UNIVERSITY KASDI MERBAH OUARGLA
Faculty of Applied Sciences
Department of Hydraulic and Civil Engineering

Dissertation
Professional Master
Domain: Sciences and Technology
Major: Water Drilling

**Submitted by:** Berddis BELMESSAOUD

Title

# A Novel Approach for the Determination of Groundwater Potential

Master in Water Drilling.

Publically Defended on:

**June,12th 2022**

**Before the Jury:**

| | | |
|---|---|---|
| Dr. Sofiane SEGGAI | President | UKM – Ouargla |
| Dr. Oussama DERDOUS | Supervisor | UKM – Ouargla |
| Dr. Ali BOUAMARANE | Co-Supervisor | UKM – Ouargla |
| Dr. Moussa ZERROUKI | Examiner | UKM – Ouargla |

Academic Year: 2021/2022

# DEDICATION

I dedicate my dissertation work to my mother, Without your endless love and encouragement I would never have been able to complete my studies. I love you and I appreciate everything that you have done for me.

This thesis is also dedicated to my sisters, Sihem and Hanine whose words of encouragement and push for tenacity ring in my ears.

# ACKNOWLEDGEMENTS

***“If I can see farther it is only because I stand on the shoulders of giants.”***

***–Issac Newton (1642-1727)***

This part may be the most difficult part of the thesis for me to write. During the past few months, I met a lot wonderful people. They gave me a lot of helps without asking any response. Just like that an old Chinese proverb says, "We always acquire too much from the world, and gave ourselves’ to others too less." A lot of people contribute to this thesis and my personal development. I have to thank them all at the beginning of this thesis. This is why I quote Sir Issac Newton’s words of wisdom here. I cannot say that I have seen farther, but I will always take this as my goal and keep myself moving forward to contribute my endeavors to the lovely world.

Foremost, I would like to express my warm and sincere thanks to the Eternal Allah Almighty for giving me the strength and courage to carry out this master research.

I would like to express my deepest gratitude to my supervisor, Dr. Derdous Oussama, for his sincere supervision, guidance, and encouragement throughout this research work. Without his constant supervision and guidance, the completion of this research work would not have been possible. I am extremely grateful to him for giving me an opportunity to work as his student and for sharing his immense knowledge with me. I am also extremely thankful to my co-supervisor, Dr. Bouamrane Ali, for his assistance in learning GIS and R Studio. As well as, for his valuable suggestions and guidance throughout my research work, which helped me to complete my research work. Last but not least, I would like to thank my thesis committee members, Dr. Seggai Sofiane and Dr.Zerrouki Moussa for all of their guidance through this process, your discussion, ideas, and feedback have been absolutely invaluable.

Finally and most importantly, I express my utmost gratitude to my family for their unstinted support and encouragement all along. Their blessings and unfailing encouragement have helped me sail through the difficult times. This thesis represents my responsibility and promise for their encouragement.

# A Novel Approach for the Determination Groundwater Potential

## ABSTRACT

Groundwater is one of the most valuable natural resources owned by many countries. In semi-arid areas, groundwater may be a major resource for drinking, agricultural, and industrial purposes. The Cheliff basin, which is the largest basin in the north of Algeria, is affected by water scarcity due to the expansion of industrial and agricultural activities with the population growth, on the one hand, and to the reduction in water resources due to extreme droughts on the other hand. Therefore, the present research aims at delineating potential groundwater zones in the Cheliff basin, through the combination of an artificial intelligence model (ANNs: artificial neural networks) and Geographic Information Systems (GIS). The Geographic Information System (GIS) was used to identify and characterize a set of factors influencing groundwater potential in the watershed, including slope, rainfall, ground elevation, land cover/land use, soil type, normalized difference vegetation index (NDVI), topographic wetness index (TWI), and distances from the river, geology, and drainage density. Then, the weight of each factor was calculated via ANNs based on a number of validation points which were divided into 70% as a training set and 30% as a validation set. This process enabled ranking the factors depending on their effectiveness and relevance to groundwater potentiality. a groundwater potential zone (GWPZ) map was generated using the weighted linear combination (WLC) method through GIS. The resulting groundwater potential zones are classified into five categories, namely poor, low, moderate, high, and very high zones. It is observed that 33% (14267.040 km2) and 18% (7640.065 km2) of the study region fall under the "poor" to "low" groundwater potential zone, respectively. Approximately 11367.29 km2 of area, accounting for 26% of the study area, falls under the "moderate" category. Areas of high groundwater potential constitute only 17% (7364.19 km2) of the total study area, and a "very high" groundwater potential zone encompasses an area of 2685.92 km2, accounting for 6% of the total study area. The overall potential map suggests the dominant influence of drainage density, geology, and topographic features in the delineation of the groundwater zone. Finally, in order to validate the accuracy of the ensemble model, the RMSE indices were used. Also, in order to validate the accuracy of the maps, AUC was used. The results of this study showed that the values of the RMSE for training and validation are equal to 0.302 and 0,246, respectively. The evaluation results of the ROC curve indicated that the AUC was 95,0 and 100%, respectively. The outcomes of this study should be useful in enhancing agricultural productivity and solving water shortages related to the recurrent droughts that have been witnessed in last decades.

**Key words:** Groundwater potential; GIS; ANNs; thematic layers; WLC; RMSE; AUC.

# Une nouvelle approche pour la détermination du potentiel des eaux souterraines

## RÉSUMÉ

Les eaux souterraines sont l'une des ressources naturelles les plus précieuses que possèdent de nombreux pays. Dans les zones semi-arides, les eaux souterraines peuvent constituer une ressource importante pour la consommation, l'agriculture et l'industrie. Le bassin du Cheliff, qui est le plus grand bassin du nord de l'Algérie, est affecté par la pénurie d'eau à cause de l'expansion des activités industrielles et agricoles avec la croissance de la population, d'une part, et à la réduction des ressources en eau à cause des sécheresses extrêmes, d'autre part. Par conséquent, cette thèse vise à délimiter les zones d'eau souterraine potentielles dans le bassin de Cheliff, par la combinaison d'un modèle d'intelligence artificielle (RNA : Réseau de neurones artificiels) et de systèmes d'information géographique (SIG). Le système d'information géographique (SIG) a été utilisé pour identifier et caractériser un ensemble de facteurs influençant le potentiel des eaux souterraines dans le bassin versant, notamment la pente, les précipitations, l'élévation du sol, la couverture/utilisation des sols, le type de sol, l'indice de végétation par différence normalisée (NDVI), l'indice d'humidité topographique (TWI), et les distances par rapport à la rivière, la géologie et la densité de drainage. Ensuite, la pondération de chaque facteur a été calculée via des RNA sur la base d'un nombre des points de validation qui ont été divisés en 70% comme ensemble d'entraînement et 30% comme ensemble de validation. Ce processus a permis de classer les facteurs en fonction de leur efficacité et de leur pertinence pour la potentialité des eaux souterraines. Une carte des zones de potentiel en eaux souterraines a été générée en utilisant la méthode de combinaison linéaire pondérée (CLP) à l'aide du SIG. Les zones de potentiel des eaux souterraines résultantes sont classées en cinq catégories, à savoir les zones pauvres, faibles, modérées, élevées et très élevées. Il est observé que 33% (14267.040 km2) et 18% (7640.065 km2) de la région d'étude se situent respectivement dans la zone de potentiel des eaux souterraines "pauvre" à "faible". Une superficie d'environ 11367,29 km2, représentant 26% de la région d'étude, relève de la catégorie "modérée". Les zones à fort potentiel pour les eaux souterraines ne représentent que 17 % (7364,19 km2) de la zone d'étude totale, et une zone à très fort potentiel pour les eaux souterraines couvre une superficie de 2685,92 km2, correspondant à 6 % de la zone d'étude totale. La carte globale du potentiel suggère l'influence dominante de la densité de drainage, de la géologie et des caractéristiques topographiques dans la délimitation de la zone des eaux souterraines. Finalement, afin de valider la précision du modèle d'ensemble, les indices MSE été utilisés. De même, afin de valider la précision des cartes, l'ASC a été utilisé. Les résultats de cette étude ont montré que les valeurs du MSE pour la formation et la validation sont égales à 0.302 et 0,246, respectivement. Les résultats de l'évaluation de la courbe ROC ont indiqué que l'ASC était de 95,0 et 100%, respectivement. Les résultats de cette étude devraient être utiles pour améliorer la productivité agricole et résoudre les pénuries d'eau liées aux sécheresses récurrentes qui ont été observées au cours des dernières décennies.

