen into the transportation sector as fuel can help the country achieves many goals. This study focuses on utilizing the Multi-Criteria Analysis (MCA) ,fuzzy logic and AHP method within a Geographic Information Systems (GIS) environment to locate optimum areas for hydrogen production projects in the Ouargla region from 2018 to 2048. The study also used the network analysis tool to reach the number of hydrogen stations required according to the consumer requirement. Seven different criteria have been selected and weighted to represent the favourite conditions for hydrogen production. The attained suitability model represents the optimum locations for hydrogen production in Ouargla scale. It has been found that the entire Ouargla territories is almost suitable for solar hydrogen production in 2048 with varying suitability index. 16.5% of the total study area was very strongly suitable to the hydrogen production and only 7% not suitable. The integration of fuzzy sets, the Multi-Criteria Analysis and AHP methods with GIS provides a powerful and precise combination for analyzing the suitability of land for a specific project.

Key words : Multi-Criteria Analysis, GIS, Ouargla, FAHP, Network Analysis.

منهجية اختيار المواقع القائمة على نظام المعلومات الجغرافية من أجل نشر وقود الهيدروجين بكفاءة

ملخص

الهيدروجين هو ناقل للطاقة يمكنه تحويل اقتصادنا المعتمد على الوقود الأحفوري إلى اقتصاد الهيدروجين، والذي يمكنه توفير وقود خالٍ من الانبعاثات. إن دمج الهيدروجين في قطاع النقل كوقود يمكن أن يساعد البلاد على تحقيق العديد من الأهداف. تركز هذه الدراسة على استخدام تحليل متعددة المعايير (MCA)، والمنطق الضبابي، وأسلوب AHP في بيئة نظم المعلومات الجغرافية (GIS) لتحديد المناطق المثلى لمشاريع إنتاج الهيدروجين في منطقة ورقلة من 2018 إلى 2048. كما استخدمت الدراسة أداة تحليل الشبكي للوصول إلى عدد محطات الهيدروجين المطلوبة وفقا لمتطلبات الاحتياج والمستهلك. تم اختيار وتعيين سبعة معايير مختلفة لتمثيل الظروف المفضلة لإنتاج الهيدروجين. يمثل نموذج الملاءمة الذي تم تحقيقه المواقع المثلى لإنتاج الهيدروجين في منطقة ورقلة. وقد وجد أن مناطق ورقلة بأكملها تكاد تكون مناسبة لإنتاج الهيدروجين الشمسي في عام 2048 مع مؤشر ملاءمة متفاوت. 16.5٪ من المساحة الكلية للمنطقة ورقلة كانت مناسبة جداً لإنتاج الهيدروجين و 7٪ فقط غير مناسبة تماما. يوفر دمج المجموعات الضبابية، وتحليل متعددة المعايير، وطرق AHP مع نظم المعلومات الجغرافية مزيجًا قويًا ودقيقًا لتحليل مدى ملاءمة الأراضي لمشروع محدد.

الكلمات المفتاحية : تحليل متعدد المعايير، نظم المعلومات الجغرافية، ورقلة، منطق الضبابي، التحليل الشبكي.

Summary

Nomenclature

Symbol	Definition	Unit
CAGR	Compound annual growth rate	%
CI	Consistency index	%
CR	Consistency ratio	%
D_H	Demand for hydrogen	kg/day
t_0	First year of observations	Year
$P(t_0)$	Initial value of (inhabitants or vehicles)	Hab. or veh.
KTD	Kilometers traveled daily	km/day
$P(t_n)$	Last value of (inhabitants or vehicles) observed	Hab. or veh.
t_n	Last year of observations	Year
PR	Market penetration rate for hydrogen vehicles	%
P	Population	Inhabitants
RI	Random index	%
SSCHV	Specific consumption for a hydrogen vehicle	KgH_2/year/veh
TNV	Total number of vehicles	Vehicles
Greek letters		
λ_{max}	Highest eigen value of the matrix	-
Abbreviations		
AHP	Analytic hierarchy process	
DED	Digital elevation model	
FAHP	Fuzzy analytic hierarchy process	
GIS	Geographic Information Systems	
GPS	Global positioning system	
LOHC	Liquid Organic Hydrogen Carriers	
MCA	Multi criteria analysis	
MCDA	Multi criteria decision analysis	
MCDM	Multi criteria decision making	

OR	Operations Research
TOPSIS	Technique for Ordered Preference by Similarity to Ideal Solution
TFN	Triangle fuzzy number

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General Introduction

General Introduction

At the COP21 (Conference of the Parties) meeting in Paris in 2015, 195 countries signed a legally binding agreement to keep global warming "well below two degrees Celsius above pre-industrial levels, and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius" within this century. This target is ambitious, since it will require the world to a radical transformation of the global energy system. Hydrogen abundant, versatile, clean, and safe can play many vital roles to meet the challenges of the transition, which is able to decarbonizing transportation sector the most energy-consuming and pollutant sector [1].

In Algeria, the transportation sector accounts for about 36% of total national delivered energy consumption. Passenger transportation, in particular, light-duty vehicles, accounts for most transportation energy consumption (35%), with light duty vehicles consuming more energy than all modes of freight transportation, including heavy trucks, marine, and rail combined. Global transportation energy consumption is dominated by two fuels: motor gasoline and diesel. Together, these two fuels accounted for 94% of total delivered transportation energy use in [2]. Greenhouse gas emissions from this sector primarily involve fossil fuels burned for road transportation. In 2014, transport as a whole was responsible for 35.25% of total CO_2 emissions from fuel combustion and road transport was responsible for 33.7% [3].

Hydrogen as transportation fuel has the potential to solve two major energy challenges that confront Algeria today; reducing dependence on oil and gas sector and reducing greenhouse gas emissions [4].

The objective of this work is to select optimal areas for the production of solar hydrogen. This study based on utilization of multi-criteria GIS approach and FAHP method to evaluate the importance and determinate weights of criteria and based on a set of different technical and economic criteria necessary for the integration of hydrogen as a green fuel in the road transport sector in the Ouargla region by 2048.

The dissertation is divided into three chapters.

Chapter 1. Hydrogen as a green fuel for transportation sector, provides a general apercu about renewable hydrogen production infrastructure from production to its application in the transportation sector.

The chapter 2. GIS-Based Multi-Criteria Decision Analysis, review the different Multi-Criteria Decision- Making (MCDM) methods. A classification of models and approaches is done.

Chapter 3. Optimum sites for solar hydrogen production based on MCDM and GIS, is divided into three main parts. The chapter deals with the use of solar energy source as clean feedstock for hydrogen production.

The first part presents GIS-based method to model the magnitude and spatial distribution of hydrogen demand based on exogenously-derived market penetration rates and population data. The second part, it presents a decision support system for the hydrogen energy exploitation, focusing on some specific technical and economic criteria. In particular, the planning aspects regard the selection of locations with high hydrogen production mainly based on the use of solar energy. The method combines two different approaches: a detailed spatial data analysis using a geographic information system with a Multi-criteria analysis method.

The third part, of this chapter, presents the network analysis within a Geographic Information Systems (GIS) environment to locate the hydrogen distribution stations places and rely on a new service area tool according to the scenarios of needs in order to cover all consumer needs and the safetly in roads in order to travel comfortably.

In this chapter, the overall approach is applied to a specific case study in Ouargla region, in the Southeast of Algeria.

Finally, we will conclude this study with a general conclusion, present a summary of the work done and the main results obtained, and then give some perspectives for future work in this domain.

Chapter 1:

Hydrogen as a green fuel for transportation

1.1. Introduction

The total dependence of fossil fuels on energy production is detrimental to the environmental system and as an alternative to fossil energy, renewable energy is clean and has a much lower environmental impact than other energy sources. Hydrogen, as a carrier of energy, can replace all forms of energy used today and provide energy services to all sectors of the economy, and will play an important future role in a sustainable energy system.

In this chapter we focused on the hydrogen production chain. We will begin by describing the generalities about the properties of hydrogen, then we explain the different methods of production and then touch the storage of hydrogen and methods of transport. One of the most important applications that use hydrogen is transport domain, for this reason will mention in the last chapter the relationship between hydrogen and transportation sector.

1.2. Properties of hydrogen

Hydrogen, the simplest element in the universe being composed of only one proton and one electron. Hydrogen makes up the major part of the composition of the universe. On the earth's surface, hydrogen exists as a compound with other elements such as oxygen, carbon, and nitrogen, most hydrogen is found as a compound with oxygen, in the form of water. Normally pure hydrogen exists in the form of a hydrogen molecule with two atoms, H_2 [5].

There are many reports and data on the properties of hydrogen, but the properties most related to the applications of hydrogen as an energy medium are described in this table:

Table 1.1: Properties of hydrogen [5].

Properties	Numerical value
Atomic weight	1.00782519 (on 12C scale)
Density (gas) (at 0 °c ,1 atm)	0.08988 g/L
Density (liquid) (at -253 °c)	70.8 g/L
melting point	-259.35 °C
boiling point	-252.88°C
Specific heat (Cp)	14 266 J/kg.K (293K)
Specific heat (Cv)	10 300 J/kg.K

1.3. Hydrogen Production

Hydrogen can be produced using a number of different processes. A variety of process technologies can be used, including chemical, biological, electrolytic, photolytic and thermo-chemical. Each technology is in a different stage of development, and each offers unique opportunities, benefits and challenges.

Several technologies are already available in the marketplace for the industrial production of hydrogen. The first commercial technology, dating from the late 1920s, was the electrolysis of water to produce pure hydrogen. In the 1960s, the industrial production of hydrogen shifted slowly towards a fossil-based feedstock, which is the main source for hydrogen production today [6].

1.3.1. Hydrogen production by steam reforming

Steam reforming involves the endothermic conversion of methane and water vapour into hydrogen and carbon monoxide (1.1). The heat is often supplied from the combustion of some of the methane feed-gas. The process typically occurs at temperatures of 700 to 850 °C and pressures of 3 to 25 bar. The product gas contains approximately 12 % CO, which can be further converted to CO2 and H2 through the water-gas shift reaction (1.2) [6].

$$CH_4 + H_2O + \text{heat} \rightarrow CO + 3H_2 \qquad (1.1)$$

$$CO + H_2O \rightarrow CO_2 + H_2 + \text{heat} \qquad (1.2)$$

1.3.2. Hydrogen production by partial oxidation

Partial oxidation of natural gas is the process whereby hydrogen is produced through the partial combustion of methane with oxygen gas to yield carbon monoxide and hydrogen (1.3). In this process, heat is produced in an exothermic reaction, and hence a more compact design is possible as there is no need for any external heating of the reactor. The CO produced is further converted to H_2 as described in equation (1.3) [6].

$$CH_4 + 1/2O_2 \rightarrow CO + 2H_2 + \text{heat} \qquad (1.3)$$

1.3.3. Hydrogen production by auto thermal reforming

Auto thermal reforming is a combination of both steam reforming (1.1) and partial oxidation (1.3). The total reaction is exothermic, and so it releases heat. The outlet temperature from the reactor is in the range of 950 to 1100 °C, and the gas pressure can be as high as 100 bar. Again, the CO produced is converted to H_2 through the water-gas shift reaction (1.2). The need to purify the output gases adds significantly to plant costs and reduces the total efficiency [6].

1.3.4. Hydrogen production by water electrolysis

Water electrolysis is the process whereby water is split into hydrogen and oxygen through the application of electrical energy, as in equation (1.4).

$$H_2O + \text{electricity} \rightarrow H_2 + 1/2\ O_2 \qquad (1.4)$$

This method provides clean hydrogen with no carbon and Sulphur contamination is one of the advantages of this method. However, electrolysis has some disadvantages such as its higher cost and energy needs [7].

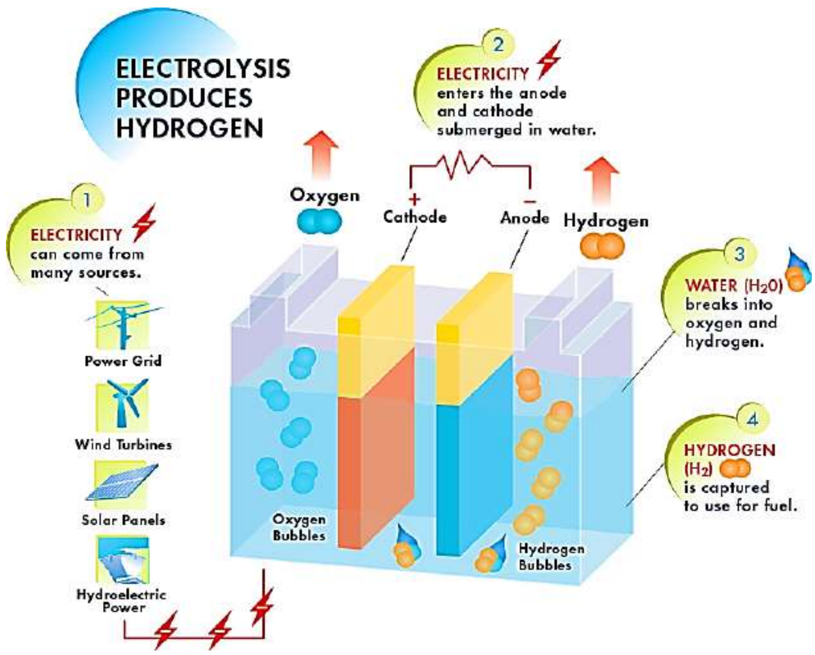


Figure 1.1: Electrolysis of water [8].

1.3.5. Hydrogen production by biomass

Biomass includes crop or forest residues; special crops grown specifically for energy use like switch grass or willow trees; and organic municipal solid waste. Because biomass resources often consume carbon dioxide in the atmosphere as part of their natural growth processes, producing hydrogen through biomass gasification may release near-zero net greenhouse gases. Improved agricultural handling practices and breeding efforts, as well as advancements in biotechnology, can reduce the cost of biomass feed stocks and therefore reduce the cost of hydrogen in the future.

Biomass, like coal, is a substance of highly variable chemistry and complexity. Cellulose is a major component in most biomass, along with lignin and other compounds. Cellulose is a polysaccharide that may be represented for the gasification process by glucose as a surrogate [9].

$$C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \text{Other species} \quad (1.5)$$

1.4. Hydrogen storage

Hydrogen storage is a materials science challenge because, for all storage methods currently being investigated, materials with either a strong interaction with hydrogen or without any reaction are needed. Besides conventional storage methods, i.e. high pressure gas cylinders and liquid hydrogen, the physisorption of hydrogen on materials with a high specific surface area, hydrogen intercalation in metals and complex hydrides, and storage of hydrogen based on metals and water are reviewed.

1.4.1. Compressed hydrogen gas

The most common storage system is high pressure gas steel cylinders, which are operated at a maximum pressure of 200 bar. But depending on the tensile strength of the cylinder material, higher pressures can be reached. New lightweight composite cylinders have been developed that are able to withstand pressures up to 800 bar, so that hydrogen can be reach a volumetric density of 36 kg/m^3 [10].

However, lightweight composite tanks designed to endure higher pressures are also becoming more and more common. Cryogas, gaseous hydrogen cooled to near cryogenic temperatures, is another alternative that can be used to increase the volumetric energy density of gaseous hydrogen. A more novel method to store hydrogen gas at high pressures is to use glass microspheres [11].

1.4.2. Liquid storage of hydrogen

Liquefying hydrogen is a means of increasing volumetric energy density. It is also called cryogenic storage because liquefaction is performed by cooling H_2 to 20 K. Although it is an energy expensive process, it increases H_2 volumetric energy density from 2.5 or 5 MJ/L (for compressed H_2 at 345 and 690 atm respectively) to 8 MJ/L (for liquid hydrogen LH_2). As a result, less volume is required for storage so a smaller, lighter container can be used. This allows longer distances to be driven. Because of this great potential, LH2 storage was extensively studied in the 1980's and 1990's.

If hydrogen is stored in the liquid form on board a FCV, it must be maintained below its boiling point of 20 K. Therefore, heat intrusion must be kept at the lowest possible level. To accomplish this, the original LH_2 tanks were metallic double-walled vessels. The inner vessel had multilayer insulation composed of several metallic foil layers separated by glass wool; space between the inner and outer vessels was evacuated to create a vacuum. This storage system is often referred to as vacuum superinsulation (Figure 1.2) [12].

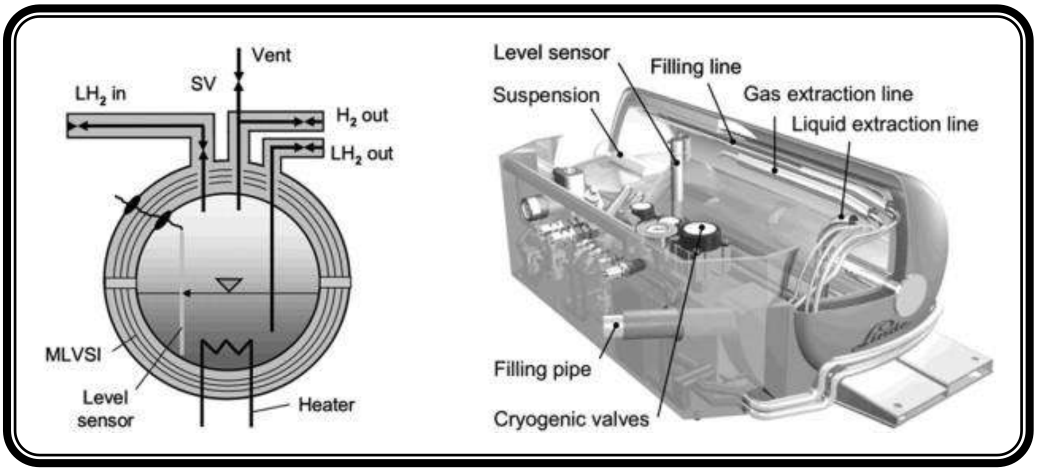


Figure 1.2: Liquid hydrogen storage tank showing the LH2 storage vessel (left) and the full system (right) [12].