**Mots clés :** Potentiel en eaux souterraines ; SIG ; RNA; couches thématiques; CLP ; MSE ; ASC

# مقاربة جديدة لتحديد إمكانات المياه الجوفية

## ملخص

تعتبر المياه الجوفية واحدة من الموارد الطبيعية القيمة التي تملكها العديد من البلدان. في المناطق شبه القاحلة، وغالبا ما تكون موردا أساسيا للشرب والمتطلبات الزراعية، والصناعية ويتأثر حوض الشلف وهو أكبر حوض في شمال الجزائر؛ بندرة المياه بسبب توسع الأنشطة الصناعية والزراعية مع النمو السكاني من ناحية، وانخفاض الموارد المائية بسبب الجفاف الشديد من ناحية أخرى. ويهدف البحث الحالي إلى تحديد مناطق المياه الجوفية المحتملة في حوض الشلف، من خلال الجمع بين نموذج الذكاء الاصطناعي (شبكة عصبونية اصطناعية) وأنظمة المعلومات الجغرافي. و قد تم استخدام نظام المعلومات الجغرافية لتحديد، وتوصيف مجموعة من العوامل التي تؤثر على إمكانات المياه الجوفية في مستجمعات المياه، بما في ذلك الميل، و معدل هطول الأمطار، وارتفاع الأرض، والغطاء الأرضي/استخدام الأراضي، ونوع التربة، مؤشر الفرق المعياري للغطاء النباتي، ومؤشر الرطوبة الطبوغرافية، والبعد من المجاري النهرية، والجيولوجيا، وكثافة الصرف حيث تم حساب وزن كل عامل عن طريق استخدام شبكة عصبونية اصطناعية من خلال عدد من نقاط التحقق من الصحة التي تم تقسيمها إلى 70 ٪ بوصفها مجموعة التدريب و 30 ٪ باعتبارها مجموعة التحقق من الصحة. مكنت هذه العملية من ترتيب العوامل اعتمادا على فعاليتها وصلتها بإمكانيات المياه الجوفية حيث تم إنشاء خريطة للمنطقة المحتملة للمياه الجوفية باستخدام طريقة التركيبة الخطية الموزونة من خلال نظام المعلومات الجغرافية. و قد توصل البحث الى تصنيف المناطق المحتملة للمياه الجوفية الناتجة إلى خمس فئات، وهي المناطق الفقيرة والمنخفضة والمتوسطة والعالية والمرتفعة للغاية. ويلاحظ أن 33 ٪ (14267.040 كم2) و 18 ٪ (7640.065 كم2) من منطقة الدراسة تقع تحت منطقة إمكانات المياه الجوفية "الفقيرة" إلى "المنخفضة"، على التوالي و ما يقارب من 11367.29 كم2 من المساحة، تمثل 26 ٪ من مساحة الدراسة، تندرج تحت الفئة "المعتدلة" و تشكل المناطق ذات الإمكانات العالية للمياه الجوفية 17 ٪ فقط (7364.19 كم2) من إجمالي مساحة الدراسة، وتضم منطقة إمكانات المياه الجوفية "العالية جدا" مساحة 2685.92 كم2، وهو ما يمثل 6 ٪ من إجمالي مساحة الدراسة. و إذ تشير الخريطة الناتجة إلى التأثير السائد لكثافة الصرف؛ جيولوجيا؛ والميزات الطبوغرافية في ترسيم منطقة المياه الجوفية. وأخيرا ، من أجل التحقق من دقة نموذج الفرقة ، تم استخدام مؤشرات خطأ الجذر التربيعي ( RMSE) . كما استخدمت المنطقة الواقعة تحت المنحنى ( AUC ) للتحقق من دقة الخرائط. وأظهرت نتائج هذه الدراسة أن قيم RMSE للتدريب والتحقق من صحة تساوي 0.302 و 0.246 ، على التوالي. أشارت نتائج تقييم منحنى ROC إلى أن AUC كانت 95 و 100٪ على التوالي. بحيث انه يمكن الاستفادة نتائج هذه الدراسة في تعزيز الإنتاجية الزراعية وحل نقص المياه المرتبط بموجات الجفاف المتكررة التي شهدها حوض الشلف في العقود الأخيرة.

**الكلمات المفتاحية:** إمكانات المياه الجوفية ؛ نظم المعلومات الجغرافية ؛ شبكة عصبونية اصطناعية؛ عوامل مؤثرة ؛ التركيبة الخطية الموزونة؛ خطأ الجذر التربيعي ؛ المنطقة الواقعة تحت المنحنى .

# Table of Contents

# LIST OF TABLES

# LIST OF FIGURES

# ABBREVIATIONS AND ACRONYMS

**ABH:** Hydrographic Basin Agency.

**ANNs:** Artificial Neural Networks.

**ANRH:** National Agency for Hydraulic Resources.

**AUC:** Area Under the Curve.

**BPANN:** Back Propagation Neural Networks.

**CI:** Continental Intercalary.

**CT:** Terminal Complex.

**DEN:** Drainage Density.

**DEM:** Digital Elevation Model.

**DIS:** Distance from River.

**ELV:** Elevation.

**ESRI:** Environmental Systems Research Institute.

**ETM:** Enhanced Thematic Mapper.

**FAO:** Food and Agriculture Organization.

**FFBP:** Feed forward Backpropagation.

**GEO:** Geology.

**GIS:** Geographic Information System.

**GRBF:** Generalized RBF Model.

**GRN:** Generalized Regression Networks.

**GWL:** Groundwater Level.

**GWPI:** Groundwater Potential Index.

**GWPZ:** Groundwater Potential Zone.

**IDW:** Inverse Distance Weighting.

**IDNN:** Input Delay Neural Network.

**LULC:** Land Use/ Land Cover.

MCM: Thousands of Circular Mils.

**MLP:** Multilayer Perceptron.

**NASA:** National Aeronautics and Space Administration.

**NDVI:** Normalized difference vegetation index.

**NE:** Northeast.

**NW:** Northwest.

**PNN:** Probabilistic Neural Network.

**RBF:** Radial Basis Function.

**RMSE:** Root Mean Squared Error.

**RNN:** Recurrent Neural Network.

**ROC:** Receiver Operator Characteristic.

**SE:** Southeast.

**SRTM:** Shuttle Radar Topography Mission.

**SL:** Slope.

**SW:** Southwest.

**TWI:** Topographic Wetness Index.

**USGS:** United States Geological Survey.

**UTM:** Universal Transverse Mercator.

**WGS 84:** World Geodetic System 1984.

**WLC:** Weighted Linear Combination.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Introduction:

Groundwater, or subsurface water, is a term used to denote all the waters found beneath the ground surface (Bear and Verruijt, 1987). It is one of the most significant natural resources worldwide serving as a primary source of water for communities for domestic purpose, industries, agricultural productions (Ayazi et al., 2010; Manap et al., 2012; Neshat et al., 2013; Pradhan, 2009).

Groundwater is naturally refilled by rain or snow melts which seep down through the soil and/or through pore spaces of underlying rocks (Nampak et al., 2014). Hence, its occurrence and distribution depends on the climatic and others regional conditions of a given region, e.g. surface and subsurface characteristics such as fractures in the underlying rock, land use type, geomorphic features, structural features and their interrelationships with the hydrological characteristics (Edet et al., 1998; Greenbaum, 1992; Jaturon et al., 2014; Kumar et al., 2007; Saud, 2010; Senthil Kumar and Shankar, 2014). Groundwater accounts for 26% of global renewable fresh water resources (FAO, 2003). Salt water (mainly in oceans) represents about 97.2% of the global water resources with only 2.8% available as fresh water.

Groundwater demand is drastically increasing due to the immense pressure on population and urbanization, global impact due to climate and weather change and repetitive drought cycles (Jaturon et al., 2014; Rahman, 2001). Currently, severe water crises are reported in worldwide, because of the day-by-day depletion of the existing groundwater resources (Adeyeye et al., 2019; Al-Ruzouq et al., 2019).

In this context, a reliable water resources management policy necessitates that the concerned authorities concerned especially in the semi-arid areas, rely on accurately acceptable prediction of groundwater levels and plan early to meet the challenges ahead. This generally requires a longer period of data of water table depth measurements in compassion to the other environmental conditions such as rainfall, temperature, etc. As the data is not available in many areas of developing and underdeveloped countries, a common approach of empirical time series models to generate a longer time series of water table depths has been developed. Unfortunately, the major limitation of empirical time series models is their inaccurate predictions, especially when the dynamical behavior of the hydrological system changes with respect to time.

In practice, the data requirements to simulate water table fluctuation for physical models are enormous, generally difficult to collect and very expensive. Therefore, a dynamical predictive model that can cape with the persistent trend and time-varying behavior of the aquifer system is very much desirable for improved water resources management and reliable water supply planning.

With the advance in space technology and the development of computer hardware, now it is possible to employ artificial intelligence and GIS to identify and mapping groundwater potential zones in a large and inaccessible area with high accuracy. Artificial intelligence and in particular artificial neural networks (ANNs) have been proven to be very effective in modeling virtually any nonlinear function to an arbitrary degree of accuracy. The main advantage of this approach over traditional methods is that it does not require the complex nature of the underlying process under consideration to be explicitly described in mathematical form. Further, ANNs are proved to be more realistic predictive tool even when the input data is not sufficiently large enough. This makes ANN as an attractive tool for forecasting of groundwater potentiality.

The main objective of this research work is to integrate ANNs and GIS technology to develop thematic data layers for identification and mapping of GWPZ based on various conditioning factors in Cheliff basin, Northern Algeria.

## 1.2 Problem Statement:

The Cheliff basin, located in northwestern Algeria, is a perfect example of an arid region with a semi-arid Mediterranean climate, In recent years, the region has seen important population growth as well as industrial and agricultural development. In the observation wells located in this basin, groundwater levels have shown a decline in the last decade due to overexploitation to provide water for drinking and crop irrigation, as well as industrial manufacturers. Due to this, the identification of groundwater potential zones is one of the key processes for enhancement, management, and development of groundwater resources in our area. Therefore, we have used GIS and ANN algorithms because of their efficiency and accuracy to identify the groundwater potential zones by assessing and weighting all factors that have a direct or indirect effect on groundwater distribution and occurrence.

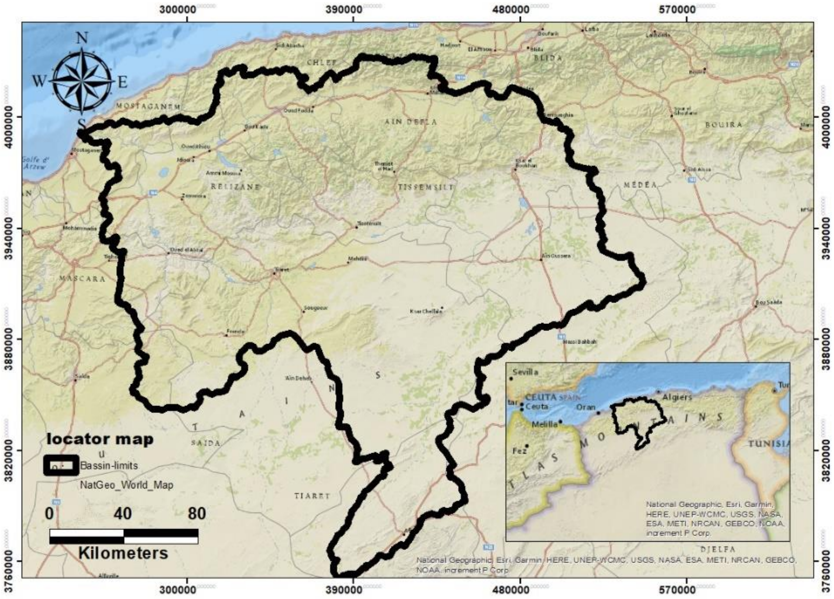


**Figure 1.1: Locator Map of Cheliff Basin.**

## 1.3 Research Questions:

- What are the factors that influence groundwater potential?
- How to calculate the conditioning factors' weights?
- What are the most important factors favoring the groundwater potential in the study area?
- Where can groundwater potential areas be located?
- Will this GIS based ANN approach produce sufficient predictive performances, allowing it to be considered as a decision-making support tool?

## 1.4 Main Objective:

The main objective of this study is to delineate the groundwater potential zones in the study area by combining the use of geographic information systems (GIS) and artificial neural network models (ANNs). The final map generated by this study will provide authorities with an accurate assessment of groundwater potential areas that can be used to cope with water scarcity in the study area along with reducing the cost of traditional surveying techniques.

## 1.5 Specific Objectives:

- Delineation of the study watershed and evaluation of its physical characteristics.
- Collect climatic data, like rainfall and spatial data including geology, soil type, topography, land use, etc from different sources.
- Development of thematic maps such as soil type, stream network, land cover, etc.

- Identify and weighting the conditioning factors that influence the distribution of the GWPZs.
- Demonstrating the significance of the AI techniques for preparing an efficient and low-cost approach for delineating GWPZs.

## 1.6 Chapter Overview:

This thesis is made up of five (5) chapters that focus on achieving the purpose of this research and answering research questions. A summary of the chapters is provided below;

**Chapter one** provides a background to the study including statement of the problem, objectives, research questions.

**Chapter two** presents the literature review of groundwater and presents different factors that can be responsible for the distribution of groundwater potentials zones. This chapter also outlines the different tools and methods generally used in modeling and predicting GWPZs. Finally, it presents a brief summary of the past ground-water modeling studies particularly those that used ANNs.

**Chapter three** describes the materials and methods used in this study and describes the used procedures to carry out the study and the detailed description of the procedures used to carry out the research to give an understanding of the real situation occurring in the study area.

**Chapter four** presents the main results and discussions from the current groundwater potential mapping exercise.

**Chapter five** is made up of the Conclusion and Recommendations. This highlights the key results of this study in relation to the overall problems, research and questions.

# CHAPTER TWO

# LITERATURE REVIEW :

## 2.1 Introduction:

Groundwater is water found in pore spaces in subsurface with generally low velocity (Fitts, 2002), and the fact that it is buried under the ground, are becoming like any other type of subsurface natural resource on the planet progressively more difficult to locate. Accordingly, any new technique which will assist in the location of borehole site and eliminate the sinking of unproductive wells in large numbers is of a great value (Selvam et al, 2016). Hence, surveys of a multidisciplinary nature are necessary for understanding the presence and efficient planning and management of groundwater in different regions is of the utmost importance (Selvarani et al, 2016).

Since, myriad challenges connected with groundwater exploration, contemporary technology in the form of geospatial techniques and artificial intelligence are increasingly capable for locating water-bearing formations, through the analysis of the factors that the occurrence and the movement of groundwater depend on. These factors are either as a result of terrains characteristics such as topography, drainage, land use and land cover, depth of weathering, geology or due to climatic conditions such as precipitation patterns (Pratap et al., 2000).

As, several scholars from across around the world are investigating the availability of groundwater in various types of areas. A literature study has been done for geospatial techniques and artificial intelligence methods being used for groundwater exploration. These techniques are successfully used in different terrains for the delineation of potential groundwater zones at an international level.

The current chapter is divided into 4 sections: The first section discusses groundwater resources either globally and in Algeria. Next, the factors influencing groundwater potential are listed. The third section is devoted to outlining the technologies utilized for groundwater modeling. Finally, an overview of previous similar work in the field of groundwater potential locating using artificial neural networks is given.

## 2.2 Groundwater Occurrence:

Groundwater is stored in the open spaces and fractures within geologic formations beneath the earth's surface known as aquifers (Lehr et al., 2005). An aquifer is a saturated bed, or formation which not only stores water but yields it in sufficient quantity to be of consequence as a source of supply. Aquifers may be made of consolidated or unconsolidated rock (Lehr et al., 2005). Consolidated rock occurs in the form of rocks of such materials as sandstone, tuffs, limestone, and granite. The main properties of an aquifer are its capacity to release the water held in its pores and its ability to transmit the flow easily (Lehr et al., 2005). These properties essentially depend upon the composition of the aquifer and they include the porosity, specific yield, hydraulic conductivity, permeability and coefficient of storage.

Groundwater potential means having a latent possibility or likelihood of occurrence of groundwater in an area. Areas or zones of abundant groundwater available for use are referred to as areas of good groundwater potential. Productive water bearing zones are referred to as good groundwater potential aquifers, which when correctly sited yields sufficient quantities. Knowledge of groundwater potential acts as a guide and therefore, makes it easy for exploitation. (Madan et al., 2010).

## 2.3 Global Groundwater Situation:

Groundwater as a resource can be characterized by two main variables, its rate of renewal and its volume in storage. Groundwater is renewed globally at a rate about equal to 30% of the rate of renewal of surface water. However, in terms of volume stored, there is approximately one hundred times more groundwater than surface water stored on the globe (FAO.,2004). Where present-day annual groundwater renewal is negligible compared with the stored volumes, most of the groundwater stored is not related to contemporaneous recharge but to recharge events which took place in the remote past. Such groundwater is called 'non-renewable groundwater' or 'groundwater reserves'. Its exploitation cannot be balanced by recharge of groundwater today, but will cause a steady reduction of the stored volume.

The world's largest nonrenewable groundwater systems are located in arid zones of Northern Africa, the Arabian Peninsula and Australia, and under the permafrost in Western Siberia. it is the main source of drinking water supply in this region. Some of these reserves are large enough to maintain sizeable abstraction rates for many tens to hundreds of years.

## 2.4 Groundwater Resources in Algeria:

Algeria's water is not always available in the right place at the appropriate time to fulfill present and future demands. Algeria suffers from a severe scarcity of freshwater because the majority of its terrain is classified as arid or semiarid. Groundwater resources are estimated to total 7.6 BCM, but demand is much higher in the north of the country (Bouchekima et al., 2008).

The northern coastal regions of the country are more densely populated; nearly 90% of the population lives in urban areas which represent 10% of the country's area (Sadi., 2004). Algeria lies below the desirable resource threshold of 1000 $m^3$ /year per inhabitant (Iglesias et al., 2006); it is ranked sixth among countries suffering most severely from water shortage, and it will jump to fourth place by the year 2025 if no suitable alternative solution to the water shortage problem is adopted (Mitiche et al., 2010).

In the last two decades, Northwestern Algeria in particular has experienced severe and persistent droughts with annual rainfall some 30 percent below average (Meddi and Hubert 2003; Touchan et al. 2008; Masih et al. 2014); this has affected remarkably the availability of water and over all socioeconomic activities The potential for available exploitable groundwater of Northwestern Algeria basins has been estimated by ANRH (National Water Resources Agency) to 428.52 MCM (thousands of circular mils) though withdrawals are estimated to be 391 MCM which means that some of the aquifers are overexploited (e.g., Ghriss Plain aquifer) mainly due to increasing water demand (Bekkoussa et al. 2008).

On the other hand, the South is characterized by the existence of considerable groundwater resources. They come from the Continental Intercalary (CI) and the Terminal Complex (CT) aquifers. The exploitable reserves without risk of hydrodynamic imbalance are estimated at 5 billion m3/year. The Intercalary Continental aquifer, which is more extensive and deeper than the Terminal Complex, covers an area of more than 10 million km2, spread over three countries (Algeria, Tunisia and Libya). It is a fossil aquifer also called Albian aquifer estimated at 60,000 billion m3 but its waters are not or hardly renewable (Rémini., 2005).

## 2.5 Groundwater Exploration:

The search for groundwater has intensified in human history. This is due to the fact that many governments are unable to meet the ever increasing water demand; inhabitants have had to search for alternative sources such as surface streams, shallow wells and boreholes (Trimmer, 2000). Groundwater exploration is carried out in many ways ranging from traditional to modern methods. Groundwater exploration is developing everyday through new means and devices. Several techniques can be used to explore groundwater resources, test drilling and stratigraphy analysis are the most reliable and standard methods for determining the location of a borehole and the thickness of the aquifereous unit (Madan et al., 2010). However, these methods of groundwater investigation are not time and cost-effective, and also often require skilled personnel (Roscoe, 1990; Fetter, 1994).

Geophysical prospecting techniques have also been used by various researchers to explore groundwater resource in different types of geologic terrain (Ako et al., 1989; Amadi et al., 1990; Olorunfemi et al., 1995; Olayinka et al., 2001 and Adiat et al., 2009). However, due to lack of precision of an onsite analysis, results and interpretations of geophysical surveys always require validation with borehole data (Adiat, 2012).

The advent of the Geographic Information System (GIS) has also provided another cost and time effective means of assessing and managing groundwater resources (Jha et al., 2007; Meijerink, 2007). Locating promising groundwater locations for exploration and exploitation is based on evaluating a set of hydrological, geologic and topographical parameters that influence its availability using GIS and an artificial intelligence technology.

## 2.6 Groundwater Potential Zones:

Groundwater is the water that is found underneath the Earth’s surface at profundities where all the open spaces in the soil, sediments, or rock are completely stacked with water. Groundwater of any structure whether from a shallow well or a significant well, devises and is refilled (energized) by rainfall. Groundwater is a piece of the hydrologic cycle, beginning when a piece of the precipitation that falls on the Earth’s surface infiltrates through the soil and enters diving to wind up ground. It is the water that found underground in the cracks and spaces in soil, sand and rock in the study area. It is stored in and moves slowly throughout geological formation of soil, sand and rocks were called aquifers (Toddy, 1995).

There are different definitions given to groundwater potential zone by different authors in different time. As (Rashman., 2016), said groundwater is the most important natural resources found beneath the earth surface stored in void space of geological stratum used in economic development, domestic life, and ecological diversity. And also he concludes that, the occurrence and flows system of groundwater is depending on geological characteristics of its porosity and permeability and the formation of landforms such us high mountains, Rift Valley's and flat areas and the role of landform on surface runoff and infiltration to the ground.