1.4.3. Solid storage of hydrogen

In the solid state storage there are various types of potential hydrogen storage materials. But as in every technological solution, there are always advantages and drawbacks, and the selection of a technology depends on the nature of the problem in a way that the disadvantages have less impact in the overall application. Storage by absorption as chemical compounds or by adsorption on carbon materials has definite advantages from the safety perspective such that some form of conversion or energy input is required to release the hydrogen for use. A great effort has been made on new hydrogen storage systems, including metal, chemical or complex hydrides and carbon nanostructures.

Metal hydrides store atomic hydrogen in the bulk of the material. In the case of interstitial metal hydrides, the molecular hydrogen in the gas is split into atomic hydrogen on the surface of the material and then, it diffuses into the atomic structure of the host metal. In these hydrides, hydrogen acts as a metal and forms a metallic bond. A large number of different metallic compounds exist that will absorb hydrogen in this manner. In most cases, however, the absorption does not occur at moderate temperature and hydrogen pressure for practical storage purposes and, the low mass of the absorbed hydrogen is only a small fraction of the mass of the host metal [10].

1.5. Transport of hydrogen

Hydrogen must be transported from the production point to the point of use and be handled within refueling stations or stationary power facilities. There are three different delivery methods:

- Gaseous hydrogen delivery.
- Cryogenic liquid hydrogen delivery.
- New solid or liquid hydrogen carriers.

The present solutions for hydrogen transportation are divided into road and rail transportation, and hydrogen pipelines. Hydrogen ocean transportation is also emerging as a promising alternative that will be available in the near future.

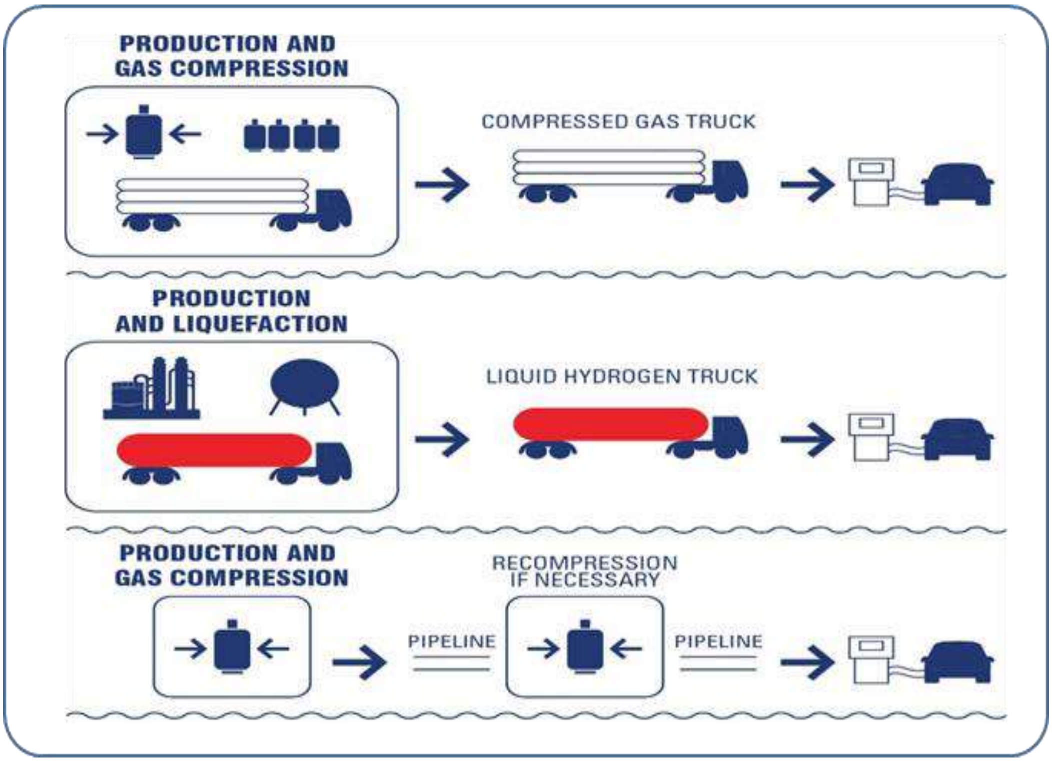


Figure 1.3: Types transport of hydrogen [13].

1.5.1. Transport via road and rail

The transportation of hydrogen by road and rail can be carried out using compressed gas cylinders via tube trailers of approximately 2000 l, with a pressure of around 180-250 bar, or as a liquid in tanktainers (specialized containers for transporting liquid hydrogen) that range from 20,000 to 50,000 l, with pressure levels of 6-10 bar, and extremely low temperatures (-252.8 ºC) [13].

1.5.2. Transport via LOHC

The use of Liquid Organic Hydrogen Carriers (LOHCs) allows transportation of hydrogen at normal temperature and pressure in 10, 20, or 40 foot standard containers. After that, hydrogen is released from the LOHC through a dehydrogenation process at the destination point [13].

1.5.3. Transport via pipelines

Design requirements for hydrogen pipelines are still evolving. Although there are several hundred miles of hydrogen pipelines throughout the world, most hydrogen pipelines are designed to transport hydrogen only short distances, from the production facility to the end user. Many such applications typically represent only a few hundred feet of pipeline and operate with pressures of considerably less than the 1,000 psi absolute (psia) or more that would likely be required for long-distance pipeline transmission of hydrogen. The safety record for these pipelines is considered to be very good. This safe history notwithstanding, the definition of required safety margins, codes, and standards for application to large-scale hydrogen transport remains a work in progress. It is therefore not possible at this time to definitively specify the design details of hydrogen transmission pipelines [14].

1.5.4. Ocean transportation

Ocean transportation of hydrogen has been studied since the late 1980s, and one of the projects by the Japanese government dealt with the design of liquid hydrogen tankers for overseas transport. Nowadays, a Japanese company (Kawasaki Heavy Industries) is developing a test vessel with a capacity of 2,500 m3. The carrier is about 116m long and can accommodate two cargo containment systems of 1,250 m3. Hydrogen is not to be used for propulsion in the first version of this carrier [13].

1.6. Hydrogen and transportation sector

Hydrogen could be ideal as a synthetic energy carrier for transport sector as its gravimetric energy density is very high, abundantly available in combined form on the earth and its oxidation product (water) does not contribute to greenhouse gas emissions. However, its sustainable production from renewable resources economically, on-board storage to provide desirable driving range, usage in durable energy conversion devices and development of infrastructure for its delivery remain significant challenges.

Finding feasible solutions to different challenges may take some time but technological breakthrough by way of on-going efforts do promise hydrogen as the ultimate solution for meeting our future energy needs for the transport sector.

1.6.1. Hydrogen vehicles

There are currently two technologies that use hydrogen for vehicle propulsion, hydrogen can directly supply specific thermal engines or allow the production of electricity in fuel cells suitable for electric vehicles.

1.6.1.1. Hydrogen engine

An internal combustion engine using hydrogen as fuel. Dihydrogen (H_2) "explodes" in oxygen (O_2), this reaction resulting in the production of water (H_2O) and an energy release. This energy is used to propel the vehicle. For comparison, burning one kilogram of hydrogen releases three times more energy than one kilogram of gasoline .

An alternative is to add dihydrogen to a conventional fuel to reduce pollutant emissions. This decrease, however, depends on the way in which hydrogen is produced. Moreover, according to several studies, this mixture of dihydrogen and conventional fuel induces an increase in the overall consumption of the vehicle when the hydrogen is produced on board from an electrolyzer.

Some vehicles in the world, like the BMW Hydrogen 7 (100 model produced and stopped in 2009), have been developed with engines that accept both conventional fuels and hydrogen. They possess for this purpose two separate tanks [15].

1.6.1.2. Fuel cell

Works on producing electricity that powers an electric motor. The oxidation of hydrogen on an electrode coupled to the reduction of oxygen on a second electrode connected to the first leads to the appearance of an electric current which serves to operate an engine.

These two technologies make it possible to obtain engine efficiencies higher than those of conventional engines. These efficiencies reach nearly 45% for hydrogen engines and electric motors (the efficiency of the complete traction chain must be taken into account, about 50% for the battery and 90% for the electric motor) against nearly 20%. On average for conventional thermal engines.

Another major characteristic is that hydrogen has a high energy density per unit mass (3 times more than diesel) but a very low density energy at atmospheric pressure (3,000 times lower than diesel). Practically, it is therefore necessary to compress it several hundred times (between 350 and 700 bar). In addition to the technical problems that this poses, compression increases the risk of self-ignition of hydrogen and consumes energy [15].

1.6.2. Hydrogen stations

Hydrogen fueling stations are key building blocks of a hydrogen transportation infrastructure. They can provide hydrogen fuel for vehicles in many different ways. For instance, station scan be designed to produce hydrogen on-site, or to have hydrogen en fuel delivered from centralized production plants in liquid or gaseous form. Hydrogen can be produced from a variety of feed stocks, such as water and electricity, natural gas or biomass (e.g. agricultural waste, wood clippings, etc.) [16].

Despite the many variations on station design, most stations contain the following pieces of hardware:

- ❖ Hydrogen production equipment (e.g. electrolyzer, steam reformer) (if hydrogen is produced on-site);
- ❖ Purification system: purifies gas to acceptable purity for use in hydrogen vehicles;
- ❖ Compressor: compresses hydrogen gas to achieve high pressure 5000 - 10,000 psi fueling and minimize storage volume;
- ❖ Storage vessels (liquid or gaseous);
- ❖ Safety equipment (e.g. vent stack, fencing, bollards);
- ❖ Mechanical equipment (e.g. underground piping, valves);
- ❖ Electrical equipment (e.g. control panels, high-voltage connections).

1.7. Conclusion

In this chapter we describe and explain the stages of hydrogen. At first we explained the different ways of producing hydrogen and then mentioned the techniques used in storage and different delivery methods from the point of production to the point of use, we have finished the chapter by mentioning the use of hydrogen in transportation through the hydrogen vehicle.

Hydrogen product using renewable energy is really a form of green energy, here show this need to utilize hydrogen as an energy source in order to provide cleaner, more efficient, and more reliable energy for the world’s economies.

Chapter 2 :

GIS-Based Multi-Criteria Decision Analysis

2.1. Introduction

The Geographic Information System (GIS) is the one of the most important tool for collecting, storing, processing, analyzing and providing spatial and non-spatial data to develop a technical solution for different problems. The multi-criteria decision-making (MCDM) method provide comprehensive evaluation of the projects and facilitate the decision aid under considered objectives, in order to provide many options for decision makers, they are applied in GIS because it contains spatial analysis and data processing.

In this chapter we will present some generalities of the GIS system and then explain MCDM with the most important methods and classification, then we will discuss the method of FAHP, a combination of analytical hierarchy process method and fuzzy logic methodologies. In the last, we will explain the importance of integration between GIS and MCDA with a description of the most important modes .

2.2. Geographic Information Systems

Spatial information has been stored in the form of maps from as early as ancient Egypt times. Recently, invention of the microprocessor in the twentieth century boosted the development of data collection and data processing technologies. It was only after this that manual cartographic computations were, to large extent, replaced by automated and computerized ways of gathering data. For example, precise surveying instruments, global positioning system (GPS), aerial photographs and scanning add up to the field. Growing processing capabilities of desktop computers allowed development of relational database system, processing of satellite images and air photos and manipulation of large quantities of data, which all constitute a modern GIS.

For the first time, GIS was adopted into geodesy and natural sciences, but soon it turned out that it can be applied into other research disciplines, like business or transportation. Further, the environmental modelling applications evolved into demographic and business activities analyses and the results could be used for decision making [17].

2.2.1. Definition of GIS

GIS stands for Geographic Information Systems, often defined as a computerized database management system for capture, storage, retrieval, analysis, and display of spatial data. Many different types of data can be integrated into GIS and represented as a map layer. When these layers are drawn on top of each other, spatial patterns and relationships often emerge [18].

To simplify, the goal of any GIS (technology and science) is to do data visualizations, which are the key to the exploration to find an answer on certain questions. In such a manner, data is the core of any GIS, and to be precise, spatial data coupled with attribute data [19].

2.2.2. Function of GIS

The functionality of GIS can be described at three levels with an increasing complexity:

The first level of functionality is cartographic representation or spatial visualisation. It is the simplest and most basic function of GIS. A map is a basic form of spatial visualisation and representation of spatial data. Maps in GIS are in digital form and called digital maps. A digital map in GIS is a set of data recording the properties and their geographical locations (often recorded as latitude and longitude) [20].

The second level of functionality is spatial data management. Spatial data are typically organised in what is commonly referred to as data layers. A data layer is a digital map of a particular theme. A collection of data layers constitutes a spatial database. Figure 2.1 shows an example spatial database. GIS manage a spatial database with specialised database management systems and support a spatial query that retrieves features based on their locations and spatial relationships among the features (e.g., adjacency, inclusion, connectivity and direction).

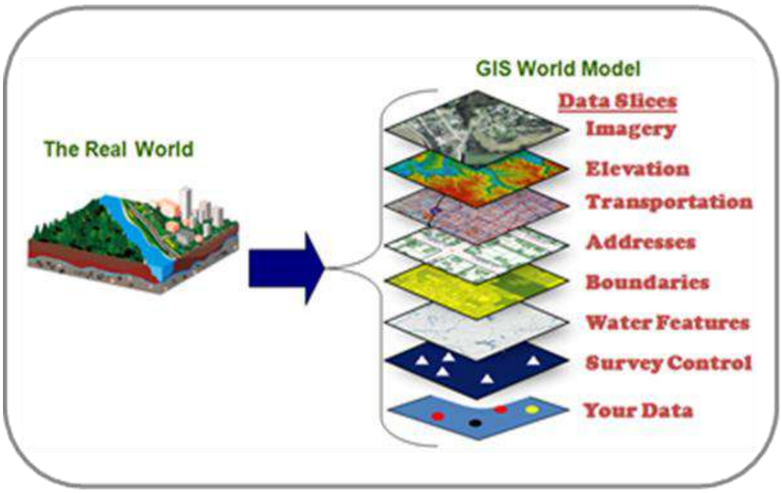


Figure 2.1: Conceptualization of GIS data and layers [21].

The third level of functionality is spatial analysis and modelling. Spatial analysis and modelling is location based, and the results of spatial analysis are also dependent on the locations of the features being analysed. Spatial analysis and modelling functions in GIS allow users to define and execute spatial and attribute procedures to conduct analysis in space and about place. The functionality of this level is commonly thought of as the heart of a GIS [20].

2.2.3. Spatial data types in GIS

Spatial data sets are categorized into two main data models called objects and fields. The object-based data model is used to represent real world features that are discrete, can be identified and touched and is often confined to a limited space. Object-based data models are represented in a GIS as vector data i.e. points, lines and polygons.

Points are used to represent spatial objects in which only the locations are important and not its extent. An example is a large-scale map where cities can be represented as points. Lines and Polygons, are used to represent spatial objects that move through space (e.g. rivers, electricity, roads etc.) and objects that have extent (e.g. cities, countries etc.) respectively. Field data models represent phenomenon that varies across space such as temperature, altitude, rainfall etc. Field-based data models are recorded in GIS as raster layers where the geographic variations of the field are represented in pixels with assigned cell values [22, 23].

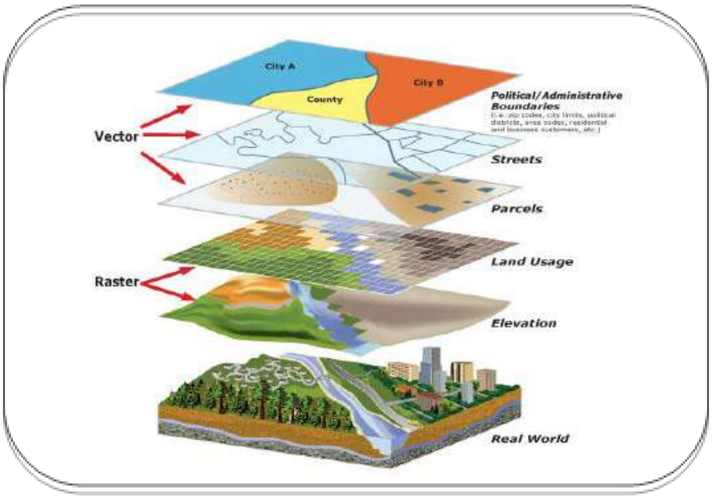


Figure 2.2. Feature types and their representations in two spatial data models [24].

2.3. Decision making

Decision making is the process of sufficiently reducing uncertainty and doubt about the alternatives to allow a reasonable choice to be made from among them [25].

The decision itself depends on "the nature of the problem, the policy of the decision maker and the overall objective of the decision". The possible types of action include: choice of an alternative solution, ranking of the alternatives from the best to the worst ones or the assignment of the considered alternatives into predefined classes [17, 26].

2.4. Concept of decision problem

This last concept is related to the expected outcome of the decision problem and represents a major role in choosing the right method for the Decision Making Situation (DMS) under consideration. Bernard Roy 15 categorised the decision making situations according to four major problematics, and the way the Decision Aid (DA) should be envisaged [27]:

- ❖ The Description problematic – Decision Aid focuses in providing an appropriate set of actions and a suitable family of criteria, without making any recommendation.
- ❖ The Choice Problematic – The aid intends to narrow down the number of actions to find a single alternative or a possible smaller subset (usually containing the most fulfilling actions to the predefined goals).
- ❖ The Sorting Problematic – In this problematic the aid seeks to assign each action a category from a set defined a priori. These categories can be related with the feasibility of the actions and the possibility of their implementation.

- ❖ The Ranking Problematic – The DA results in a complete or partial preorder of the set of alternatives, after comparing them with each other.