## 2.7 Factors Influencing Groundwater Potential:

Groundwater recharge and storage in shallow unconfined aquifer is complex. It is dependent upon the occurrence, intensity and duration of precipitation, temperature, humidity, wind velocity as well as character and thickness of soil and rock above the water table and the surface topography, vegetation and land use (Arnold et al., 2000). Groundwater occurrence also depends on climatic conditions, as well as soil type, soil moisture status, vegetation cover and condition, slope, cultivation practices and most of all, on evapotranspiration, which is a function of the other factors (Yeh et al, 2016). Several factors are selected from previous studies including slope, drainage density, land cover and rainfall and others and all described here and their influence on groundwater occurrence is discussed.

### 2.7.1 Rainfall:

Rainfall is the major component of water cycle and is generally the main source of groundwater recharge through infiltration. The rate of infiltration depends on the characteristics of the rainfall such as its intensity and duration. It is also influenced by the physiographic characteristics of the area which include the geology, slope, soil type, land use/cover, etc.

Increase of rainfall is expected to increase the infiltration and as result, the water level in subsurface increases. Therefore, the rainfall is the major contributor of the groundwater potential of specific areas except for the fossil groundwater (Shamuyarira, 2017). It may help also in preventing the groundwater overexploitation. (Post et al,2017) highlighted also the importance of rainfall on groundwater recharge. In the northern region of Algeria, the rainfall is estimated to be from 200 to 400 mm per year during the rainy season (Hassini et al, 2011).

### 2.7.2 Geology:

The geology of a specific region gives an idea on groundwater recharge and movement, it has been described as a major parameter in groundwater potential and analysis (Gouri et al.,2013; Indhulekha et al., 2019). According to Indhulekha et al. (2019), the geology is the main factor which determines the ability of an area to store and discharge water and then theoccurrence of groundwater. Therefore, Shamuyarira (2017) and Indhulekha et al. (2019) gave to the geology theme the highest weight in their groundwater potential assessment studies and Gouri et al. (2014), the second highest weight after the land use/ land cover.

### 2.7.3 Land Use and Land Cover:

One of the parameters that influence the occurrence of sub-surface groundwater is the land cover and land use of the area. The effect of land cover is manifested either by reduced runoff or by trapped water on their leaf. Water droplets trapped in this way go down to recharge groundwater. Vegetal cover increases infiltration as compared with barren soil because it retards surface flow giving the water additional time to enter the soil. Also the root system makes the soil more pervious and the foliage shields the soil from raindrop impact thus reducing rain packing of surface soil.

Types of land cover/ land use include forest plantations, crop farms, bare denuded soils surfaces, water bodies and settlements. Each type of land use/ land cover has a certain influence on groundwater potential indirectly through infiltration, runoff and evaporation (Fashae et al., 2014). Vegetation cover reduces evaporation and runoff hence increases infiltration. Vegetation increases chances of groundwater recharge and can be an indication of high groundwater potential (Leduc et al., 2001). Forest plantations require large amounts of water, which they absorb from the vadose zone and in other cases from beneath the water table. In settlements and built up areas, infiltration is low because of roads, pavements and buildings covering the soil surface and consequently, low groundwater potentials are expected (Fashae et al., 2014).

### 2.7.4 Slope:

Yeh et al. (2016) states that slope is one of the factors controlling infiltration of water to the ground and the indicator of groundwater potential suitability. The study found that areas with steep slopes caused more runoff, less infiltration and have low groundwater prospects compared to the areas with gentle slope. Gentle slope areas caused less runoff, high infiltration rate and have good ground water prospects. Fashae et al. (2014) illustrated that slope is a good proxy for groundwater potential analyses. The study demonstrates that slope highly influences groundwater infiltration and recharge. Where steep slopes are present, groundwater potential is low because there is more surface runoff than infiltration. Areas characterized by flatlands groundwater potential was discovered to be high because it is easier for the water to form pools and infiltrate than to runoff on the surface.

### 2.7.5 Soil:

The soil is another important variable in terms of groundwater potential investigations. It hasa great influence on groundwater recharge and hence on groundwater potential depending on its water retaining and transferability capacities. Soil properties such as porosity and permeability which depend mainly on soil texture and structure, play a significant role on water infiltration and runoff (Basavarajappa *et al.,* 2016).

The porosity refers to soil ability to hold water whereas the permeability refers to the motion of water into the soil. One soil type like sand can be both porous and permeable whereas another one like limestone is very permeable but less porous. The more the soil is permeableand porous, the more it facilitates the infiltration and hence favors the groundwater potential. Sandy soils are supposed to be assigned the highest weight comparatively to clay soils in the groundwater potential assessment (Shamuyarira, 2017).

### 2.7.6 Drainage Density:

The drainage system of an area is determined by the slope, nature and attitude of the bedrock and also by the regional and local fracture pattern (Adiat, 2012). Drainage density is the ratio of the sum of lengths of streams to the size of area of the grid under consideration (Greenbaum, 1989). It is an inverse function of permeability. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff (Magesh et al., 2012). It is a measure of surface water, sub-surface water and groundwater (Nampak et al., 2014). They reflect the lithology and structure of a given area and can be of great value for groundwater resources evaluation (Godebo, 2005).

The drainage density with respect to groundwater potential is determined by analyzing the drainage length within grid area (Ozdemir, 2011). When the drainage density of an area is high, it is indicative of high runoff and consequently low infiltration rate whereas low drainage density in an area implies low runoff and high infiltration (Prasad et al., 2008). Since the drainage density can indirectly indicate the suitability for groundwater recharge of an area because of its relation with surface runoff and permeability, it is mostly considered as one of the factors that is used to identify recharge potential zones. Drainage density can be derived from the drainage pattern by adopting steps similar to those of (Greenbaum, 1989; Edet et al., 1998; Sener et al., 2005; Al Saud, 2008).

### 2.7.7 Distance from River:

Distance from hydrographic networks is important in hydrogeological studies because it is noted that the presence of local alluvial layers is located essentially near the river courses especially in semi-arid regions (Benjmel et al., 2020). Areas close to rivers are favorable for effective infiltration and consequently groundwater recharge. In contrast, it is difficult to find alluvial layers in areas beyond a distance of 600 m (Moghaddam et al, 2015).

According to (Hyun-Joo et al, 2011) a negative relationship is reported between distance to river and water supply from river. As such, the closer the areas to rivers, the higher weights were assigned in groundwater potential calculation.

### 2.7.8 Topographic Wetness Index TWI:

The topographic wetness index (TWI) was developed by Beven and Kirkby (1979) within the runoff model TOPMODEL. It is defined as ln(a/tanβ) where a is the local upslope area draining through a certain point per unit contour length and tanβ is the local slope. The TWI has been used to study spatial scale effects on hydrological processes (Beven et al., 1988; Famiglietti and Wood, 1991; Sivapalan and Wood, 1987; Siviapalan et al., 1990) and to identify hydrological flow paths (Robson et al., 1992).

The topographic wetness index plays an important role in influencing the movement and accumulation of runoff at the soil surface. It relates upslope areas as a measure of water flowing towards a certain point, to the local slope, which is a measure of the subsurface lateral transmissivity (Beven and Kirkby, 1979). According to (Hyun-Joo et al, 2010) higher TWI value indicates a lower slope and a larger slope area. With higher TWI, groundwater potential could therefore also be higher because the conditions are favorable for groundwater recharge.

### 2.7.9 Elevation:

Elevation is one of the topographic factors and considered as surface indicators to explore groundwater potential. Elevation is an important factor on groundwater occurrence because weather and climatic conditions vary greatly at different elevation, and this caused differences in soil and vegetation (Aniya.,1985).

According to (Botzen et al. 2013), (Condon and Maxwell., 2015): Groundwater potential in highly elevated terrain approaches zero however, in the area where the rainfall is ample, highly elevated region can act as a recharge zone through the cracks and joints available in the rock and pressure head can create as the water flow from areas with high energy to those with low energy. Therefore, recharge areas are at higher elevations.

### 2.7.10 Normalized Difference Vegetation Index NDVI:

NDVI is this property that is exploited as an indirect indicator of the availability of groundwater below the surface of the earth. Vegetation succession and cover patterns may be controlled by the groundwater table (Stromberg et al., 1996). In arid and semi-arid areas, soil moisture may be feed by groundwater through capillary forces. With shallower depth to groundwater, more soil moisture may be available, and vice versa (Rodriguez-Iturbe, 2000; Farmer et al., 2003; Pan et al., 2008). Thus, many plants take the groundwater as a source for growth especially in semi-arid regions, where groundwater supports a large density of vegetation by providing additional water for plant growth and transpiration (Naumburg et al., 2005; Wang et al., 2011).

The Normalized Difference Vegetation Index (NDVI) is an index obtained from reflectance measurements in the visible and near-infrared regions to analyze the relative vegetation awning (Deering, 1978). Quantitatively, assessment of vegetation growth may be determined by NDVI, where high vegetation coverage will have positive values, while soil and non-vegetation coverage will have less positive values. Living green vegetation absorbs solar radiation as a part of photosynthesis and plants reflect solar energy in the near infrared. This difference in absorption is unparalleled for living vegetation and determines the greenness of vegetation. NDVI is an index that measures this difference, providing a measure of vegetation density and condition. The fractional cover of the ground influences the NDVI by vegetation, vegetation density and vegetation greenness. It indicates the photosynthetic capacity of the land surface cover. NDVI can be calculated from the red reflectance and near-infrared reflectance. NDVI values affects by many factor like plant cover, biomass, photosynthetic activity of the vegetation, and soil moisture (Dubey et al., 2012). NDVI calculated from satellite data can be used to indicate beginning and stopping of greenness, rate of green-up and senescence, daily and seasonally growing (Olusegun & Adeyewa, 2013).

## 2.8 Geographic Information System:

There are different definitions for Geographic Information System, each developed from a different perspective or disciplinary origin. Some focus on the map connection, some stress the database or the software tool kit and others emphasis applications such as decision support. Defining a GIS can be done by either explaining what it can do (Functions) or by looking at the components. Both are important to really understand a GIS and use it optimally. An analysis of the three letters of the acronym GIS gives a clear picture of what GIS is all about:

G: Geographic: Implies an interest in the spatial identity or locality of certain entities on, under

or above the surface of the earth.
I: Information: Implies the need to be informed in order to make decisions. Data or raw facts are interpreted to create information that is useful for decision-making.
S: System: Implies the need for staff, computer hardware and procedures, which can produce the information required for decision-making that is data collection, processing, and presentation.

A GIS is a computer-assisted system for the collection, storage, management, analysis and representation of geo-referenced data to support decision-making.

A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps — Environmental Systems Research Institute (Environmental Systems Research Institute- ESRI).

GIS is defined as a computerized system for capture, storage, retrieval, analysis and display of spatial data describing the land attributes and environmental features for a given geographic region, by using modem information technology (Thurgood, 1995). According to this definition, a GIS includes not only computing capability and data, but also managers and users, the organization in which they function and institutional relationships that govern their management and use of information.

A GIS can be defined as a computing application capable of creating, storing, manipulating, visualizing, and analyzing geographic information. It finds its strongest applications in resources management, utilities management, telecommunications, urban and regional planning, vehicle routing and parcel delivery, and in all of the sciences that deal with the surface of the Earth.

Geographic Information System is a system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth.

GIS is a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems (Rhind, 1989).

GIS is defined as a decision support system involving the integration of spatially referenced data in a problem-solving environment. (Cowen, 1988)

GIS is defined as a powerful set of tools for collecting, storing, retrieving, at will, transforming and displaying spatial data from the real world (Burrough, 1986)

GIS is any manual or computer based set of procedures used to store and manipulate geographically referenced data. (Aronoff, 1989)

GIS is an institutional entity, reflecting an organizational structure that integrates technology with a database, expertise, and continuing financial support over time (Carter, 1989)

In the strictest sense, a GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e. data identified according to their locations. Practitioners also regard the total GIS as including operating personnel and the data that go into the system (United States Geological Survey- USGS).

GIS is an integrated system of computer hardware, software, and trained personnel linking topographic, demographic, utility, facility, image and other resource data that is geographically referenced (National Aeronautics and space Administration- NASA).

Nowadays, GIS techniques are being used in water resources management such as drought, floods, surface and ground water studies and are recognized as effective and powerful toolsby different researchers such as Howari *et al.* (2007); Beser *et al.* (2016) and Şener *et al.* (2017). GIS has been widely used either in assessing or modelling the quantity of groundwater resources (Şener *et al.*, 2017). Furthermore, It has the ability to present theresults in a more understandable way.

### 2.8.1 Role of GIS in the Determination of Groundwater Potential:

Test drilling and stratigraphic analysis are the most reliable and standard methods for determining the location of a borehole and the thickness of the aquifereous unit (Madan et al., 2010). However, these methods of groundwater investigation are not time and cost effective and also, they often require skilled personnel (Roscoe, 1990; Fetter, 1994). Geophysical prospecting techniques have also been used by various researchers to explore groundwater resource in different types of geologic terrain (Ako et.al, 1989; Amadi et.al, 1990; Olorunfemi et al., 1995; Olayinka et al., 2001, Adiat et al., 2009). However due to lack of precision of an in-situ analysis, the results and interpretations of geophysical surveys can be validated by the use of borehole data.

The advent of GIS has also provided a cost and time effective means of assessing and managing groundwater resources (Jha et al., 2007; Meijerink, 2007). The Geographic Information System offers spatial data management and analysis tools that can assist users in organising, storing, editing, analysing, and displaying positional and attribute information about geographical data (Burrough, 1986).

In recent years, digital techniques are being used to integrate various data to solve problems related to groundwater including delineating groundwater potential zones. These various data are prepared in the form of a thematic map using GIS software tools. These thematic maps are then integrated using “Spatial Analyst” tool. The “Spatial Analyst” tool with mathematical and Boolean operators is then used to develop a model depending on the objective of the problem at hand, such as delineation of groundwater potential zones.

## 2.9 Weighting:

To apply multi-criteria evaluation (MCE), a set of relative weights is assigned for each map using weights. The weights that are calculated for each factor map are the results weighted Index Overly analysis and are based on their relative importance to groundwater accumulation. Weighted overlay analysis is one of the most widely used methods in spatial multi-criteria decision analysis. It is a simple and straightforward method for a combined analysis of multi-class maps. Human judgment can be incorporated into the analysis, and this improves the efficacy of this method. This method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighted overlay method. For this purpose, the criteria for the analysis should be defined, and each parameter should be assigned importance (Saraf and Chowdhury, 1998; Nag, 2005).

Determination of weight of each class is the most crucial in the integrated analysis, as the output is mostly dependent on the assignment of appropriate weight (Chowdhury, 1999). During the process of groundwater potential determination, the factors considered do not have the same influence, and not every factor was independent. When calculating potential groundwater, these factors were used for evaluation, and weight accumulation was applied to determine a groundwater potential score.

## 2.10 Groundwater Modelling:

Modelling is generally a representation of a reality in a simple manner of a certain phenomenon in order to ease the understanding or to predict the future behaviour. For instance, a simplification or a representation of a real system. Groundwater modeling in some form is now a major part of most projects dealing with groundwater development, protection, and remediation. As computer hardware and software continue to be improved and become more affordable, the role of models in highly quantitative earth sciences such as hydrogeology will continue to increase accordingly. It is essential, however, that for any groundwater model to be interpreted and used properly, its limitations should be clearly understood. In addition to strictly ‘‘technical’’ limitations, such as accuracy of computations (hardware and software), the following is true for any model:

- It is based on various assumptions regarding the real natural system being modeled.
- Hydrogeologic and hydrologic parameters used by the model are always just an approximation of their actual field distribution, which can never be determined with 100% accuracy.
- Theoretical differential equations describing groundwater flow are replaced with systems of algebraic equations that are more or less accurate.

It is therefore obvious that a model will have a varying degree of reliability, and that it could not be ‘‘misused’’ as long as all the limitations involved are clearly stated.

### 2.10.1 Types of Groundwater Models:

In general, a model simulates the areal and temporal properties of a system, or one of its parts, in either a physical (real) or mathematical (abstract) way. An example of a physical model in hydrogeology would be a tank filled with sand and saturated with water the so called ‘‘sandbox,’’ an equivalent to a miniature aquifer of limited extent. This aquifer can be subject to miniature stresses such as pumping from a perforated tube placed into the sand thus representing a water well. An obvious question when considering similar models is how feasible it is to build a multilayer ‘‘aquifer’’ exposed to various stresses such as precipitation, surface streamflow, leakage from deep underlying strata, and then change some of its geometric and hydrogeologic properties as needed. Consequently, the application of real physical models has been limited to educational and demonstration purposes.

A groundwater system can also be simulated using the analogy between groundwater flow and some other similar physical process such as the flow of electrical currents through conductors. Such models are called analog and were often used in hydrogeologic practice before the rapid development of numeric computer modeling.

Models that use mathematical equations to describe elements of groundwater flow are called mathematical. Depending upon the nature of equations involved, these models can be: .

- Empirical (experimental) .
- Probabilistic.
- Deterministic.

### 2.10.1.1 Empirical Models:

They are derived from experimental data that are fitted to some mathematical function. A good example is Darcy’s law. Although empirical models are limited in scope and are usually site or problem-specific, they can be an important part of a more complex numeric modeling effort. For example, the behavior of a certain pollutant in porous media can be studied in the laboratory or in controlled field experiments, and the derived experimental parameters can then be used for developing numeric models of groundwater transport.

### 2.10.1.2 Probabilistic Models:

They are based on laws of probability and statistics. They can have various forms and complexity starting with a simple probability distribution of a hydrogeological property of interest, and ending with complicated stochastic, time-dependent models. The main limitations for a wider use of probabilistic (stochastic) models in hydrogeology are that:

- they require large data sets needed for parameter identification.
- they cannot be used to answer (predict) many of the most common questions from hydrogeologic practice such as effects of a future pumping, for example.

### 2.10.2.3 Deterministic Models:

They assume that the stage or future reactions of the system (aquifer) studied are predetermined by physical laws governing groundwater flow. An example is the flow of groundwater toward a fully penetrating well in a confined aquifer as described with the Theis equation. Most problems in traditional hydrogeology are solved using deterministic models, which can be as simple as the Theis equation or as complicated as a multiphase flow through a multilayered, heterogeneous, anisotropic aquifer system.

There are two large groups of deterministic models depending upon the type of mathematical equations involved:

- **Analytical :** Simply stated, analytical models solve one equation of groundwater flow at a time and the result can be applied to one point or ‘‘line of points’’ in the analyzed flow field (aquifer). For example, if we want to find (i.e., to model) what the drawdown at 50 m from the pumping well would be after 24 h of pumping, we would apply one of the equations describing flow toward a well depending upon the aquifer and well characteristics (confined, unconfined, leaky aquifer; fully or partially penetrating well). To find the drawdown at 1000 m from the well, we would have to solve the same equation (say, the Theis equation) for this new distance. If the aquifer is not homogeneous, these solutions would be applicable just for a limited radial distance of 50 or 1000 m within the same distribution of aquifer transmissivity. Obviously, if our aquifer is quite heterogeneous, and we want to know drawdown at ‘‘many’’ points, we might spend a rather long period of time solving the same equation (with slightly changed variables) again and again. If the situation gets really complicated, such as when there are several boundaries, more pumping wells, and several hydraulically connected aquifers, the feasible application of analytical models terminates.
- **Numeric models:** describe the entire flow field of interest at the same time, providing solutions for as many data points as specified by the user. The area of interest is subdivided into many small areas (referred to as cells or elements) and a basic groundwater flow equation 500 Hydrogeology and Groundwater Modeling is solved for each cell usually considering its water balance (water inputs and outputs). The solution of a numeric model is the distribution of hydraulic heads at points representing individual cells. These points can be placed at the center of the cell, at intersections between adjacent cells, or elsewhere. The basic differential flow equation for each cell is replaced (approximated) by an algebraic equation so that the entire flow field is

represented by x equations with x unknowns, where x is the number of cells. This system of algebraic equations is solved numerically, through an iterative process, thus the name numeric models. Based on various methods of approximating differential flow equations, and methods used for numerically solving the resulting system of algebraic equations, numeric models are divided into several groups. The two most widely applied groups are :

- finite differences (numeric models).
- finite elements (numeric models).