2.5. Multi criteria decision making approaches

Multi-criteria decision analysis (MCDA), sometimes called multi-criteria decision making (MCDM), is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting evaluations. MCDA aims at highlighting these conflicts and deriving a way to come to a compromise in a transparent process. Unlike methods that assume the availability of measurements, measurements in MCDA are derived or interpreted subjectively as indicators of the strength of various preferences. Preferences differ from decision maker to decision maker, so the outcome depends on who is making the decision and what their goals and preferences [28].

Are powerful tools used for evaluating problems and addressing the process of making decisions with multiple criteria. MCDM problems typically are quite complex, but the distinguishing characteristic is the fact that various conflicting criteria and the interactions between them have to be modeled explicitly in order to gain an understanding of the problem or to provide a solution to the problem. MCDM as a multi-disciplinary field of Operations Research (OR), uses mathematical approaches involving the following steps [29].

1. Structuring decision processes;
2. Defining and selecting alternatives;
3. Determining criteria formulations and weights;
4. Applying value judgments and evaluating the results to make decisions in design or selecting alternatives with respect to multiple conflicting criteria.

2.5.1. Framework for MCDM

MCDM begins with stating the problem and continues with the steps in (figure 2.3) until reaching a decision. For any decision process, definition of decision problem is vital. After the definition of the problem, decision maker needs to define the selection criteria and evaluate the feasible alternatives with regarding the constraints to structure the decision matrix.

MCDM proceeds with a generation of a decision matrix that includes the scores of the alternatives according to the selected criteria [30].

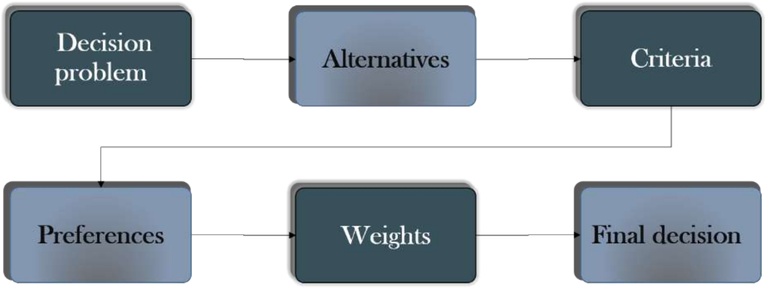


Figure 2.3: Basics of Decision Process.

2.5.2. Classification of MCDM methods

MCDA approaches have been classified in a number of ways. One of the first categorizations makes a distinction between multi-objective decision making (MODM) and multi attribute decision making (MADM). The main distinction between the two groups of methods is based on the number of alternatives under evaluation. MADM methods are designed for selecting discrete alternatives while MODM are more adequate to deal with multi-objective planning problems, when a theoretically infinite number of continuous alternatives are defined by a set of constraints on a vector of decision variables [31].

A more thorough distinction was made between these two groups of methods. The general classification of MCDA methods adopted in this paper is the one suggested by [32] because it reflects more directly the range of their application. They classify MCDA methods into four broad categories:

1. Elementary methods;
2. The single synthesizing criterion approach;
3. The outranking synthesizing approach;
4. The mixed methods.

Table 2.6 shows the main methods belonging to each of these categories [32].

Table 2.1: MCDM classification by Guitouni and Martel (1998) [32].

Category	Methods
Elementary methods	Weighted sum, lexicographic method, conjunctive methods, disjunctive method, maximin method
Single synthesizing criterion	Topsis, maut, mavt, smart utility theory additive (uta), ahpevamix, fuzzy weighted sum, fuzzy maximin
Outranking methods	Electre, promethee, melchior, oreste, regime
Mixed methods	Qualiflex, martel & zaras method, fuzzy conjunctive/disjunctive method

2.6. Fuzzy Decision Making

The inability of the normal decision making methods to address the imprecision and uncertainty paved the path for the fuzzy decision making techniques. Goals, constraints and consequences are known imprecisely in much of the real world decision-making processes and in such a situation fuzzy set theory becomes functional [33].

Triantaphyllou and Lin (1996) present the development and evaluation of five Multi-attribute Decision-Making methods – Fuzzy Weighted-Sum Model, Fuzzy Weighted-Product Model, Fuzzy AHP, Revised Fuzzy AHP and Fuzzy TOPSIS (Technique for Ordered Preference by Similarity to Ideal Solution). Though none of these methods are perfect with respect to their evaluative criteria, they summarize that the revised fuzzy AHP is the best method. Saaty's AHP is first extended by Van Laarhoven and Pedrycz (1983). They use triangular fuzzy numbers for fuzzification of the pair wise comparison matrix [34, 35].

But all of these researches are oriented towards addressing the uncertainty that is associated with the input data. Although these methods incorporate expert knowledge derived from the input data, still the uncertainty and ambiguity that can be associated with the expert knowledge left unan-swered [33].

2.7. Analytical Hierarchy Process

Analytic Hierarchy Process (AHP) is a decision-making technique developed by Thomas L.Saaty. This method introduce a systematic process for making optimal logical decisions in complex decision situations characterized by conflicting criteria and uncertainty [36].

The AHP techniques form a framework for decisions that use a one-way hierarchical relation with respect to the decision layers. The hierarchy is constructed in the middle level(s), with decision alternatives at the bottom, as shown in Fig. 1. The AHP method provides a structured framework for setting priorities on each level of the hierarchy using pair-wise comparisons that are quantified using a 1 ÷ 9 scale [37].

This process generally involves six steps show in Figure 2.4.

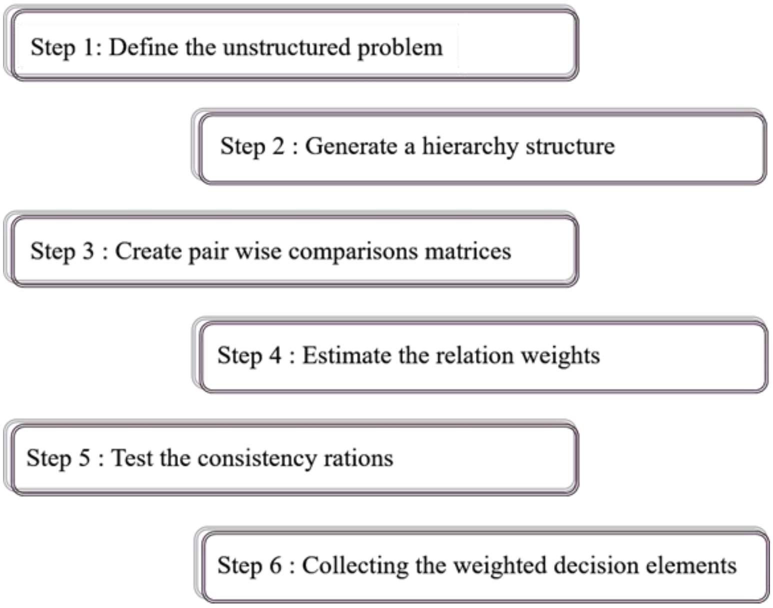


Figure 2.4: AHP process of evaluation alternatives.

2.7.1. Principles and axioms of the AHP

We now turn our attention to the three related basic principles of the AHP [33, 38]:

1. Decomposition: speaks: is to structure a complex problem into different clusters at various hierarchies;

2. Pairwise Comparisons: is to create Pairwise Comparison Matrices (PCMs) for all the elements or criteria under evaluation to derive the weights or the preferences;
3. Hierarchical composition, to aggregate these local comparisons over the hierarchy to arrive at the final evaluation.

And the four simple axioms those constitute the theory of AHP are:

1. Reciprocal axiom, requires that, if PC(A, B) is a paired comparison of elements A and B with respect to their parent element C, representing how many times more the element A possesses a property than does element B, then PC(B, A) = 1/ PC(A, B);
2. Homogeneity axiom: Elements clustered and arranged under a hierarchy must be ho- mogeneous i.e. they must be comparable with an order of magnitude. It means that elements within a cluster should preferably be compared within the AHP scale, 1 to 9;
3. Independency of judgment at each level: judgment at one level of hierarchy should be independent of the elements under it. One should carefully consider this axiom while making decisions, as the human tendency force one to look at the elements under the hierarchy during evaluation;
4. A fourth AHP axiom, introduced later by Saaty, says that individuals who have reasons for their beliefs should make sure that their ideas are adequately represented for the outcome to match these expectations. While this expectation axiom might sound a bit vague, it is important because the generality of the AHP makes it possible to apply it in a variety of ways and adherence to this axiom prevents applying it in inappropriate ways.

2.7.2. Fuzzy Analytical Hierarchical Process

The fuzzy AHP technique is embedded with a fuzzy theory for AHP. In order to systematize complex problems in an unknown situation. Despite its popularity, AHP does not include vagueness to effectively deal with the uncertainty and imprecision dependency of the decision maker’s perception of the crisp values .

Such inconveniences have been addressed by using a fuzzy logic approach. In the fuzzy AHP, the evaluation criteria and alternatives are compared on a pairwise basis, and through the linguistic variables, which are represented by triangular fuzzy numbers (TFNs), to solve the ambiguity involving in ranking and prioritizing the alternatives in healthcare decision-making [39].

2.7.2.1. Fuzzy number

In complex evaluation systems, human's judgments, knowledge and experiences are presented by linguistic terms and vague patterns. These are not presented as numbers but are defined as <be represented quantitatively as a fuzzy number in various formats such as trapezoidal, triangular or Gaussian. Moreover, modeling using TFN was shown to be an effective approach for handling the decision problems involving vague and imprecise information [40].

Let $\tilde{A}$ be a fuzzy triangular number on $\Re$,$\tilde{A}$ is defined as follows:$\tilde{A} = (l, m, u)$ if the membership function $\mu_{\tilde{A}}(x)$ satisfies the following rules:

$\mu_{\tilde{A}}(x)$:$\Re \rightarrow [0,1]$

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-l}{m-l}, l \leq x \leq m \\ \frac{u-x}{u-m}, m \leq x \leq u \\ 0, \text{otherwise} \end{cases} \quad (2.1)$$

Where R is the set of real number; $l \leq m \leq u$, l and u are the lower and upper value of the support of $\tilde{A}$, and m is the modal value (Figure 4). The triangular fuzzy number can be mean by (l, m, u). The support of $\tilde{A}$ is the set of element$(x \in \Re | \ l < m < u)$. When $l = m = u$, it is a non fuzzy number by convention [39, 41].

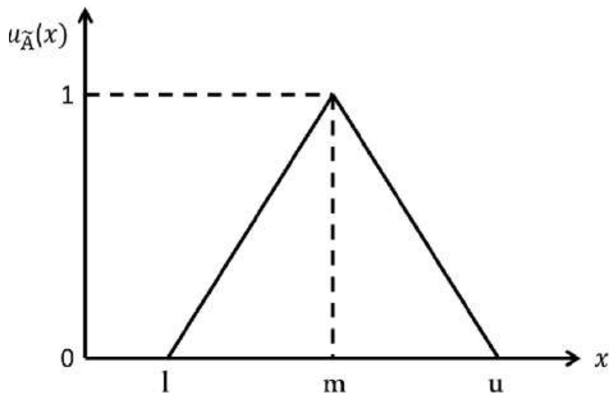


Figure 2.5: Membership functions of the triangular fuzzy number [41].

2.8. GIS-MCDA Integration

Solution of spatial decision problems means combining and transforming geographical as well as decision data (input) to have a resulting decision (output).

GIS is an excellent tool for acquisition, storage, manipulation and spatial analysis of geographic data, but has a lack to deal with spatial decision problems especially with conflicting objectives in the decision-making process. Below some critics addressed to GIS technology [42].

- ❖ Decision data like decision maker's preferences are not taken into account by current GIS;
- ❖ Assessment and comparison of different scenarios are not permitted by GIS. The solutions given by GIS satisfy all criteria simultaneously;
- ❖ Analytic functionalities found in most GIS are oriented towards the management of data, but not towards an effective analysis of them.

MCDA is a technique to assess and structure actions according to a set of conflicted criteria and a proposed decision maker's preference. MCDA comes to overcome the lack of GIS in tackling spatial decision problems. Salem in [33] underlines the necessity of GIS-MCDA integration and proposes three modes: (1) An indirect GIS MCDA integration mode; (2) A built-in GIS-MCDA integration mode; (3) A full GIS-MCDA integration mode.

GIS and MCDA are two different areas of research, but they complement each other for solving spatial decision problems. The conceptual idea on which GIS-MCDA integration is based is to use the capabilities of GIS to prepare inputs necessary for multi-criteria method and exploit the potential of GIS for results visualization.

2.9. Conclusion

In the first part of this chapter, we describe how geographic systems evolved over time, after that, we explained GIS program, then we discussed the methodology of MCDM, an important tool for decision-making with the most important methods, and then explained FAHP as one of the method of MCDM. In the last chapter we explained how to integrate GIS and MCDM and its impact on decision-making in many fields.

GIS has long been used for decision support, mainly for their map design, comparison, and spatial analysis capabilities. This capability can be further enhanced by integrating GIS with MCDM models that will provide decision makers with easier access to GIS procedures, allow them to assess the performance of different MCDM techniques, evaluate the importance of the selected criteria.

Chapter 3 :

Optimum sites for solar hydrogen production based on MCDM and GIS

3.1. Introduction

The Solar hydrogen production site selection is critical point in the process of starting. One of the main objectives in solar hydrogen production site selection is finding the most appropriate site with desired conditions defined by the selection criteria.

The GIS-based multi-criteria approach has proven to be an efficient decision-support tool for locating optimum spatial sites particularly for solar hydrogen production. Where the multi-criteria methods provide comprehensive evaluation of the solar hydrogen production projects and facilitate the decision aid under considered objectives.

However, selecting appropriate sites for solar hydrogen production is not a single-criteria task. Basically, it is based on several sets of physical, environmental, and socio-economical criteria in order to decide optimum geographic location.

In this work, we chose to develop a hydrogen infrastructure at regional scale which we will apply to the region of Ouargla.

This chapter begins with a presentation of the Ouargla region. Then we conduct a prospective study to determine the temporal and spatial distribution of hydrogen demand in the road transport sector by 2048. then will propose a methodology that allowed us to determine the optimal locations for the establishment of a solar hydrogen production facility in the Ouargla region using a multi-criteria GIS approach with combining Fuzzy logic (FAHP).

3.2. Presentation of the study area

Ouargla is located in the Southeast of Algeria, which is the 30th state in the Algerian administrative division, and is one of the oldest states. The city of Ouargla is located almost north of latitude 32 degrees and east by 5 degrees at a height of 135 meters at sea level [43].

The wilaya of Ouargla large territory of 163.230km^2, is one of the largest administrative communities in the country,It is considered an economic city because it has the municipality of HassiMassoud, which is characterized by internal resources such as oil and natural gas and othersOuargla is limited [44] :

- From the north: by the Wilaya of Djelfa, El-Oued and Biskra
- The East: by Tunisia

- The South: by the Wilaya of Tamanrasset and Illizi
- The West: by the Wilaya of Ghardaia.

Currently has 21 municipalities grouped into 10 Daïras,and has 3 airports : Ain El Beida , HassiMessaoud and Touggourt,the following figure shows the administrative division of Ouargla city.

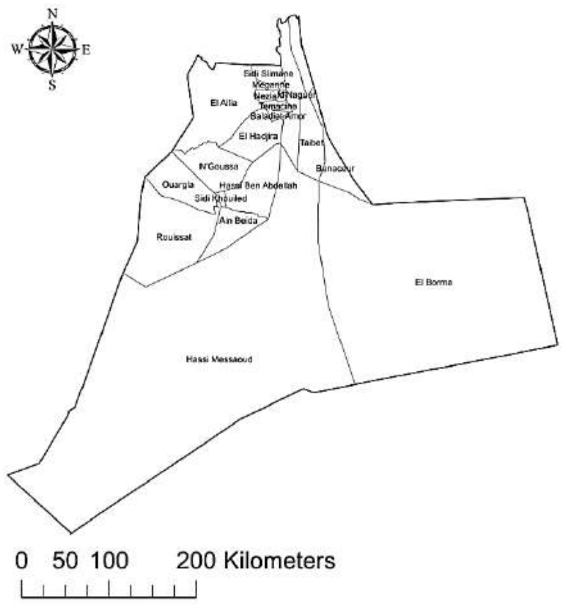


Figure 3.1: Administrative division of Ouargla city.

3.3. Modeling future hydrogen demand

Modeling future hydrogen demand is an important issue in understanding a transition to a hydrogen economy in the transport sector. Understanding the evolution of a hydrogen fuel delivery infrastructure depends on the spatial characteristics of the hydrogen demand. We have developed a GIS-based method to model the magnitude and spatial distribution of hydrogen demand based on penetration rates of hydrogen vehicle at the market and population data, depending on many studies [45, 46].

This approach is applied to a study of hydrogen demand in the region of Ouargla. However, our method could be applied to any region, where census data is available. The following describes the data and factors and equations we used in our analysis:

1. Our analysis begins with census data, this methodology is based on a retrospective study of the population and vehicle fleet in the 21 Municipalities of Ouargla region to know the average annual growth rate in previous years from 1998 to 2015 [47]. Using the following equation:

$$\mathbf{CAGR} = \left[\left(\frac{V(t_n)}{V(t_0)}\right)^{\frac{1}{t_n - t_0}}\right] - \mathbf{1} \quad (3.1)$$

As hydrogen demand will occur in the future, a base year of 2048 was used for the analysis. We calculated projected population in the 21 Municipalities growth from 2018 to 2048 for each city, With the following equation (3.2).
The results are represented in (Annex 1).

$$\mathbf{P(t_n) = P(t_0) * (1 + CAGR)^{(t_n - t_0)}} \quad (3.2)$$

Where :

CAGR : Compound annual growth rate;

$\mathbf{t_0}$: the first year of observations;

$\mathbf{t_n}$: the last year of observations;

$\mathbf{P(t_0)}$:the initial valueof (inhabitants or vehicles);

$\mathbf{P(t_n)}$**:** the last value of (inhabitants or vehicles) observed.

2. An estimate of total the number of vehicles calculated by multiplying the population by an estimate of auto ownership per person (number of vehicles per inhabitant) equation (3.3).

And number of vehicles per inhabitant obtained by dividing the total number of vehicles on the population of the state of Ouargla equation (3.3).

$$\mathbf{TNV = P * NV_{inh}} \quad (3.3)$$

TNV: The total number of vehicles;

P : The population (inhabitants);

$\mathbf{NV_{inh}}$**:** Number of vehicles per inhabitant.

3. We proposed the market penetration rate for hydrogen vehicles until the year of 2048 so as to have a curve with a linear equation going from the year 2018 to the year 2048, as indicated in the following figure and (Annex 2):

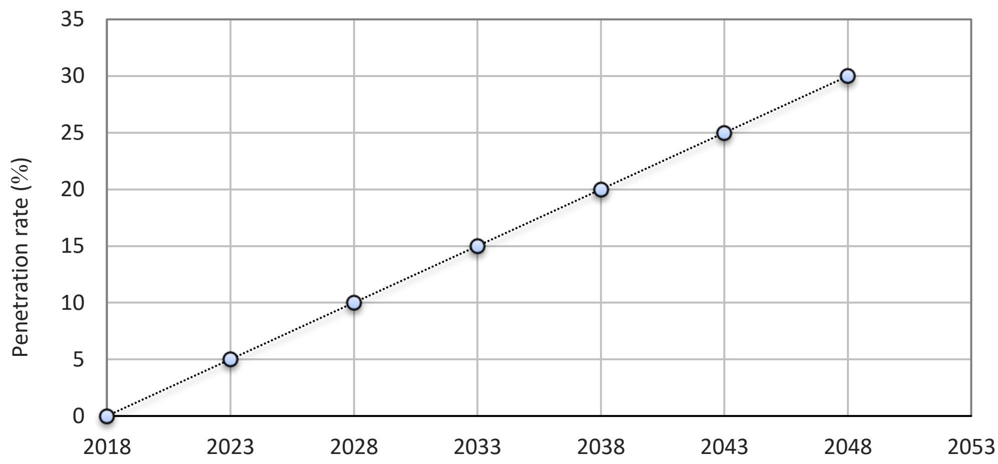


Figure 3.2: Variation in the penetration rate of total number of vehicles according to the periods.

4. Number of Hydrogen vehicle (H2 vehicles) was calculated by multiplying the total number of vehicles by exogenously specified market penetration rates equation (4).

The results are represented in (Annex 3).

$$\mathbf{NVH = TNV * PR} \qquad (3.4)$$

NVH : Number of hydrogen vehicle;

PR : Market penetration rate for hydrogen vehicles (1%, 15%,…. 30%).

5. Hydrogen demand (kg H2/day) was derived by multiplying the Number of hydrogen vehicle (H2 vehicles) with an estimate of Specific consumption for a hydrogen vehicle. This estimate is based on the assumption that the average annual number of kilometres traveled for different types of vehicles in Algeria equal to 38000 km/year [48] (roughly equivalent 104 km/day) and has a fuel economy of a Toyota Mirai prototype vehicle: 1kg H2/ 100km [49].

In order to calculate the specific consumption for a hydrogen vehicle we apply the equation:

$$\mathbf{SCHV = \frac{KTD*1kg\ H2}{100km}} \qquad (3.5)$$

SCHV : Specific consumption for a hydrogen vehicle;

KTD: Kilometres traveled daily (km/day).

$$\mathbf{SCHV} = \frac{104 * 1}{100} = 1.04\ kg\ H_2/\text{day}$$

6. As for the calculation hydrogen demand in the 21 city of Ouargla region, we use the following equation:

$$\mathbf{D_H} = \mathbf{NVH} * \mathbf{SCHV} \tag{3.6}$$

$\mathbf{D_H}$**:** Demand for hydrogen. The results of demand for hydrogen are represented in figure (3.3) and (Annex 3), after dividing the interval from 2018 to 2043 into the periods each period is 5 years.

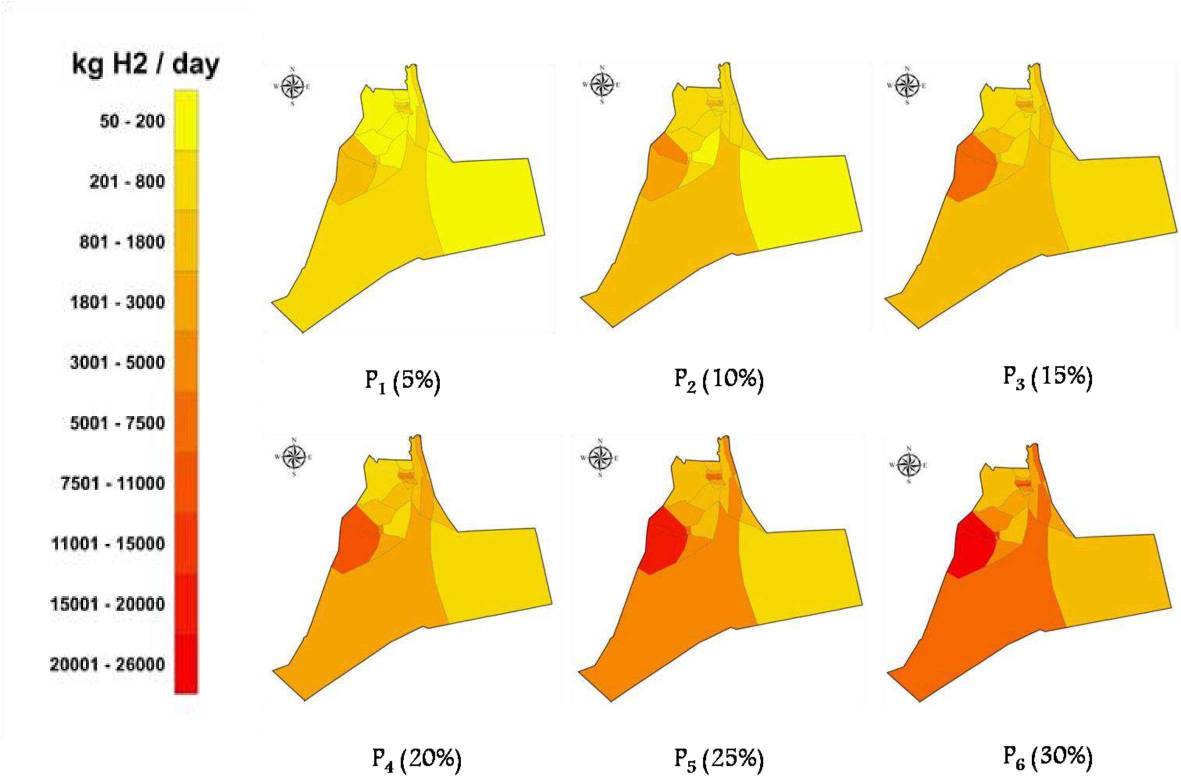


Figure 3.3: Conceptual representation of spatial distribution of daily hydrogen demand.

3.4. Method and methodology of the work

Decision makers can use multi-criteria approach and statistical methods to judge various subjective and conflicting criteria whereas evaluating the suitability of a specific area with regards to a certain development. The method is often utilized within a GIS environment system because it contains spatial analysis and data processing, where the suitability of an area for solar hydrogen production is represented with visual aids such as maps and some conditions. GIS has been utilized extensively in the last decades for sighting optimum locations for a variety of objects, spatial multi-criteria decision analysis can be thought of as a process that combines and transforms geographical data (input) into a resultant decision (output).

The multi-criteria method aims at examining the availability of a set of conditions and criteria in a particular area. In order to provide many options for decision-makers, these are applied in geographic information systems because contains spatial analysis and data processing.

There are different ways to apply multiple criteria, the fuzzy analytic hierarchy process method (FAHP) will be used in our study [50].

The FAHP method is an extension of the AHP method and since AHP relies on the use of conventional crisp numbers and since the ambiguity of the attributes is fundamental to decision-making problems, the FAHP has been developed to solve this problem.

The following figure shows the steps we will take to reach optimum areas.

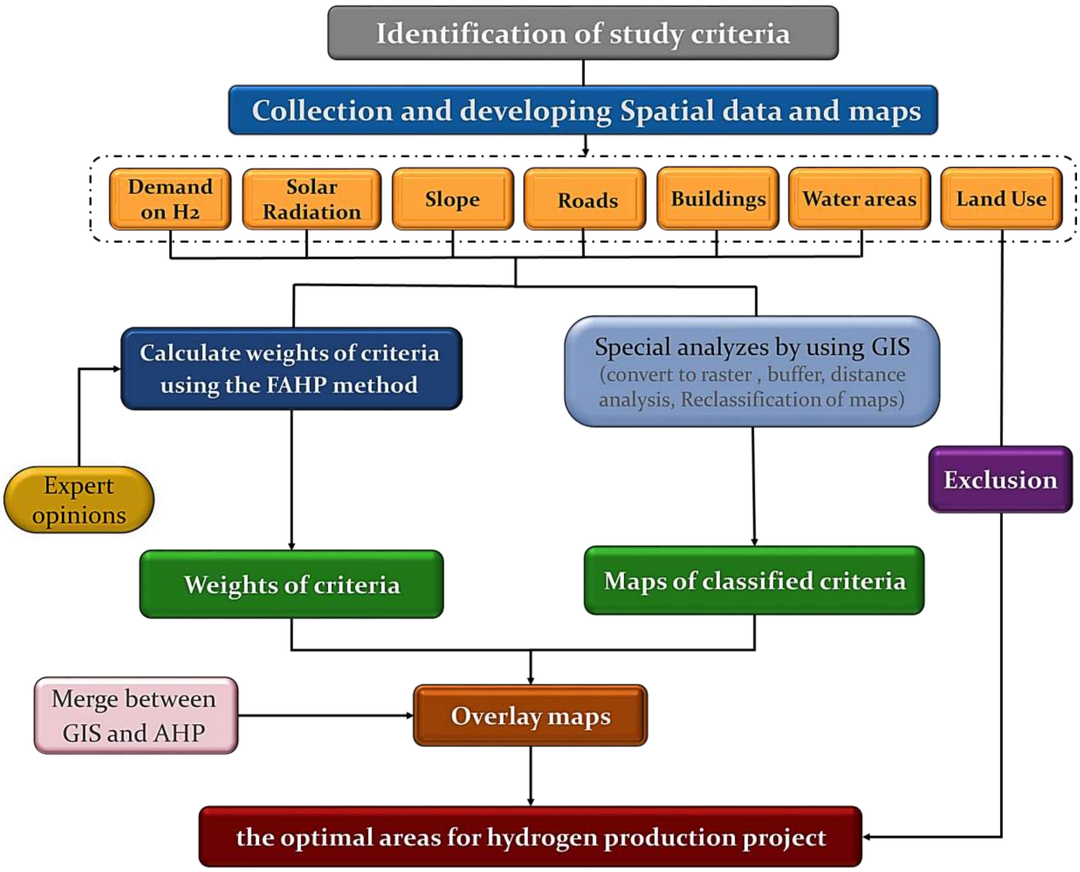


Figure 3.4: The steps for solar hydrogen production selection site.

3.5. Application of fuzzy analytic hierarchy process for Site Selection Assistance

3.5.1. Identification of criteria for multi-criteria analysis

Based on a set of previous studies specialized in selecting the criteria used in our research, including [51, 52].

The input datasets consist of several geospatial databases, each represents a specific criterion. In the current research, the acquired input data contain a Digital Elevation Model (DEM) for Ouarglacity,thedaily average of solar radiation map obtained from Solargis site and several topographic , among these topographic maps we have a roads map obtained from open street map site and a waters, buildings and land use map.

The value of solar radiation reaching the earth is the first criterion in the production of solar hydrogen and then the demand for hydrogen and the slope of the surface of the earth that effects on the equipment and installations of this project, and also distance from water areas, residential areas and land use are also important factors in the production of solar hydrogen. Criteria are set of guidelines used as basis for a decision that can be measured and Evaluated, Criteria can be two types factors and constraint [53].

a. Constraint: element or feature that represents limitations area that is not preferred in any way or considered unsuitable like land use.

Land use areas

Important in the regional economy and protection of environmental characteristics because they contain agricultural land, recreation areas, airports and industrial areas. Therefore, this area is prohibited and unsuitable for the project so we have removed the land areas from the map by using clip tool to cut out the land use.

The following maps illustrate the land use before and after treatment:

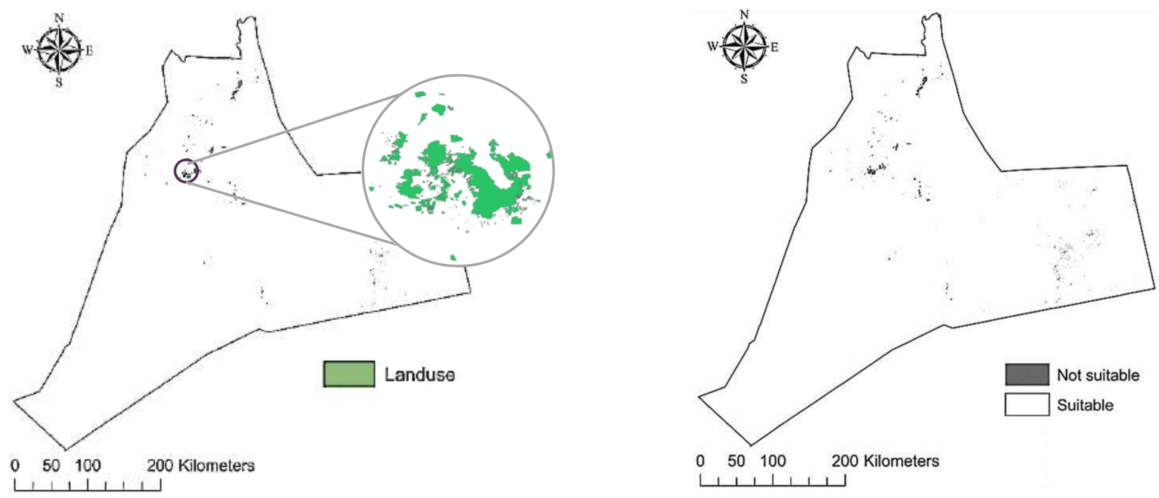


Figure 3.5: land use before and after treatment.

b. Factor: is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration like distance from the road (near or far from it).

In this study, seven criteria were selected, including technical factors and economic factors, which should be available at the most suitable locations for a solar hydrogen production project, and one constraint to avoid the establishment of this project on the land use.

b.1. Technical factors: this type contains the hydrogen demand, the potential of solar irradiation and the slopes.

b.1.1. Slope

By Using the global digital elevation model DEM of Ouargla region showed that elevations range from - 28 meters to 540 meters, examples of that The height of sand dunes can reach 200 meters and rocky hills that largely situated in the western part of the city, and a few of depressions are in the OuedRigh.

Using the spatial analyst tool of the slope in GIS system we extracted the slope of ouargla region from the available DEM.

The slope can be in different measurement units degrees or percentages. For degrees, the range of slope values is 0 to 90, and for percent rise, the range is 0 to essentially infinity. A flat surface is 0 percent, a 45 degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly larger.

The result showed that the slope in region of Ouargla range between 0 degree to 2.05645 degree, the following maps illustrate the DEM and slope.

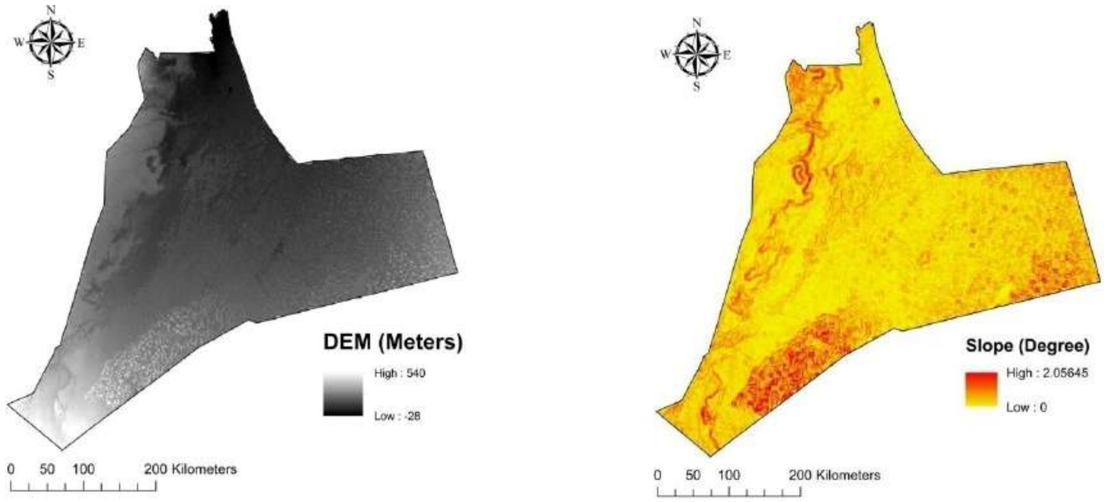


Figure 3.6: Map of elevation (DEM) and slope.

b.1.2. Solar irradiation

The daily average of solar radiation of the Ouargla region was taken by Solargis site [54], the data was taken as an raster file then processed by GIS system.