Both types of models have their advantages and disadvantages and for certain problems one may be more appropriate than the other. However, because they are easier to design and understand, and require less mathematical involvement, finite-difference models have prevailed in hydrogeologic practice. In addition, several excellent finite-difference modeling programs have been developed by the Unites States Geological Survey (USGS) and are in public domain, which ensures their widest possible use. One of these is Modflow, probably the most widely used, tested, and verified modeling program today and it has become the industry standard thanks to its versatility and open structure, unfortunately SUTRA3D is not yet part of any of the most widely used user-friendly commercial programs for processing model input and output data, which severely limits its greater application.

### 2.10.3 Groundwater Modelling Purposes's:

- To predict or forecast expected artificial or natural changes in the system (aquifer) studied. The term predict is more appropriately applied to deterministic (numeric) models as it carries a higher degree of certainty, while forecasting is the term used with probabilistic (stochastic) models. Predictive models are by far the largest group of models built in hydrogeologic practice.
- To describe the system in order to analyze various assumptions about its nature and dynamics. Descriptive models help to better understand the system and plan future investigations. Although not originally planned as a predictive tool, they often grow to be full predictive models.
- To generate a hypothetical system that will be used to study principles of groundwater flow associated with various general or more specific problems. Generic models are used for training and are often created as part of a new computer code development.

### 2.10.4 Choosing Models and Application:

There is a large range of models available for modeling the groundwater potential. These models are different in terms of complexity, objectives basic process description, and input data required. Typically, there is no one optimal model for all applications. The most appropriate model will depend on the intended use and the characteristics of the environmental modeling. Other factors influencing the choice of a model for an application include:

- Nature of input data (including temporal variations in inputs and outputs) ;
- Accuracy and validity (including underlying assumptions) ;
- Model components, which reflect its capabilities;
- The user's goals (including their ability to take charge of the model, nature and scale of expected results) ;
- Quality of computer hardware.

## 2.11 Artificial Neural Network (ANNs):

An Artificial Neural Network (ANN) is an interconnected group of artificial neurons that uses a mathematical model or computational model for information processing based on a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network. In more practical terms neural networks are non-linear statistical data modeling tools. They can be used to model complex relationships between inputs and outputs or to fine patterns in data.

Artificial Neural Networks has been motivated right from their inception by the recognition that the brain computes in an entirely different way from the conventional digital computers. The struggle to understand the brain owes much to the pioneering work of Ramon V.Caial, who introduced the idea of neurons as structural constituents of the human brain. A neuron is the smallest processing unit in a human brain which is about five to sixtimes slower than the smallest processing unit in a computer. However, the brain makes up for the relatively slow rate of operation of a neuron by having a truly staggering number of neurons (nerve cells) with massive interconnection between them; it is estimated that there must be of the order of 10 billion neurons in the human cortex and 60 trillion synapses or connections. The net result is that the brain is an enormously efficient structure. Specifically, the energetic efficiency of the brain is approximately 1046 joules per operation per second, whereas the corresponding value for the best computers in use today is about 104 joules per operation per second (Faggin, 1991).

Artificial Neural Networks are mathematical models originally designed to mimic aspects of how the human brain works. ANNs, like people, learn by example. An ANN is configured for a specific application through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons. This is true of ANNs as well. In its most general form, an ANN is a machine that is designated to model the way in which the brain performs a particular task or function of interest; the network is usually implemented using electronic components or simulated in software on a digital computer. To achieve good performance, ANNs employ a massive interconnection of simple computing cells referred to as "neurons" or "processing units".

Following is the definition of an ANN viewed as an adaptive machine (Aleksander, 1990):

"Artificial Neural Network is (3 massive parallel distributed processor made up of simple processing units, which has a natural propensity for storing experiential knowledge and making it available for use. It resembles the brain in two respects:

**(1) Knowledge is acquired by the network from its environment through a learning process.**

**(2) Inter-neuron connection strengths, known as synaptic weights, are used to store the acquired knowledge".**

## 2.12 Previous Applications of ANNs in Groundwater Modelling:

In recent years, Artificial Neural Networks (ANNs) are used in many areas of science and Engineering. ANNs have proved to be effective in modeling virtually any nonlinear function to a reasonable degree of accuracy. ANN is an attractive tool for modeling groundwater levels. We present below a brief outline of various earlier works carried out on the application of ANN in Groundwater modelling:

Rizzo and Dougherty, (1994) introduced the idea of neural kriging for characterization of aquifer properties. A three- layer neural network utilizing the counter propagation algorithm was combined with kriging for estimating hydraulic conductivity. The input nodes represented the coordinates of observation points. The output nodes predicted the class of hydraulic conductivity at various locations. They concluded that ANNs could be useful tools in geohydrology when applied to specific problems of aquifer characterization. Johnson and Rogers (1995) they concluded that ANNs, combined with a genetic algorithm, result in robust and flexible tools that can be used for planning effective strategies in ground-water remediation.

Yang et al. (1997) predicted water table elevations in subsurface drained farmlands by using ANN model. Inputs which they used are daily rainfall, previous water table locations and potential evapotranspiration. The output was the current location of the water table. They found that a three-layer feedforward ANN could predict water table elevations satisfactorily after training using observed values.

Gumrah et al., (2000) applied ANN approach to forecast hydraulic heads of a groundwater source. In order to check the validity of the approach, a hypothetical field data as a case study was produced by using groundwater simulator. Hydraulic heads were obtained from groundwater simulations. ANN was trained by using the historical data of last two years. Hydraulic heads were estimated by applying both the long term and the short term ANN predictions. Results suggested that ANN model appeared to be a useful tool for forecasting hydraulic heads in the aquifer system.

Paulin Coullbaly et al., (2001) developed three types of functionally different Artificial neural network models using a relatively short length of groundwater level records and related hydro meteorological data to simulate water table fluctuations for *the* Gondo aquifer located in the Sahel region, West Africa. Input delay neural network (IDNN) with static memory structure and globally recurrent neural network (RNN) with inherent dynamical memory are proposed for monthly water table fluctuations modeling. The simulation performance of the IDNN and the RNN models was compared with results obtained from two variants of radial basis function (RBF) networks, namely, a generalized RBF model (GRBF) and a probabilistic neural network (PNN). Overall, simulation results suggest that the RNN was the most efficient of the ANN models tested for a calibration period as short as 7 years. The results of the IDNN and the PNN *were* almost equivalent despite their basically different learning procedures. The GRBF performed very poorly as compared to the other models. Furthermore, the study showed that RNN may offer a robust framework for improving water supply planning in semiarid areas where aquifer information is not available.

Nayak et. Al, (2005) used Artificial Neural Network (ANN) approach for groundwater level forecasting in a shallow aquifer. This paper reports a research study that investigates the potential of artificial neural network technique in forecasting the groundwater level fluctuations in an unconfined coastal aquifer in India. The most appropriate set of input variables to the model are selected through a combination of domain knowledge and statistical analysis of the available data series. The results suggest that the ANN models are able to forecast the water levels up to 4 months in advance reasonably well. Nourani et. al. (2012) estimates ground water level (GWL) by mathematical based model of Ardabil located at northwest of Iran. Three layer Feed Forward Artificial Neural Network (ANN) was used to correlate the model via groundwater level records from representative wells and relevant hydrological data. Results can be used to frame the corresponding strategies to reduce the monitoring cost and to increase the effective cost-benefits.

loannis N. Daliakopoulos at al., (2005) tested a total of seven different ANN configurations in terms of optimum results for a prediction horizon of 18 months. The performance of different neural networks in groundwater level forecasting was examined in order to identify an optimal ANN architecture that could simulate the decreasing trend of the groundwater level and provide acceptable predictions. Messara Valley in Crete (Greece) was chosen as the study area as its groundwater resources were being overexploited during the last fifteen years and the groundwater level has been decreasing steadily.

Lallahem at al., (2005) evaluated the feasibility of using ANN methodology for estimating the groundwater level in some piezometers implanted in unconfined chalky aquifer of Northern France. The reasonably good ANN based simulations revealed the merit of using ANNs and specifically Multilayer Perceptron (MLP) model. The proposed ANN methodology using minimal lag and number of hidden nodes, along with the optimal number of spatial and temporal variables consistently produced the best performing network based simulation models.

Puma C.Nayak et al., (2006) investigated the potential of artificial neural network technique in forecasting the groundwater level fluctuations in an unconfined coastal aquifer in India. The most appropriate set of input variables to the model were selected through a combination of domain knowledge and statistical analysis of the available data series. Several ANN models were developed that forecast the water level of two observation wells. The results suggested that the model predictions were reasonably accurate as evaluated by various statistical indices. An input sensitivity analysis suggested that exclusion of antecedent values of the water level time series might not help the model to capture the recharge time for the aquifer and may result in poorer performance of the models. In general, the results suggested that the ANN models were able to forecast the water levels reasonably well.

Asefa et al., (2007) presented afield scale applicability of three forms of ANN algorithms in forecasting short term groundwater levels at specific control points. Feed forward backpropagation (FFBP), radial basis networks (RBN) and generalized regression networks (GRN) were studied. It was shown that although learning algorithms have emerged as a viable solution at field scale much larger than previously studied, no single algorithm performed consistently better than others on all the criteria. On average, FFBP networks were 20 and 26% respectively more accurate than RBN and GRN in forecasting one week ahead water levels and this advantage dropped to 5 and 9% accuracy in forecasting four weeks ahead water levels, whereas GRN posted a. training time that was only 5% of the training time taken by that of FFBP networks. This suggests that in field scale applications one may have to trade between the type of algorithm to be used and the degree to which a given objective is honored.

Azhar K.Affandi et al., (2008) used multilayer backpropagation neural networks (BPANN) to simulate groundwater level fluctuations. The case of study area was Jakarta, Indonesia, that had high population density and several purposes of groundwater resource usage. Input variables of five daily groundwater level fluctuations of observation well were used to predict current groundwater level fluctuation. Results showed that application of BPANN to simulate groundwater level fluctuation gave satisfied prediction results.

Zhongping Yang et al., (2008) discussed the modeling process of back propagation artificial neural network (BPANN) and accuracy of this method was evaluated using root mean squared error (RMSE), the mean absolute error (MAE) and coefficient of correlation (R2). The arid and semi-arid areas of western Jilin province (China) were chosen as study area owing to the decline of groundwater levels during the past decade mainly due to over exploitation. The simulation results indicated that BPANN was accurate in reproducing and forecasting the groundwater level. It is evident that the BPANN was able to predict the groundwater levels reasonably well.