The data showed that the horizontal rate of solar radiation in the administrative region of Ouargla range from 5.253(KWh /m2/day) to 6.028(KWh /m2/day).The following figure shows that the solar radiation has a maximum value in the southern side of the Ouargla region and a small value in the northern area of the region, The following maps illustrate the solar irradiation in Ouargla

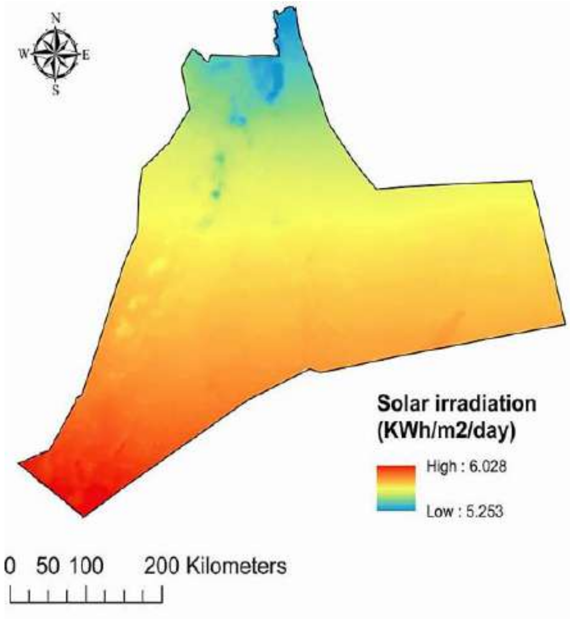


Figure 3.7: Solar irradiation in Ouargla region.

b.2. Economical factors : they include proximity to the road network ,proximity to residential areas and waters area.

b.2.1. Network roads

The road network in ouargla was taken by site Open Street Map [55], contains 1485 km of national roads and 366 km of wilaya roads and 235 km of communal roads [43] The road network is one of the most important factors in the project of producing solar hydrogen, because the transport process is done through the road network so we have chosen 500 meters as distance near from the production areas. The following map illustrate the road**.**

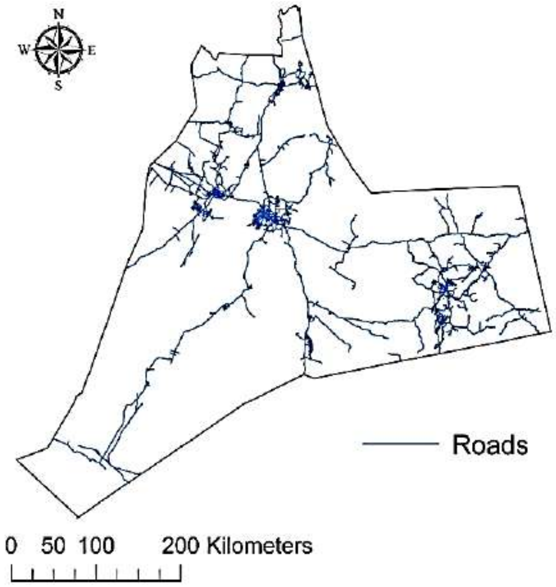


Figure 3.8: Map of the Roads**.**

b.2.2. Buildings areas

In order to protect residential areas from excessive disturbances resulting from the production of solar hydrogen, a five kilometer buffer zone around residential areas was chosen as an unsuitable area for the installation of solar hydrogen production.

The following map illustrate the buildings and the buffer.

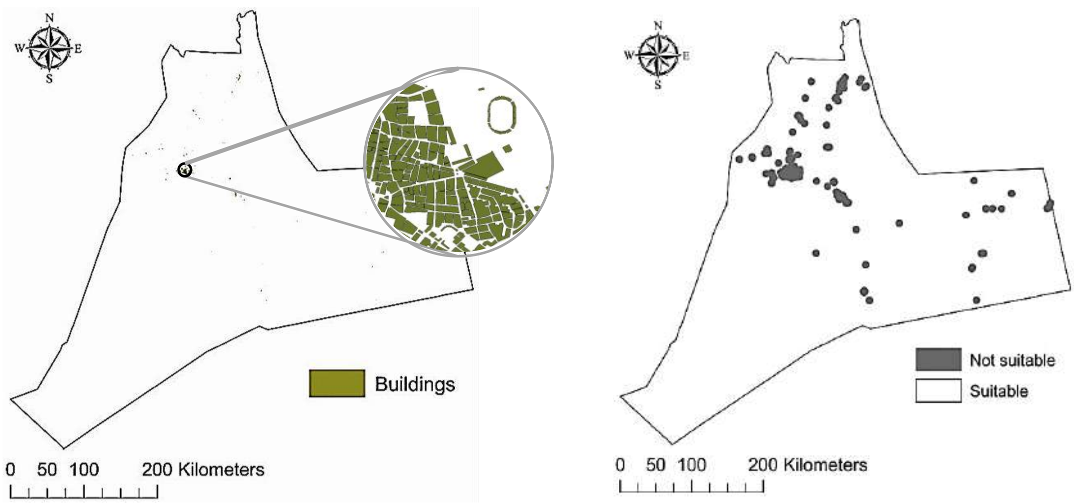


Figure 3.9: Map of the buildings and the buffer.

b.2.3. Water areas

Water areas are represented by the fossil valley of Oued Mya and Oued Righ valley [43].

Water represents an important part of the environmental characteristics must not be exposed to harmful effects as a result of exploitation of the site.For this two and a half kilometres buffer zone around water areas was chosen as an unsuitable area for the installation of solar hydrogen production ,by using the buffer analysis tool of GIS system.

The following map illustrate the water area and buffer:

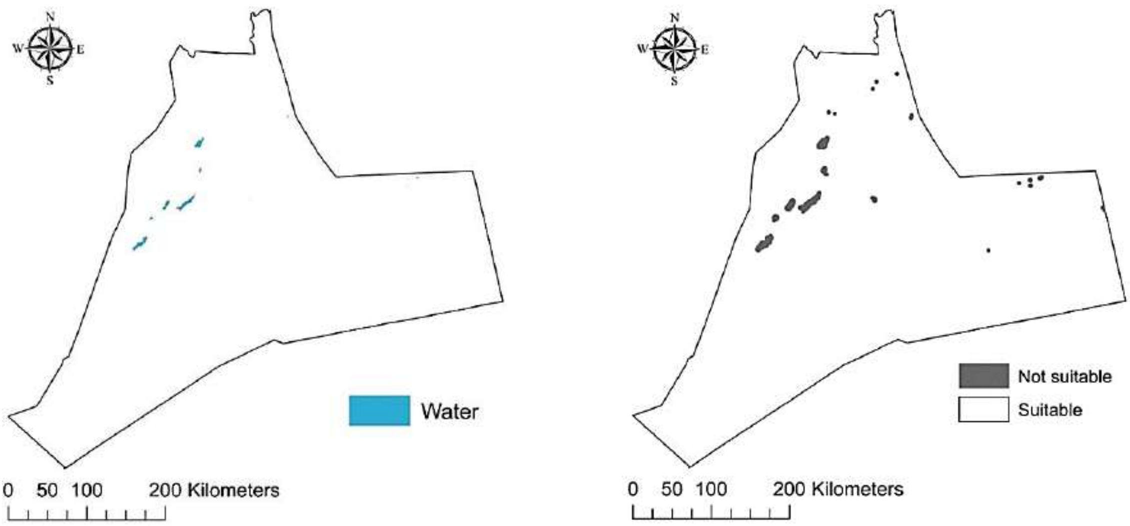


Figure 3.10: Map of the Water and the Buffer.

The following table illustrates the hierarchy of standards and sub-criteria of the decision.

Table 3.1: Hierarchy of criteria and sub-criteria of decision.

Criteria	Subcriteria	Geometry Type	symbole	Scale	source
Technical	Demand on hydrogen (kg H2/day)	Polygon	M1	1:7,409,729	Calculated
	Solar Radiation (KWh /m2/day)	Point	M2	1:7,409,729	Solargis
	Slope(degree)	Point	M6	1:7,409,729	CGIAR CSI
Economical	Distance form Building (km)	Polygon	M4	1:7,409,729	Geofabrik
	Distance form Road(km)	Line	M3	1:7,409,729	Geofabrik
	Distance form Water (km)	Polygon	M5	1:7,409,729	Geofabrik
Constraints	Land Use	Polygon	-	1:7,409,729	Geofabrik

3.5.2. Categorization and standardization of the factors criteria

Suitability models have been developed according the classification schemes applied and based on the classification adopted in the previous work [51, 52]. Unite the values of reclassification function is mandatory because different criteria are measured in different units and different scales. Re-classification function has been carried out to convert values of each raster on a scale of 0 to 10, which are divided into three categories: low, medium and high. Where 0 represents the unsuitability index, 10 represents the high suitability index. The table presents the classification of the criteria.

Table 3.2: Classification and standardization of criteria.

Subcriteria	Categories	Suitablity	Range(0-10)
M_1	>2000	High	8-10
	2000 – 500	Medium	4-7
	<500	Low	1-3
M_2	> 6	High	10
	6-5	Medium	4-9
	5-4.5	Low	1-3

M_6	0-1	High	9-10
	1-2	Medium	7-8
	2-3	Low	1-6
	> 3	Not Suitable	0
M_4	> 5	Suitable	10
	< 5	Not Suitable	0
M_3	0.5 – 2	High	9-10
	2 – 10	Medium	2-8
	>10	Low	1
	<0.5	Not Suitable	0
M_5	> 2.5	Suitable	10
	<2.5	Not Suitable	0

The following figure shows the steps to process the criteria by GIS system and finally get the criteria categorized according to the three categories mentioned previously.

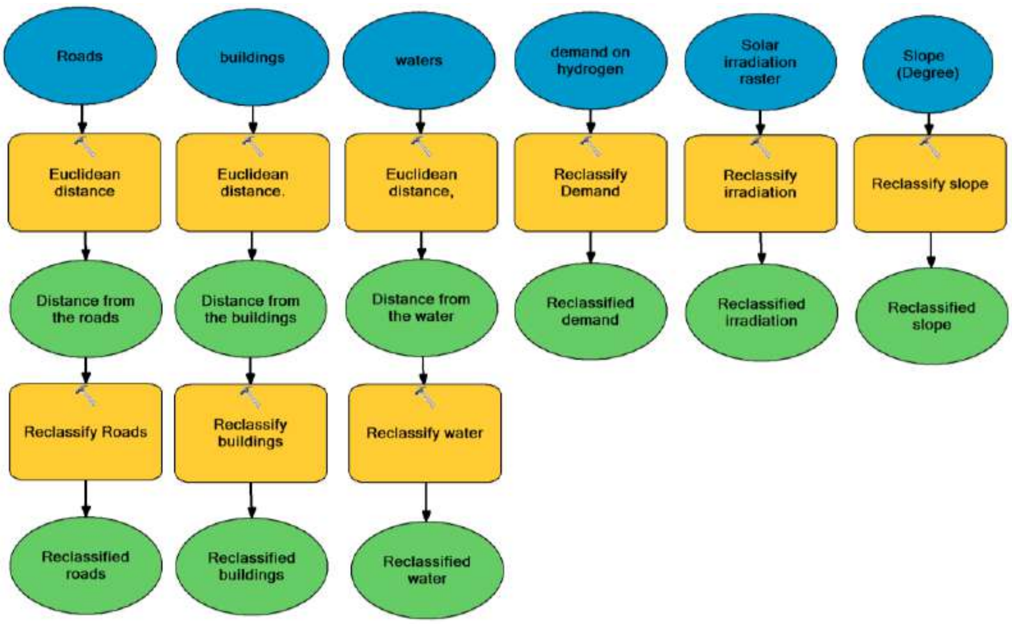


Figure 3.11: The process of criteria by GIS system.

Criteria after processing:

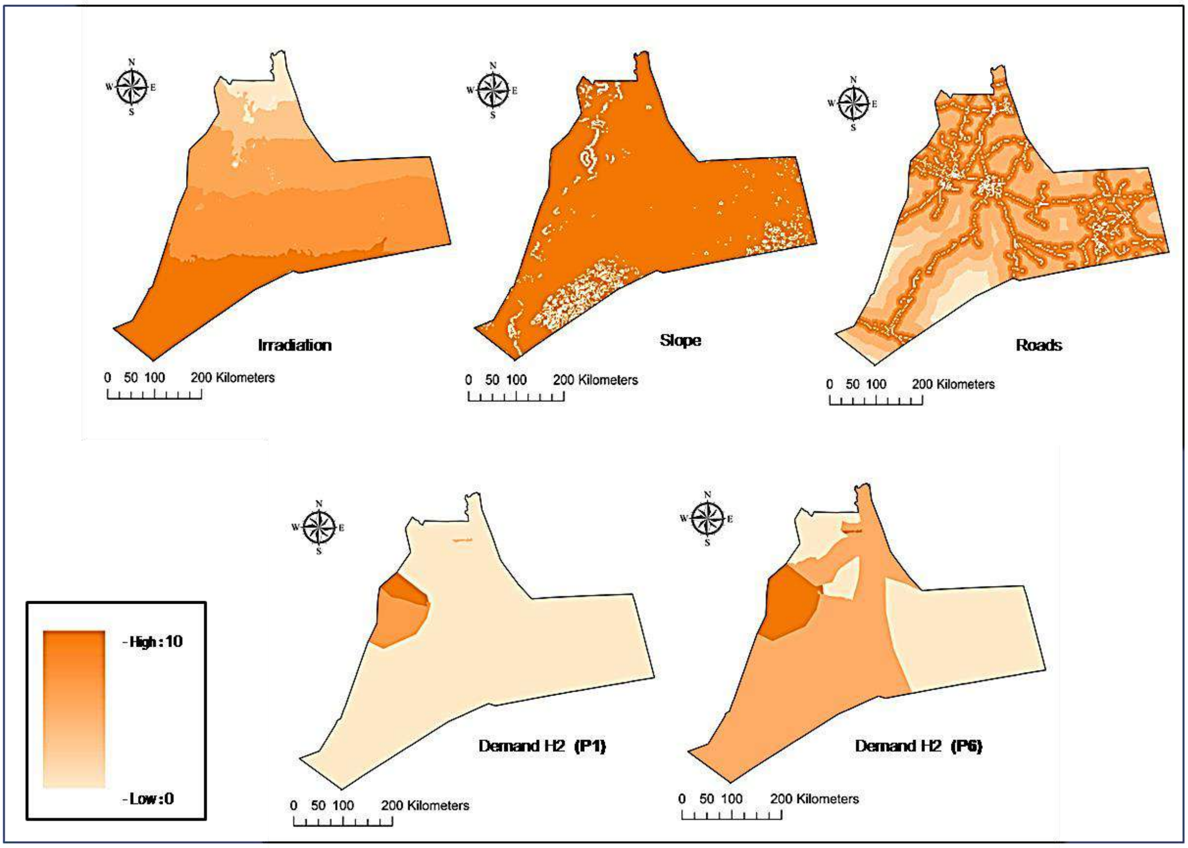


Figure 3.12: Reclassification of criteria.

The following figure illustrates the Re-classification of Water and building that gave them a division (0 and 10).

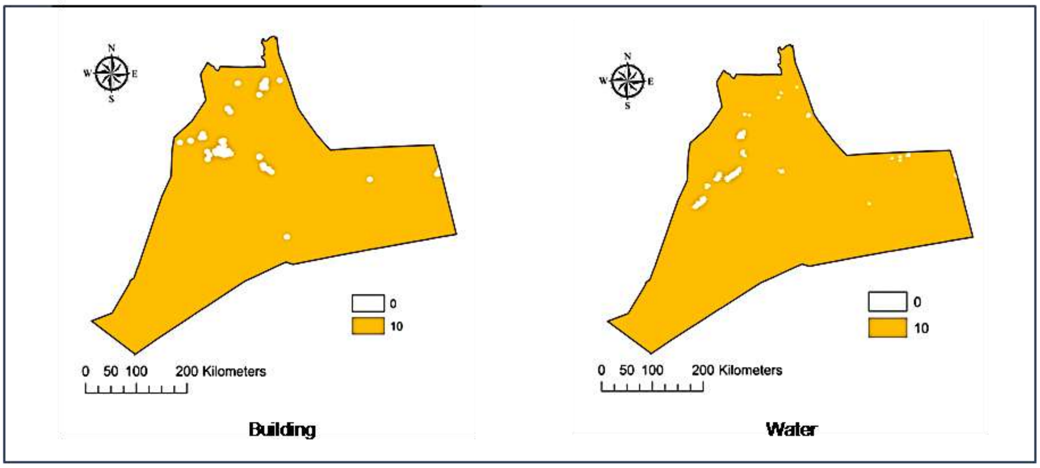


Figure 3.13: Reclassification of water and building.

3.5.3. Weighting of the criteria

Multi criteria decision making is a method to deal with the process of making decision among number of alternatives with conflicting criteria on them . AHP is one of the very popular MCDM method it is a multi-criteria decision method that uses hierarchical structures to represent a problem and then develop priorities for alternatives based on the judgment of the user (Saaty, 1980) and fuzzy AHP is an extension of original AHP method suggested by saaty to deal with qualitative and quantitative data .

The FAHP procedure involves six essential steps [56, 57]:

1. **pairwise comparison:**

For each element of the hierarchy structure all the associated elements in low hierarchy are compared in paiwise comparison matrices as follows:

$$A = \begin{bmatrix} 1 & \frac{w1}{w2} & \cdots & \frac{w1}{wn} \\ \frac{w2}{w1} & 1 & \cdots & \frac{w2}{wn} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{wn}{w1} & \frac{wn}{w2} & \cdots & 1 \end{bmatrix} \quad (3.7)$$

Where A = comparison pairwise matrix,

$w1$ = wheight of element M_1,

$w2$ = wheight of element M_2,

wn = wheight of element M_3.

In order to determine the relative preferences for two elements of the hierarchy in matrix$A$, an underlying semantical scale is employs with values from 1 to 9 to rate (Table3.3).

Table 3.3: Scales for pair wise comparison [36].

linguistic variables	linguistic variables	Triangular fuzzy numbers	Reciprocal triangular fuzzy numbers
Equal importance	1	(1,1,1)	(1,1,1)
Moderate importance	3	(2,3,4)	(1/4,1/3,1/2)
Strong importance	5	(4,5,6)	(1/6,1/5,1/4)
Very strong importance	7	(6,7,8)	(1/8,1/7,1/6)
Extreme importance	9	(8, 9,9)	(1/9,1/9,1/8)
Intermediate values between adjacent scale values	2, 4, 6,8	(1,2,3) , (3,4,5), (5,6,7), (7,8,9)	(1/3,1/2,1) ,(1/5,1/4,1/3), (1/7,1/6,1/5), (1/9,1/8,1/7)

In this study we consulted several experts in the field, and the results from expert K1 represented in this table.

Table 3.4: Pairwise comparison of the study from expert K1.

Criteria	M_1	M_2	M_3	M_4	M_5	M_6
M_1	1	3	5	5	7	7
M_2	1/3	1	3	3	5	5
M_3	1/5	1/5	1	2	3	3
M_4	1/5	1/3	1/2	1	3	3
M_5	1/7	1/5	1/3	1/3	1	2
M_6	1/7	1/5	1/3	1/3	1/2	1

2. **Check the consistency**:

The evaluation requires a certain level of matrix consistency, i.e. that the elements are linear independent. That can be assessed employing consistency index CI as follows:

Firstly the λ_{max} has to be calculated by using equation (3.8), the details of the calculations are presented in Table 3.5.

$$\lambda_{max} = \sum_{j=1}^{n} \frac{(S.V)_j}{n.V_j} \tag{3.8}$$

λ_{max} : The highest eigenvalue of the matrix;

V: The matrix eigenvector;

S: Pair-wise comparison matrix;

n: Number of criteria.

Table3.5: Calculation of maximum eigenvector.

	M1	**M2**	**M3**	**M4**	**M5**	**M6**
$(\boldsymbol{S} \cdot \boldsymbol{V})_j$	0.4500	0.2349	0.1219	0.0994	0.0530	0.0408
$\boldsymbol{n} \cdot \boldsymbol{V}_j$	0.4953	0.1974	0.0984	0.0857	0.0513	0.0476
$\boldsymbol{\lambda_{max}}$	[(0.4500/0.4953)+(0.2349/0.1974)+(0.1219/0.0984)+(0.0994/0.0857) +(0.0530/0.0513)+(0.0408/0.0476)]=6.38					

Then the consistency index (CI) can be calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{3.9}$$

<u>AN:</u>

$$CI = \frac{6.38 - 6}{6 - 1} = 0.078$$

Table 3.6: Random consistency index (RI).

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

RI random index, simply obtained from the table of Random Inconsistency indices (Table 3.6) for n=6, the RI is 1.24. With which the consistency ratio (CR) is calculated using Equation (3.10) .

$$CR = \frac{CI}{RI} \tag{3.10}$$

<u>AN:</u>

$$CR = \frac{0.078}{1.24} = 0.0629$$

Since this value of 0.0629 for the proportion of inconsistency CR is less than 0.10, we can assume that our judgments matrix is reasonably consistent so we will continue the process of decision-making using FAHP.

3. Triangular fuzzy comparison

Like classical AHP approach, fuzzy AHP also has a judgment matrix, using triangle fuzzy number (TFN) instead of constant pairwise comparison value so we convertpairwise comparison matrices for each expert to triangular fuzzy comparison matrix $\tilde{A}\,(a_{ij})$ can be expressed mathematically as:

$$\tilde{A}\,(a_{ij}) = \begin{bmatrix} (1,1,1) & (l_{12,}m_{12,}u_{12}) & \dots & (l_{1n,}m_{1n,}u_{1n}) \\ (l_{21,}m_{21,}u_{21}) & (1,1,1) & \dots & (l_{2n,}m_{2n,}u_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (l_{n1,}m_{n1,}u_{12}) & (l_{n2,}m_{n2,}u_{n2}) & \dots & (1,1,1) \end{bmatrix} \tag{3.11}$$

After converting pairwise comparison of the study from expert one by using the fuzzy numbers in scales for Saaty (Table 3.3), we get the results represented in this table:

Table 3.7: The fuzzy judgment matrix of the study from expert K1.

	M1			**M2**			**M3**			**M4**			**M5**			**M6**		
	l	m	U	l	m	u	l	m	u	l	m	u	l	M	u	l	M	U
M1	1	1	1	2	3	4	4	5	6	4	5	6	6	7	8	6	7	8
M2	1/4	1/3	1/2	1	1	1	2	3	4	2	3	4	4	5	6	4	5	6
M3	1/6	1/5	1/4	1/4	1/3	1/2	1	1	1	1	2	3	2	3	4	2	3	4
M4	1/6	1/5	1/4	1/4	1/3	1/2	1/3	1/2	1	1	1	1	2	3	4	2	3	4
M5	1/8	1/7	1/6	1/6	1/5	1/4	1/4	1/3	1/2	1/4	1/3	1/2	1	1	1	1	2	3
M6	1/8	1/7	1/6	1/6	1/5	1/4	1/4	1/3	1/2	1/4	1/3	1/2	1/3	1/2	1	1	1	1

4. Aggregation of the group evaluations :

Compilation of triangular fuzzy comparison matrix for each expert (Their numberis n) to obtain the final matrix to obtain the final matrix$\tilde{A}_{ij} = (L_{ij}, M_{ij}, U_{ij})$where:

$$L_{ij} = \min(l_{ijk}),\ M_{ij} = \left(\prod_{k=1}^{n} M_{ijk}\right),\ U_{ij} = \max(u_{ijk}) \tag{3.12}$$

The results represented in the table

Table 3.8: The fuzzy judgment matrix of the study after the compilation of the views of experts.

	M_1			**M_2**			**M_3**			**M_4**			**M_5**			**M_6**		
	l	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**l**	**m**	**u**	**L**	**M**	**u**	**L**	**m**	**u**
M_1	1	1	1	0.16	1.22	4	0.167	0.71	6	0.25	2.03	6	2	5.28	8	3	6.32	9
M_2	0.25	0,82	6	1	1	1	1	2.62	4	2	3.30	5	4	5.94	8	4	6.54	9
M_3	0.167	0.58	6	0.25	0.38	1	1	1	1	1	2	3	2	4.93	9	2	5.13	9
M_4	0.167	0.49	4	0.2	0.30	0.5	0.333	0.50	1	1	1	1	2	3.56	6	2	4.38	8
M_5	0.125	0.19	0.5	0.125	0.17	0.25	0.111	0.20	0.5	0.167	0.28	0.5	1	1	1	1	2.29	4
M_6	0.111	0.16	0.33	0.111	0.15	0.25	0.111	0.19	0.5	0.125	0.23	0.5	0.25	0.44	1	1	1	1

5. Computing the normalized value of row sums:

Computing the normalized value of row sums (i.e. fuzzy synthetic extent) by fuzzy arithmetic operations:

$$S = \sum_{j=1}^{n} a_{ij} \otimes \left(\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}\right)^{-1} \tag{3.13}$$

Where $\otimes$denotes the extended multiplication of two fuzzy numbers, and $S = (L_i , M_i , U_i)$

The output of this sum($\sum_{j=1}^{n} a_{ij}$) is the fuzzy additional operation of n extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{n} a_{ij} = \left(\sum_{j=1}^{n} l_{ij} , \sum_{j=1}^{n} m_{ij} , \sum_{j=1}^{n} u_{ij}\right) \tag{3.14}$$

The total some of these $\left[\left(\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}\right)^{-1}\right]$ will lead to the fuzzy addition operation of values such that, the inverse of $(j = 1, \ldots\ldots, n)$ the vector in equation (3.11) can be shown as follows.

$$\left(\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}\right) = \left(\sum_{i=1}^{n}\sum_{j=1}^{n} l_{ij} , \sum_{i=1}^{n}\sum_{j=1}^{n} m_{ij} , \sum_{i=1}^{n}\sum_{j=1}^{n} u_{ij}\right)^{-1^{-1}} \tag{3.15}$$

$$\left(\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}\right)^{-1} = \left(\frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} l_{ij}} , \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} m_{ij}} , \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} u_{ij}}\right) \tag{3.16}$$

By utilizing the information of (Table 3.8) and using Equations (3.14), (3.16) the following results can be calculated.

$\sum_{j=1}^{6} a_{1j} = (6.583333 , 17.54781 , 34)$, $\sum_{j=1}^{6} a_{2j} = (12.25 , 20.23079 , 33)$

$\sum_{j=1}^{6} a_{3j} = (6.416667 , 14.02873 , 29)$, $\sum_{j=1}^{6} a_{4j} = (5.7 , 10.23251 , 20.5)$

$\sum_{j=1}^{6} a_{5j} = (2.527778 , 4.131031 , 6.75)$, $\sum_{j=1}^{6} a_{6j} = (1.697222 , 2.171235 , 3.583)$

and $\left(\sum_{i=1}^{6}\sum_{j=1}^{6} a_{ij}\right)^{-1} = (0.007884 ,\ 0.014632 ,\ 0.028429)$

6. Calculation of weights :

There are two ways to calculate weights one directly and the other indirectly we chose the direct method.

Estimate the priority vector $W = (w_i, ... , w_n)^T$ of the fuzzy comparison matrix Ã as follows:

$$W_i = \frac{L_i + M_i + U_i}{3} \quad , \quad i = 1 , ... , n \tag{3.17}$$

In order to rank the criteria, the TFN should be defuzzified, so we used a simple centroid method, the calculated weights of each criterion were normalized as follows:

$$NW_i = \frac{W_i}{\sum_{i=1}^{n} W_i} \tag{3.18}$$

Where

$$\sum_{i=1}^{n} NW_i = 1$$

The results of weights are used equations (3.17), (3.18) and synthetic values as shown in table (3.9).

Table 3.9: The fuzzy evaluation of the study.

Criteria	synthetic values	Normalized weights
M_1	(0.051905, 0.256764 , 0.966290)	0,261158
M_2	(0.096583, 0.296022 , 0.937870)	0,272525
M_3	(0.050591, 0.205272 , 0.824189)	0,221234
M_4	(0.044940, 0.149725 ,0.582616)	0,159215
M_5	(0.019929, 0.060446 , 0.191837)	0,055758
M_6	(0.013469, 0.031770 , 0.101839)	0,030108

3.5.4. Aggregation of criteria:

There are many tools in the GIS system to aggregation the criteria and obtain the final form of optimal areas for the solar hydrogen production as a weighted overlay, raster calculator and other tool, In this work we chose the weighted overlay tool.

Weighted Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis.

The weighted overlay table allows the calculation of a multiple-criteria analysis between several rasters,the following figure is Illustration of how weighted overlay works [58].

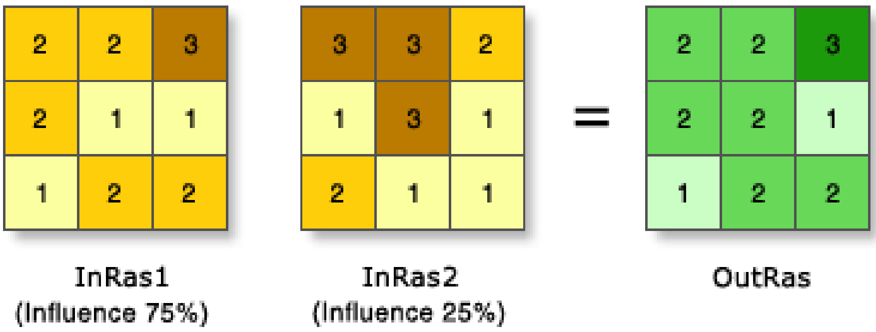


Figure 3.14: way of work the weighted overlay [58].

The steps for running weighted overlay are [58]:

- All input rasters must be integer. A floating-point raster must first be converted to an integer raster before it can be used in Weighted Overlay. The Reclassification tools provide an effective way to do the conversion.
- Each value class in an input raster is assigned a new value based on an evaluation scale. These new values are reclassifications of the original input raster values. A restricted value is used for areas you want to exclude from the analysis.
- Each input raster is weighted according to its importance or its percent influence. The weight is a relative percentage, and the sum of the percent influence weights must equal 100 percent.
- Changing the remap_assignment evaluation scale value or the percentage influences can change the results of the weighted overlay analysis.

In this step, we collected all layers of information, and then gave each layer the weight that represented by its importance in the project, using FAHP method.

Later we used the 'weighted overlay' tool available in "Arctoolbox" In order to reach the final shape, which represents the optimal areas for the solar hydrogen production , the following figure illustrates the method on the ArcGIS interface

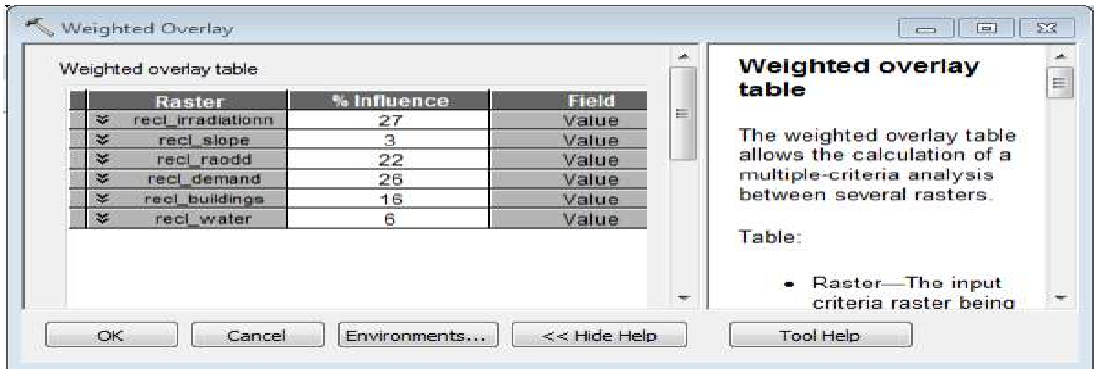


Figure 3.15: Weighted overlay interface on ArcGIS.

The following figure is a building model for weighted overlay:

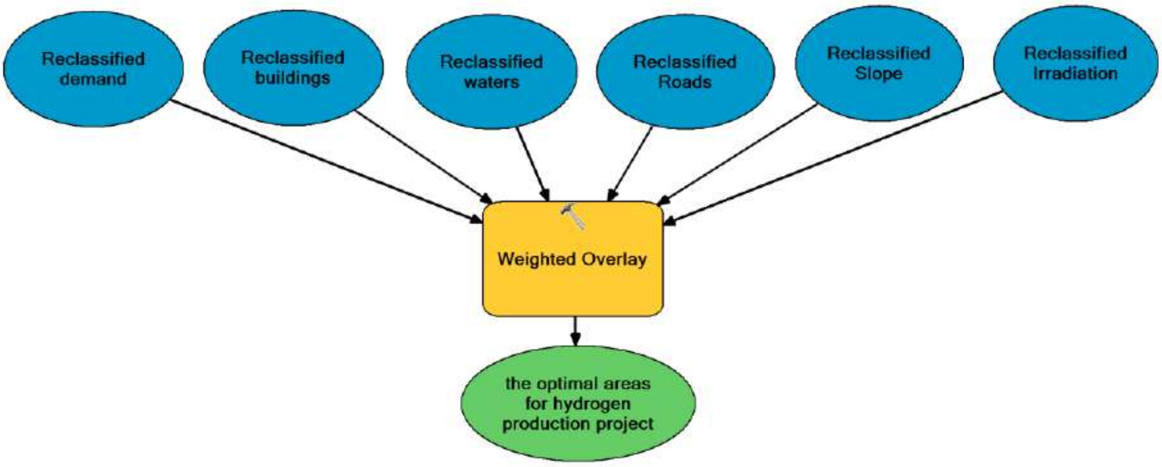


Figure 3.16: building model for weighted overlay.

3.5.5. Results and discussion

A. Result of the first period from 2018 to 2023

The attained suitability model represents the ideal locations for hydrogen production in the Ouargla region in the first five years of the study, for a penetration rate of hydrogen vehicle equal 5 %.

It has been found that the regions of the state of Ouargla have varying ratios of suitability for the production of solar hydrogen ranging from 4 to 8, on a scale of 10. In addition, the areas of high suitability with index of 8 from 10 represent 1.3% and found to have an area of 1974.67 square kilometer from the total area of Ouargla region; represented of the municipalities

Ouargla and Rouissat. This is because of the high demand for hydrogen by these municipalities, also 7% not suitable has an area of 10793.59 square kilometer.

Other municipalities have varying ratios of suitability from 4 to 7 on a scale of 10 represent 88.7% have an area of 141745.212 square kilometer from the total area.

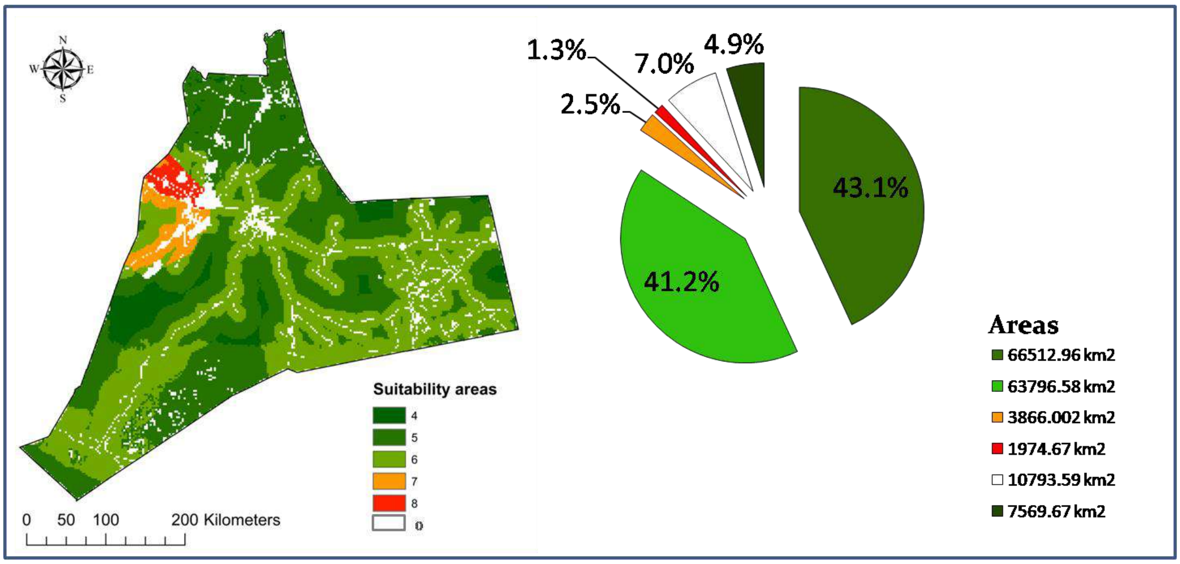


Figure 3.17: Result of the first period from 2018 to 2023.