## 2.11 Conclusion:

Demarcating the potential zones of groundwater in an area is essential for the groundwater exploration and management purposes. Different procedures were adopted by various authors to demarcate the groundwater potential zones in different parts of the world.

In this study, the groundwater potential model integrated 10 themes including the slope, rainfall, ground elevation, land cover/land use, soil type, normalized difference vegetation index (NDVI), topographic wetness index (TWI),distances from the river, geology, and drainage density. The themes were weighted using the artificial neural network. More importantly, the ANNs model can be easily modifiable, shareable, reusable and efficient.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1. Introduction:

This chapter describes in detail the characteristics of the study area. In the second section, we present the materials and methods used for delineating groundwater potential zones using a Geographic information system (GIS) and artificial intelligence network model (ANN), including types of the used data, descriptions of procedures used to prepare different thematic layers and their reclassification according to standardization method and the adopted weight calculation technique using ANN. Moreover, all the steps that were undertaken to generate groundwater potential zone delineation using GIS and ANNs are summarized in a flowchart.

## 3.2 Description of the Study Area:

This study concerns the Cheliff basin, the largest basin in Northern Algeria, which is located in the northwest of the country and lies between 34° and 36° N in latitude and between 0°12' and 3° 87' E in longitude (Figure 3.1). The Cheliff basin numbered 01 according to the nomenclature adopted by from Algerian National Agency for Hydraulic Resources (ANRH), it corresponds to an intra-mountainous basin located in the North of Algeria, it is surrounded by the chains of the Tellian Atlas, which runs parallel to the Mediterranean coast. Cheliff basin covers three sub-regions, the Cheliff upstream of Boughzoul, the Upper and Middle Cheliff and the Lower Cheliff and Mina. Occupying an area of 43750 km$^2$, it covers 77% of the total surface of the Cheliff-Zahrez watershed. It is bordered to the north by the coastal-Dahra basin, to the south by the Zahrez basin, to the east by Algiers basin and to the west by the Oran basin.

This basin is drained by the Cheliff wadi which crosses it over a length of 750km before it flows into the Mediterranean near Mostaganem. Its farthest tributary, the Sebgag River, rises in the Amour mountain range of the Saharan Atlas Mountains near Aflou.

Crossing the Hauts Plateaux (highlands) for most of the year as a chain of marshes and muddy pools, the river loses most of its water but is replenished by a stream near Chabounia, the Nahr Ouassel River. The Cheliff then turns abruptly north to rush through a deep gorge in the Tell Atlas Mountains between Ksar el-Boukhari and Djendel. Below Oued Chorfa the Wadi swings to the west, flowing for about 230 km parallel to the coast in a depression (the Cheliff plain) between the mountains of Dahra, Zaccar Rherbi, and the Telian Atlas. The river reaches the Mediterranean Sea about 13 km north of Mostaganem.

The basin is subject to a Mediterranean climate over its entire northern part, which includes the coast and the Telian Atlas, and to a semiarid to arid climate over the Highlands and the Saharan Atlas regions. It is characterized by a long period of summer drought varying from 3 to 4 months over the coastal regions and from 5 to 6 months over the other regions. (Harkat et al, 2021)

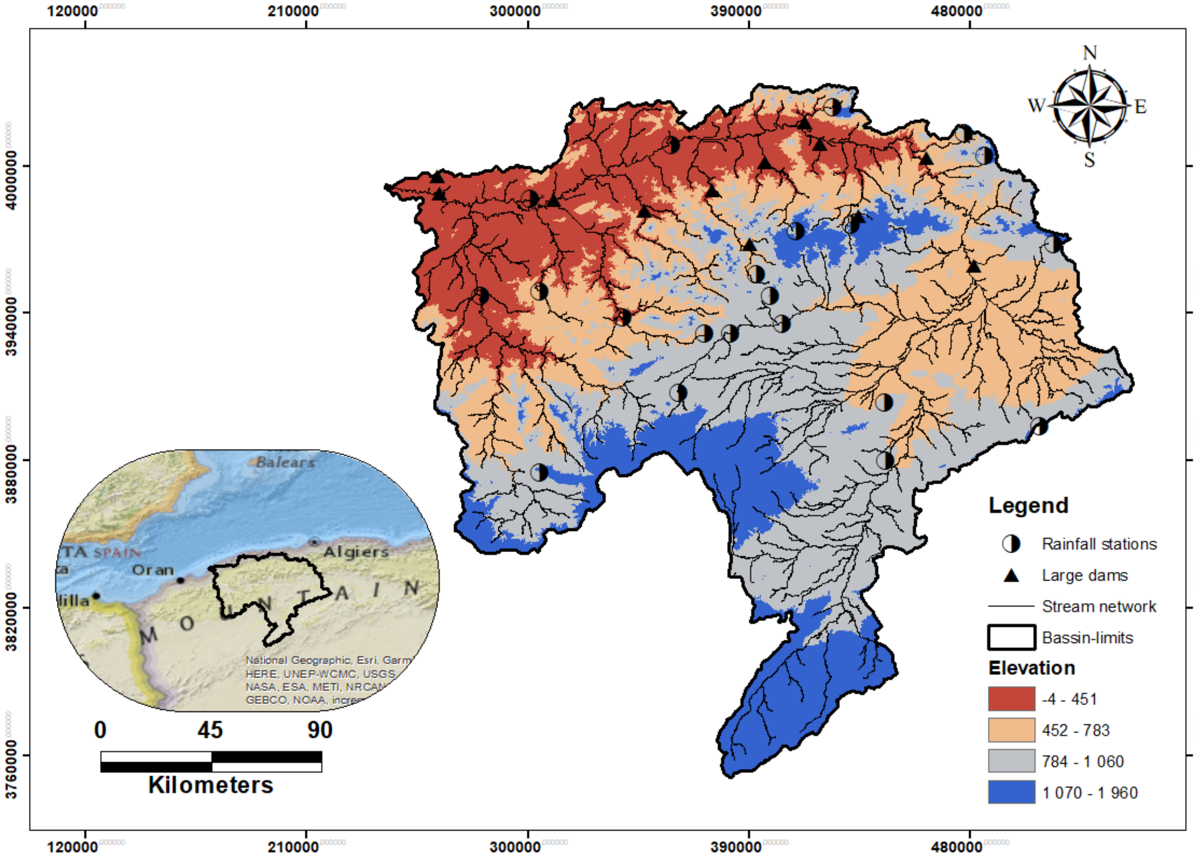


Figure 3.1: Geographical Location of Study Area.

The Cheliff basin has Seventeen (17) dams in operation, their total initial capacity 1 700 hm$^3$ With a siltation rate that varies from 1 to 62%. their capacity at the last survey totaled 1,759.58 Hm$^3$. According to PNE 2010, the total regulable volume of the 17 dams in operation is 512.30 Hm$^3$/year for water supply and 730.50 Hm$^3$/year for irrigation.

The water needs in the basin are not precisely known and the lack of reliable data does not allow us to distinguish between the volume of water withdrawn, the volume used and the volume of consumption. Moreover, we have no idea about the volumes of water illicitly pumped by various users. The needs are more or less regular and always have a peak in July and August. But we illustrate bellow the various categories of needs in our studied area:

**Potable water supply:** The domestic water needs, mainly in the Upper, Middle and Lower Cheliff, are estimated at 12.5, 8 and 12.8 $Hm^3$ respectively. It should be noted that all the towns and localities in the basin use mainly groundwater (90%) drawn from the alluvial aquifers of the wadi, while the remaining 10% is drawn from the remaining 10% correspond to the supply of springs.

**Irrigation:** Water consumption for irrigation is generally concentrated in a limited period from April to October with a peak in July and August. Four major irrigation networks are located in this valley: the Upper, Middle and Lower Cheliff supplied either from the above-mentioned dams or from the unregulated water of the Wadi from the non regularized waters of the Cheliff wadi. The needs in agricultural water have been evaluated according to the nature of the soils, their spatial distribution and the requirements of the crops is from 3000 to 7000 $m^3$/ha/year.

**Industrial water supply:** Industrial water needs are relatively small compared to those of agriculture. The evaluation of the current water needs for the industry at the scale of the basin in amounts to 21,4 Hm3 distributed as follows:

- ✓ Upper Cheliff: 6.6 $Hm^3$
- ✓ Middle Cheliff : 1,8 $Hm^3$
- ✓ Lower Cheliff : 11,6 $Hm^3$
- ✓ The area of Relizane : 1,4 $Hm^3$

The total volume withdrawn according to some estimates could reach 40 $Hm^3$.

The Chéliff basin is equipped with a rainfall grid of 127 rainfall stations and 29 hydrometric stations managed by ANRH and evenly distributed across the study area. The irregularity of the rains is the essential character of the rainfall in the Cheliff Basin, irregularity from one region to another, but above all an inter-annual irregularity. Precipitation shows a great monthly variability. The absence of rain is to be noted in August, July, September, and October (Boucefiane 2006; Meddi and Boucefiane 2008). The annual rainfall decreases as one advances towards the south and falls to less than 100 mm in the Saharan Atlas. This irregularity is due to the existence of a longitudinal gradient. Rainfall increases from West to East (300 mm/year in the West and more than 500 mm/year in the East) and by a latitudinal gradient (the average annual rains vary by 100 mm in the Highlands region and more than 900 mm to the North) (Harkat et al 2014; Khelfi et al. 2017). (Appendix A)

Overall, we can conclude that the spatial variability of rainfall across the Cheliff basin depicts a high spatial variability with two clear decreasing trends from north to south and from east to west as it is shown in Figure 3.2.