B. Result of the sixth period from 2043 to 2048

The final fit model for the last five years of the study found that most of the lands of Ouargla Suitable for the production of solar hydrogen, with an average of 8 of 10 representing 16.5 % with an area of 25576.76 square kilometer of the total area, except of municipalities Sidi Sulaiman, El Burma, El Alia and Hassi Ben Abdallah they have a low on hydrogen demand and that because of low in growing the market penetration rate of hydrogen vehicles.

The areas of medium suitability with index from 5 to 7 on a scale of 10 represent 76.5% and found to have an area of 118107.92 square kilometer.

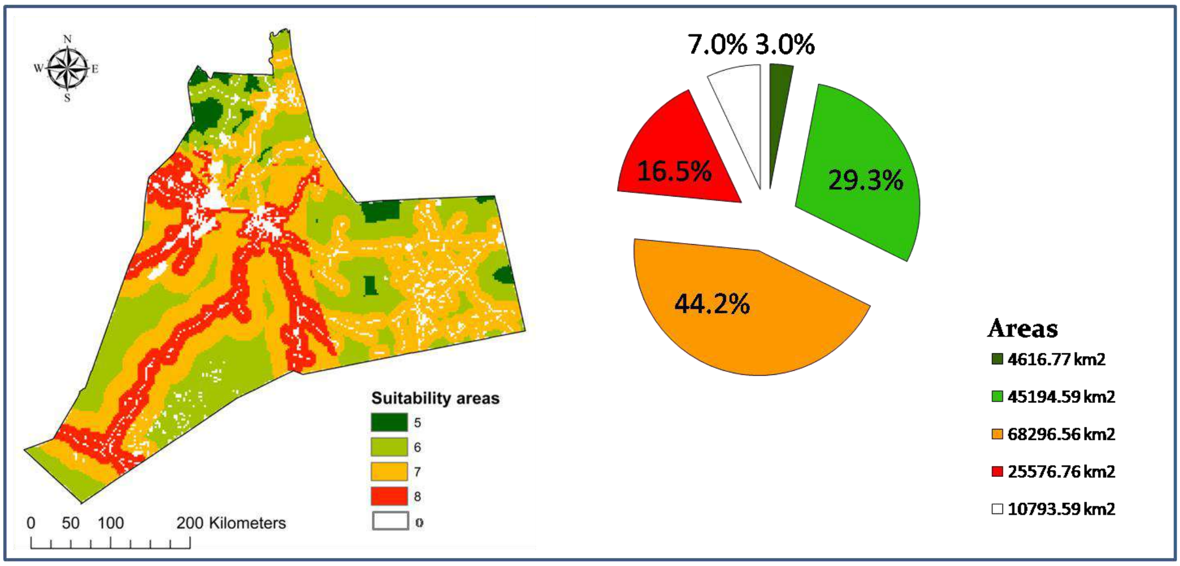


Figure 3.18: Result of the 6 th period from 2043 to 2048.

3.6. GIS-based network analysis for determination the hydrogen stations

3.6.1. Hydrogen station site scenario

Hydrogen fueling stations are the building blocks of a hydrogen transportation infrastructure. While their primary function is to provide hydrogen fuel for vehicles. Spatial locations of hydrogen stations play a key role in hydrogen production chain for the transport sector. Many studies [59, 60] are based on different methods of locating hydrogen distribution stations.

There are studies based on the calculation of the flow of vehicles through mathematical equations and through which the selection of the best locations for stations, there are also other studies based on the study of consumer behavior and how to make it acceptable to hydrogen vehicle. and other studies based on siting hydrogen stations by a maximum distance and that maximum distance should be dictated by the technology of hydrogen vehicles.

But the link between these studies is that they depend on the strategic plan in the location of the stations. In this study we tried to create a scenario that combines these studies, where hydrogen stations siting can be split into two criteria:

- ❖ The first is intra-regional siting within high demand of hydrogen, the goal here was to cover the need for hydrogen based on demand. We calculated the demand in the first period in the municipalities of Ouargla and Rouissat with high demand was about 2200 kg/day. The hypothesis was the use of distribution stations with capacity 800 kg/day. So the need is three stations. Sites are selected using the GIS program so that the sites are homogeneous.

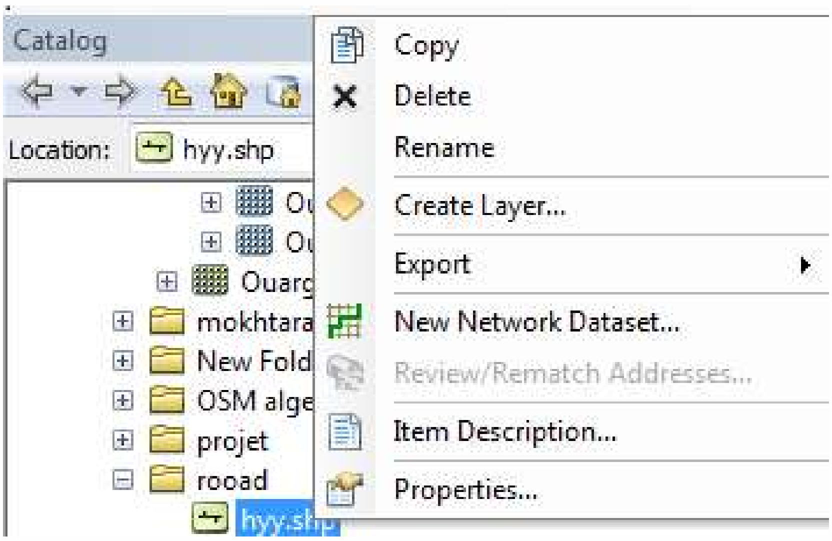
- ❖ The second is to locate the hydrogen stations in the main ways the goal here is to facilitate trips between regions. Siting hydrogen stations should be constrained by a maximum distance and that maximum distance should be dictated by the technology of hydrogen vehicles. The maximum range of a hydrogen vehicle varies widely. Toyota Highlander get a range of 280 km [61]. However, ranges vary based on conditions such as hill climbing and air conditioner use. Because of this, a range of about 160-200 km can be assumed. To facilitate a 160-200 km range, hydrogen stations can be placed about 160-200 km apart and safely provide fuel for inter-regional trips.

3.6.2. Steps creating a network dataset

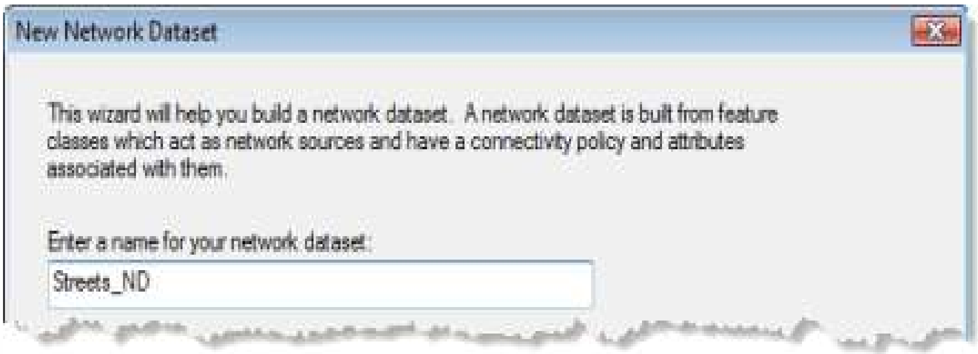
Creating a network data set is the first step before using network analysis, building a network data set can help you access network analysis services and facilitate the process of determining any service in the network.

The following steps show how to build a network data set.

- ❖ Start Arc Catalog.
- ❖ From the catalog Right-click the Road feature dataset and click Network Dataset.



- ❖ Type Streets_ND for the name of the network dataset then Click Next.



- ❖ Check the Streets feature class to use it as a source for the network dataset then Click **Next** Click **Yes** to model turns in the network.
- ❖ Check **Restricted Turns** to select it as a turn feature source < **Global Turns** > should be checked already this enables you to add default turn penalties.
- ❖ Click **Next.**
- ❖ Click **Connectivity**.

The Connectivity dialog box opens. Here you can set up the connectivity model for the network. For this Road feature class, all roads connect to each other at end points.

1. Make sure that the connectivity policy of **Roads** is set to **End Point**.
2. Click **OK** to return to the **New Network Dataset** wizard.
3. Click **Next**.

- ❖ Close Arc Catalog.

Now you can add the network dataset to ArcMap and use it to create network analysis layers, The following figure shows the road network that was created.

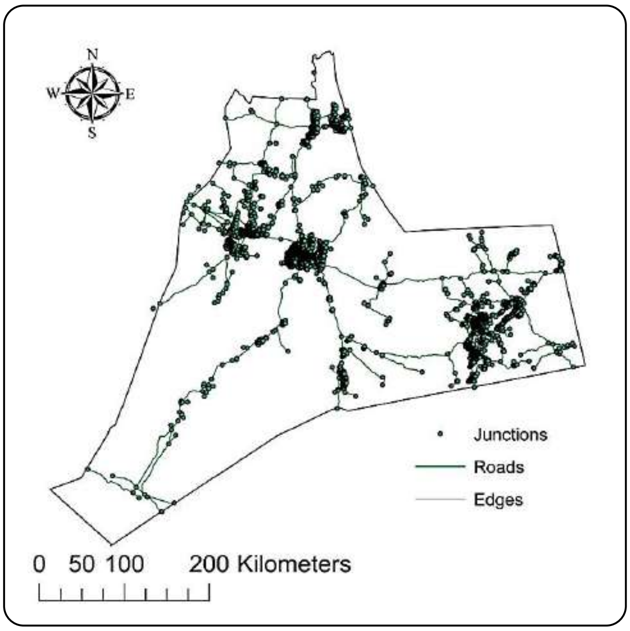


Figure 3.19: The road network of Ouargla.

3.6.3. The necessary input data in the analysis of road networks

3.6.3.1. The quality of inputs needed in the analysis of road networks

There are a set of information to be entered on the road network, which is necessary data to form a smart grid to get the desired results:

- The length of the street.
- Street type.
- Maximum speed in the street.
- The time it takes for a vehicle to cross the Street direction.
- Street orientation.

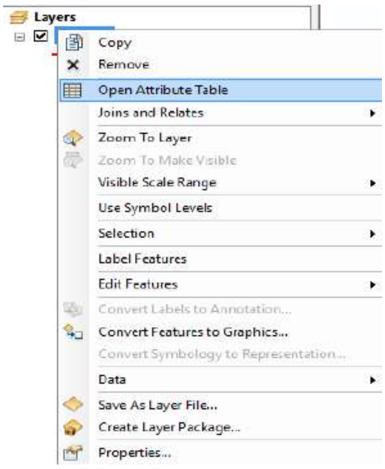
The network of roads was taken from the geofabrik site and found it contains a set of road types with their distance of each road such as primary roads, secondary roads, residential roads…..ect.

This network was processed by the GIS system and a set of preliminary information was added as the speed, each type of road was given the speed that should not be exceeded, we depended on the traffic law and road speed sign.

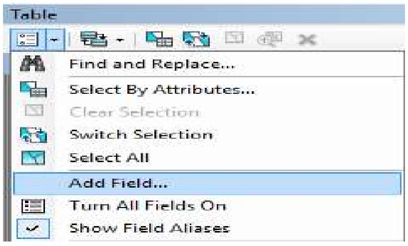
3.6.3.2. The method of adding the input data to the road network

First we must add three fields: maximum speed, time and direction of street. This is in the road layer information table in Arc GIS .

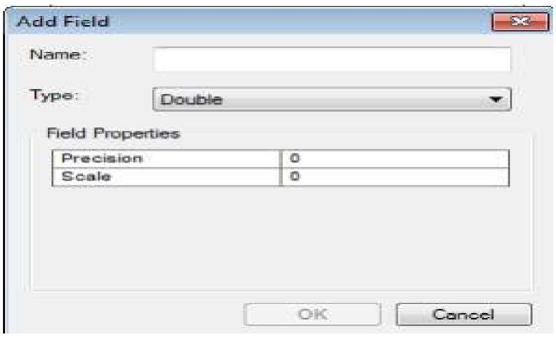
❖ Right-click on the layer of the road network and choose Open Tab Table.



❖ From the next interface choose Add File.



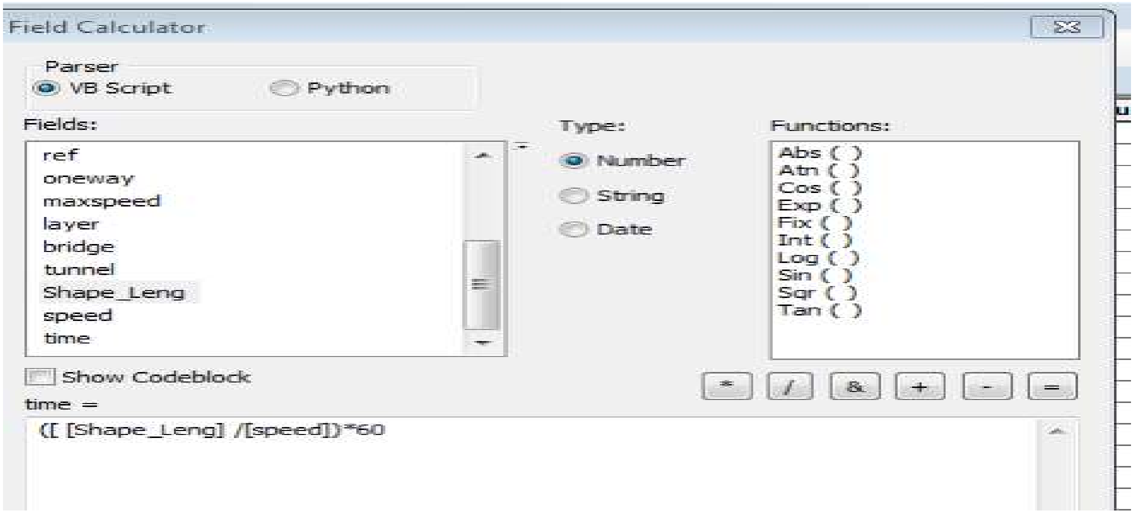
❖ After that, we will see the following interface and type the field name and field type.



Then fill the information which are: type street - maximum speed of the street - the direction of the street, Data entry is done by selecting each street and then entering street data.

After that, the time is calculated for the street by right-click on the Time field and selecting Field Calculator.

- ❖ Then the next interface we must write the time equation that is explained



After writing the time equation, GIS calculates the time taken on each route. After the time calculation is complete, the network is ready for the next step that we will use the tool of new service area analysis for selection the hydrogen station.

3.6.4. New service area tool for determination hydrogen station sites

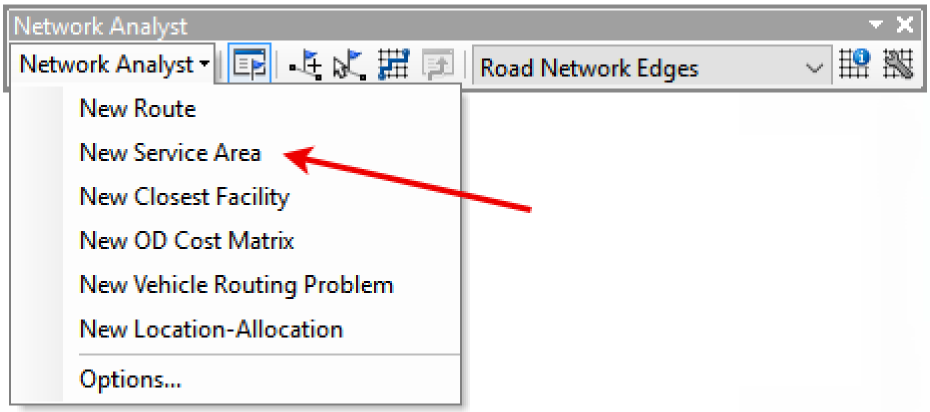
With the ArcGIS Network Analyst extension, you can find service areas around any location on a network. A network service area is a region that encompasses all accessible streets (that is, streets that are within a specified impedance) [62].

Service areas created by Network Analyst also help evaluate accessibility to different services. The ArcGIS Service Area tool can pinpoint all the streets in a given road network that can be reached from a start point facility in an allotted amount of time.

The importance of service area for a city, town or district, it could just be the deciding factor for where this is depending on the scenario we have adopted ex. fire station, police station, or hospital is built. We used the service area tool in this work to reach to the places of hydrogen stations and that depending on the scenario we have adopted.

The following steps illustrate the analysis of new service area tool.

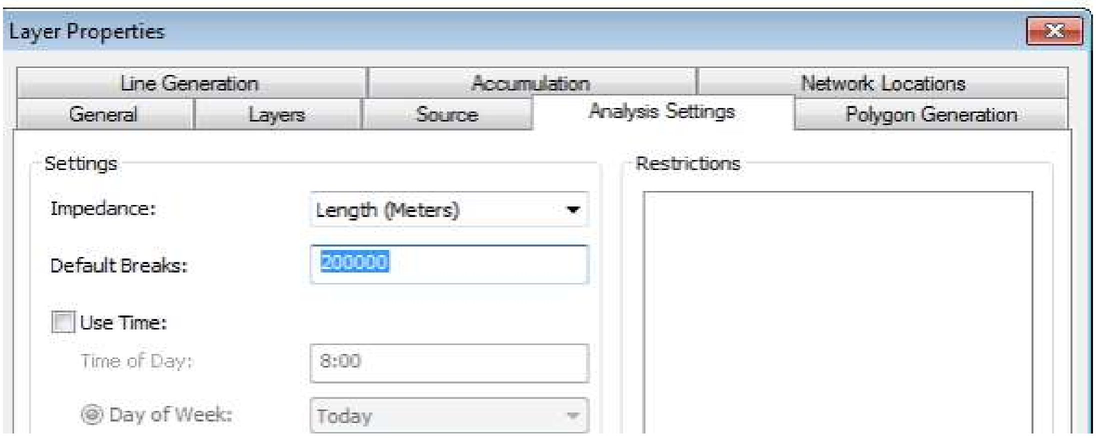
- ❖ First we add the network datset that we created, in the network analyst toolbar, select the New Service area tool by clicking Network Analyst > New Service Area.



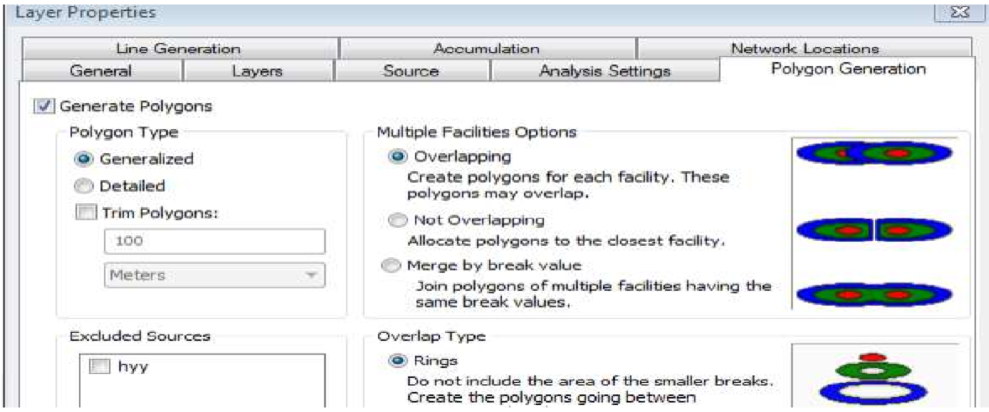
At this point, will see the service area analysis window appear in the table of contents**.**

The next step is to identify points in areas with large populations, and since the beginning of the study in the first five years of this study from 2018 to 2023 the demand on hydrogen was high by the municipality of Ouargla, Rouissat and Nazala for this reason the determination of hydrogen stations will be within these two municipalities.

- ❖ From the Table of contents right-click on the service area and choose properties.
- ❖ The next step will add the distance.



And make sure that the trim polygons is deactivate.



- ❖ Then click ok
- ❖ After that cilck on the slove

After clicking on the solve, GIS system will cover the required area and the Points identified will be station locations because the required space has been covered. The following figures illustrate the final shape of the places of stations.

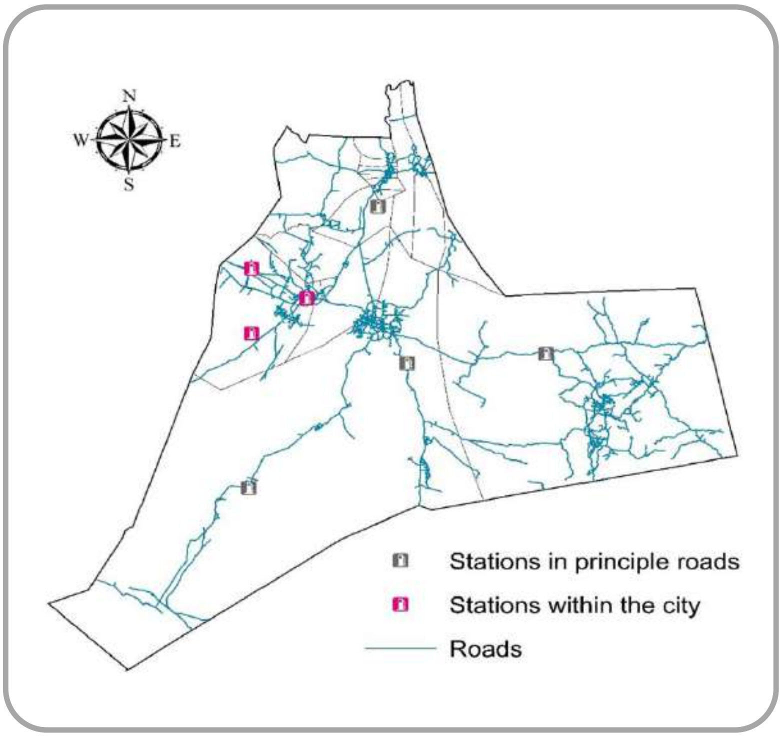


Figure 3.20: The places of stations.

3.7. Conclusion

Renewable energy, particularly the solar hydrogen, becomes an essential clean energy source worldwide. This chapter focused on the utilization of multi-criteria GIS approach ,and presented an application of combining FAHP with GIS for locating optimum sites of solar hydrogen production in Ouargla region. Based on seven technical and economical criteria.

The results obtained can be summarized as follows:

The first five years of the study demand was high only in the Ouargla and Rouissat is about 1000 kg/day that because the population is huge in those two municipalities, other have a low demand for hydrogen range from 51 kg/day to 600kg/day.

The last five years has seen an increase in the demand for hydrogen reached about 25000kg/day in the majority municipalities and remained weak in the municipality of Burma and this because of the low vehicle number of hydrogen.

The attained suitability model of first period represent 1.3% and with area of 1974.67 square kilometer has a of high suitability, Other municipalities have varying ratios of suitability represent 88.7% with area of 141745.212 square kilometer, incontrast.

The last period represent 16.5 % with an area of 25576.76 square kilometer has a of high suitability ,the areas of medium suitability represent 76.5% with area of 118107.92 square kilometer and 7% represented as area not suitable at all in both periods of study has a area of 10793.59 square kilometer.

Hydrogen stations were identified using network analysis based on a new service area analysis tool. Hydrogen stations were identified according to the needs scenario, where we obtained 3 identical stations in Ouargla, Rouaissat and safety scenario in the main roads, where we obtained 4 stations distributed on roads.

General conclusion

General conclusion

The green hydrogen obtained from the renewable sources is considered as a promising energy carrier for the future. It is universally admitted that hydrogen is one of the best energy media and its demand will increase greatly in the near future, because it can be used as clean fuel in a variety of energy end-use sectors including conversion to electricity without CO2 emission, and also can be stored and transported over long distances with lower loss compared to electricity.

Hydrogen has been touted as a clean energy and an environmentally friendly wonder fuel that can be used in vehicles and burns to produce only water as a by product it could greatly contribute to the solution of the global warming issue.

The objective of this work was to select optimal areas for the production of solar hydrogen. This study based on a set of different technical and economic criteria necessary for the integration of hydrogen as a green fuel in the road transport sector in the Ouargla region by 2048.

This study also focused on the utilization of multi-criteria GIS approach and FAHP method to evaluate the importance and determinate weights of criteria.

Also we have presented the impact of the integration of hydrogen as alternative fuel with different market penetration rates over the entire. A suitability model has been developed for combined of the fuzzy sets, the Multi-Criteria Analysis with GIS Based on seven technical and economical criteria, has allowed us to present a suitability model of the optimal areas of hydrogen production over the ouargla territories.

The results obtained can be summarized as follows:

The first five years was characterized by the high demand for hydrogen in the municipality of Ouargla and Rouissat reached 1000kg/day this increase because of the huge population in them. other municipalities have a low demand for hydrogen and this because of low the population that range from 51kg/day to 600 kg/day, but the last five years of the study were characterized by an increase in the demand for hydrogen in most municipalities, which is increasing due to increased market penetration of hydrogen vehicles, where the proportion range from 1000 kg/day to 25000 kg/day, except the municipality of Burma due to the decline in the number of hydrogen vehicles.

A suitable model has been developed to integrate all the parameters that represent the spatial area of solar hydrogen production from the final convenience model. Most of the lands of Ouargla state have been found promising in the production of solar hydrogen, especially during the last five years of the study from 2043 to 2048.

Where the percentage of high suitability in first period was 1.3% with area of 1974.67 square kilometre and 16.5% with area 25576.76 square kilometre from the total area by 2048, and 7% represented the unsuitability area in the both periods of the study.

The areas of medium suitability represent 88.7% have a area of 141745.212 square kilometer in first period ,in contrast 76.5% with area of 118107.92 square kilometer represented the last five years of the study.

After located the suitability area for hydrogen production we used to analyse network to determine the places of hydrogen distribution stations where we used the new service area tool and based on two scenarios we obtained 3 stations in region of Ouargla and Rouaissat and this because to provide the needs in those municipalities and 4 stations obtained it in the main Roads to provide the safety while traveling.

Finally, we completed this work with the identification of optimal areas for the production of hydrogen and also with the locating of the hydrogen distribution stations, showing that the region of Ouargla is promising in the production of hydrogen and this because of suit its territory with the hydrogen production project by 2048

The work, expands the views on the integration of more detailed technical and economic criteria, and the study of coupling the process of multi-criteria analysis and fuzzy set within the GIS system.

The next step is to develop a methodology and decision support to the decision maker for solving the hydrogen production site selection and it is recommended that the accomplished suitability model being considered by decision makers in the future plans of hydrogen energy development in Ouargla.

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<u>Annexe I</u> :

Table : Population of the municipalities of the state of Ouargla in the period 2018-2048.

Periods	2018-2023	2023-2028	2028-2033	2033-2038	2038-2043	2043-2048
Ouargla	169995	184442	200117	217123	235575	255596
Rouissat	107211	131343	160905	197121	241489	295844
Sidi-Khouiled	24951	35263	49837	70435	99545	140687
Ain-Beida	28086	31953	36352	41356	47050	53527
Hassi-B-Abdallah	7575	8726	10052	11579	13339	15367
Ngoussa	22640	25107	27843	30877	34242	37975
El-Hadjira	19517	21188	23003	24972	27109	29429
El-Alia	11195	12400	13733	15208	16843	18653
Temacine	27915	31142	34743	38761	43242	48242
Blidet-Amor	18838	20525	22364	24369	26553	28933
Touggourt	54056	59548	65598	72264	79607	87696
Nezla	73076	81977	91963	103165	115731	129829
Tebesbest	44447	48118	52092	56394	61050	66092
Zaouia	29045	32874	37207	42111	47664	53948
Meggarine	18931	21050	23405	26025	28937	32174
Sidi-Slimane	10258	11108	12028	13024	14103	15271
Taibet	32844	38280	44616	52000	60606	70637
Bennaceur	15400	17579	20067	22907	26149	29851
M Nagueur	16611	17921	19333	20855	22496	24268
Hassi-Messaoud	52171	54721	57396	60201	63144	66230
El-Borma	6236	6941	7723	8594	9564	10641
Total Wilaya	790998	892206	1010377	1149341	1314038	1510890

Annexe II :

Table : Number of Hydrogen vehicle (H2 vehicles) in the period 2018-2048.

Periods	2018-2023	2023-2028	2028-2033	2033-2038	2038-2043	2043-2048
Ouargla	1321	3220	5865	9453	14211	20395
Rouissat	833	2293	4716	8582	14568	23606
Sidi-Khouiled	194	616	1461	3066	6005	11226
Ain-Beida	218	558	1065	1800	2838	4271
Hassi-B-Abdallah	59	152	295	504	805	1226
Ngoussa	176	438	816	1344	2066	3030
El-Hadjira	152	370	674	1087	1635	2348
El-Alia	87	217	402	662	1016	1488
Temacine	217	544	1018	1687	2609	3849
Blidet-Amor	146	358	655	1061	1602	2309
Touggourt	420	1040	1922	3146	4802	6998
Nezla	568	1431	2695	4491	6982	10360
Tebesbest	345	840	1527	2455	3683	5274
Zaouia	226	574	1090	1833	2875	4305
Meggarine	147	368	686	1133	1746	2567
Sidi-Slimane	80	194	353	567	851	1219
Taibet	255	668	1308	2264	3656	5636
Bennaceur	120	307	588	997	1578	2382
M Nagueur	129	313	567	908	1357	1937
Hassi-Messaoud	405	955	1682	2621	3809	5285
El-Borma	48	121	226	374	577	849
Total Wilaya	6145	15576	29610	50037	79270	120559

Annexe III :

Table: Spatio-temporal distribution of hydrogen demand in the Municipalities of Ouargla

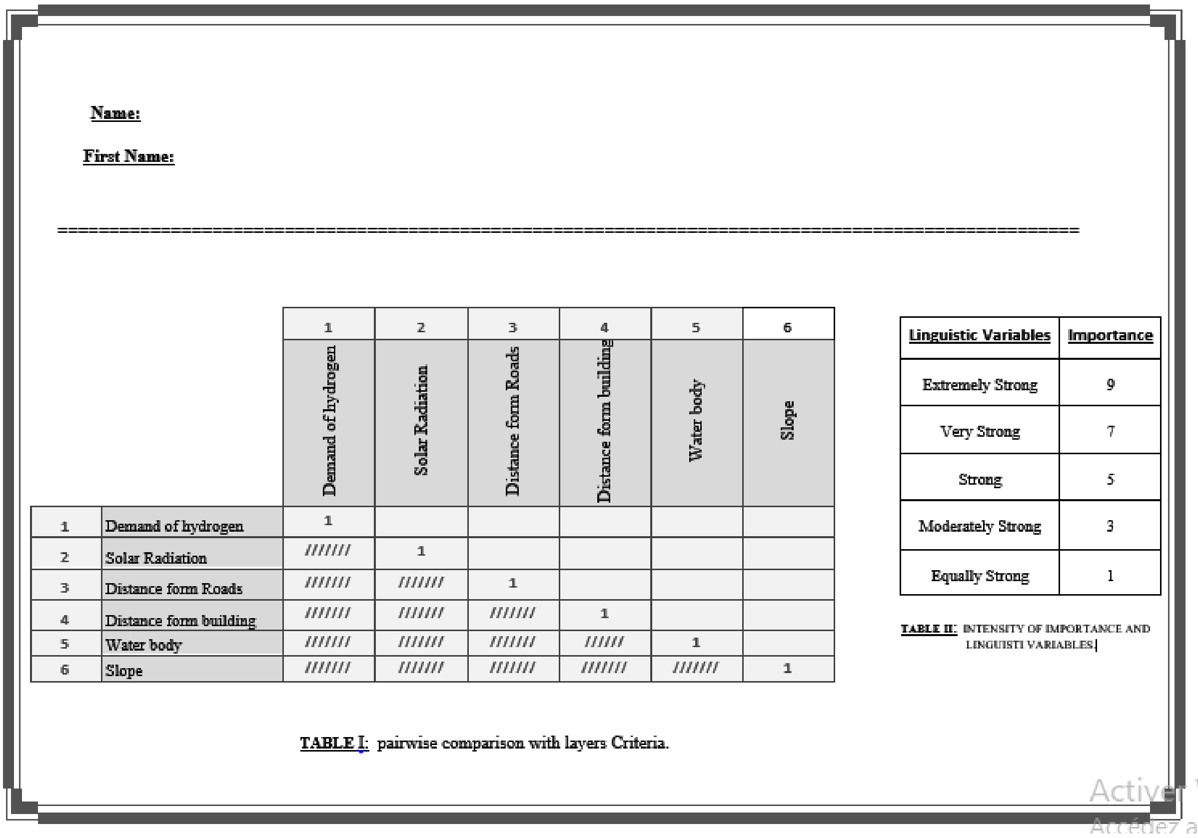
Periods	2018-2023	2023-2028	2028-2033	2033-2038	2038-2043	2043-2048
Ouargla	1410	3437	6260	10090	15169	21770
Rouissat	889	2448	5034	9161	15550	25197
Sidi-Khouiled	207	658	1559	3273	6410	11983
Ain-Beida	233	596	1137	1921	3029	4559
Hassi-B-Abdallah	63	162	315	538	859	1309
Ngoussa	188	468	871	1435	2205	3234
El-Hadjira	162	395	719	1160	1745	2506
El-Alia	93	232	429	707	1084	1588
Temacine	232	581	1087	1801	2785	4108
Blidet-Amor	156	382	699	1133	1710	2465
Touggourt	448	1110	2052	3358	5126	7470
Nezla	606	1527	2877	4794	7453	11058
Tebesbest	368	897	1630	2621	3931	5630
Zaouia	241	613	1163	1957	3069	4595
Meggarine	157	393	732	1209	1864	2740
Sidi-Slimane	85	207	377	605	908	1301
Taibet	272	713	1396	2417	3902	6016
Bennaceur	128	328	628	1064	1684	2543
M Nagueur	138	334	605	969	1448	2068
Hassi-Messaoud	432	1019	1795	2798	4066	5641
El-Borma	51	129	241	399	616	906
Total Wilaya	6559	16626	31606	53410	84614	128687

Annexe IV :

Table : Population of the municipalities of the state of Ouargla in the period 2018-2048.

Periods	**2018-2023**	**2023-2028**	**2028-2033**	**2033-2038**	**2038-2043**	**2043-2048**
Ouargla	169995	184442	200117	217123	235575	255596
Rouissat	107211	131343	160905	197121	241489	295844
Sidi-Khouiled	24951	35263	49837	70435	99545	140687

Annexe V :



Name:

First Name:

==

		1	2	3	4	5	6
		Demand of hydrogen	Solar Radiation	Distance form Roads	Distance form building	Water body	Slope
1	Demand of hydrogen	1					
2	Solar Radiation	///////	1				
3	Distance form Roads	///////	///////	1			
4	Distance form building	///////	///////	///////	1		
5	Water body	///////	///////	///////	//////	1	
6	Slope	///////	///////	///////	///////	///////	1

TABLE I: pairwise comparison with layers Criteria.

Linguistic Variables	Importance
Extremely Strong	9
Very Strong	7
Strong	5
Moderately Strong	3
Equally Strong	1

TABLE II: INTENSITY OF IMPORTANCE AND LINGUISTI VARIABLES

Figure : A sample of the questionnaire submitted to the experts.