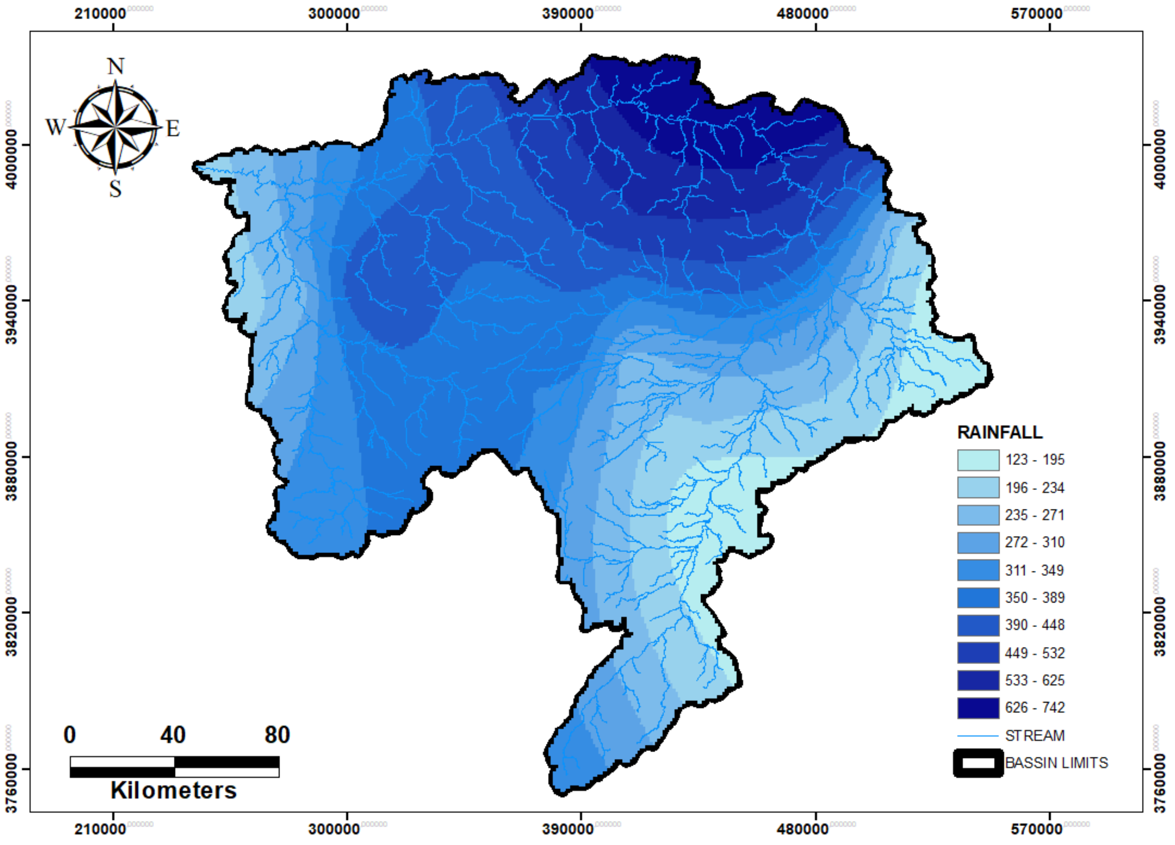


**Figure 3.2: Map of Rainfall Distribution over the Cheliff Basin.**

The thermal regime of the studied region has regional nuances that can be determined by annual and monthly average temperatures, as well as thermal amplitude values. Indeed, the average annual temperatures decrease progressively from North (Coastal, Boughzoul downstream basin) to South (Boughzoul upstream basin): 18.5 C° in Ténès, 17.0C° in Miliana, 16.2C° in Ksar Chellala and 13.4C° in Djelfa respectively (Appendix B). Average monthly temperatures follow the same pattern, but the decrease is faster in the cold season than in the hot season, owing to the particularly harsh effect of the continental climate in winter and the more regulating influence of the sea in summer.

## 3.3 Basin Geomorphological Characteristics:

Delineation of groundwater potential zones requires the knowledge of the basin characteristics such as topographic and morphological characteristics (the relief, the hydrographic network, the soil nature and the vegetation cover), geology and hydrogeology.

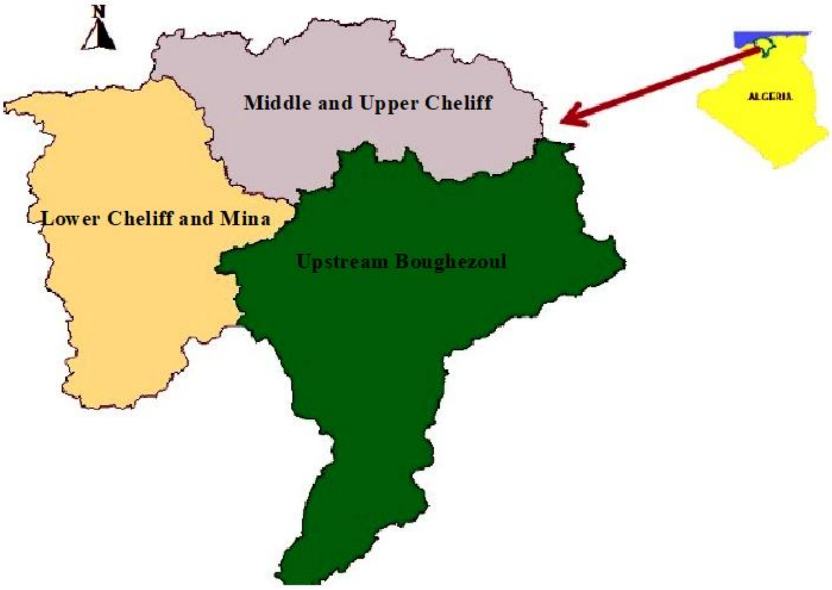


**Figure 3.3: The Three Regions of Cheliff basin. (Elmeddahi,2016)**

The study area is composed according to hydrographic delimitations, of 03 basins as illustrated in Figure 3.3. Their areas vary from 10930 km$^2$ (Middle and Upper Cheliff) to 13150 km$^2$ (Lower Cheliff and Mina) and 19 990 km$^2$ (Cheliff basin Upstream Boughzoul). These three large basins include several sub-basins (Figure 3.4): 11 sub-basins at the Middle and Upper Cheliff; 13 sub-basins at the Lower Cheliff and the Mina and 12 sub-basins at the upstream of Boughzoul.

### 3.3.1 Relief:

The study area is characterized by the heterogeneity of large natural units:

- The coastal reliefs are formed by hills of average altitude ranging between 300 and 600 m, the peaks reach 800 m. As a whole, the massifs form a long chain whose most important altitudes are in the east where the summits of the two mounts of Zaccar (1580m, 1527m) and the Djebel Bou Mad which culminates at 1417m.
- The plains and the interior basins are distant from the sea from 20 to 70 km. The altitudes range from 250 to 300 meters in the basin of Haut Cheliff, between 150 and 200 meters

in the basin of the middle Cheliff and between 60 and 150 meters in the basin of the Lower Cheliff.

- The mountains and plateaus are formed by a band of reliefs that extends from the Mediterranean to the North and the high plateaus to the South. The mountainous regions present two different aspects with folded chains more or less parallel to the coastline. The mountain ranges have a fairly strong morphological diversity and present a series of altitudes that vary between 700 and 1200 meters and can reach 1983 meters at the peak of Kef Sidi Ammar.
- The Tellian plateaus correspond to a broad platform formed by high plains that rise between 800 and 1,200 m in altitude. They are developed in the south of the high basin of the Mina to the Moroccan borders. They slope towards the High Steppes.
- The High Plains are represented by the Sersou plateau which is the only Tellian region of the High Plains. It is circumscribed by the basin of Tissemsilt to the north of the wadi, the Nahr- Ouassel and the Sersou plateau to the south of the same wadi.

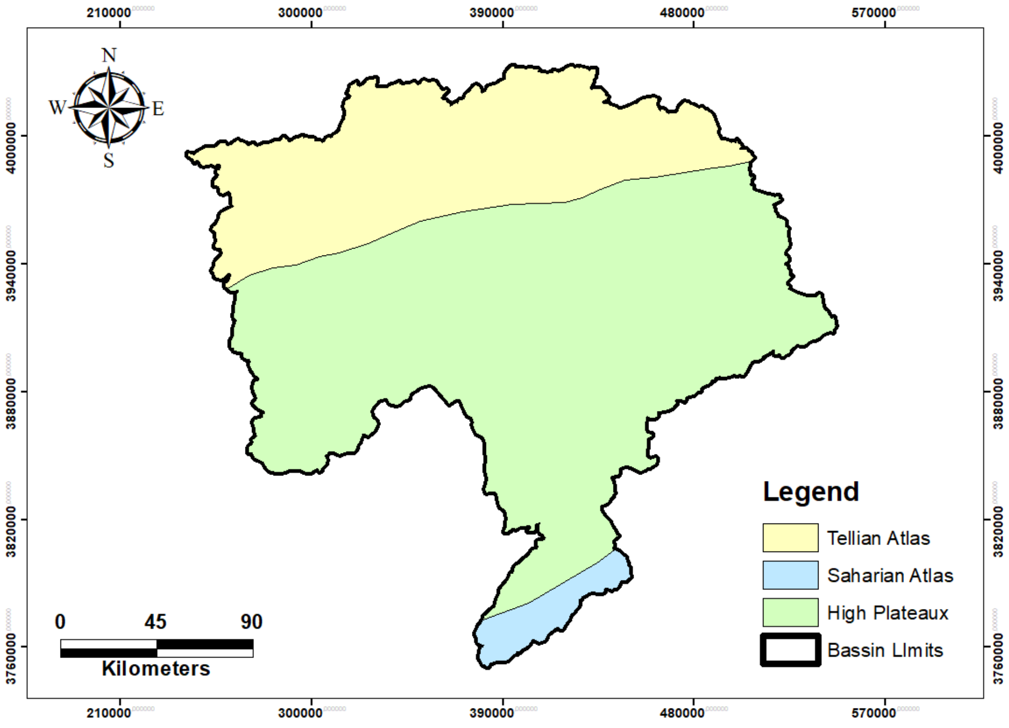


**Figure 3.4: Relief Map of the Cheliff basin.**

### 3.3.2 Hydrographic Network:

The hydrographic network of the study area is constituted by a dense network represented mostly by temporary watercourses:

The Cheliff Wadi results from the junction of two major rivers: Wadi Touil and Nahr Ouassel is among the major North African wadis; it is the only one with the longest course and the highest flow. The wadi Touil takes its source in the Saharan Atlas, near Aflou in the mountains of Djebel Ammour, with a SW-NE orientation until Chahbounia in Médéa, where it meets Nahr Ouassel which flows obliquely towards the North-East.

The Cheliff wadi is the result of the junction of these two major rivers, first takes a South-North direction and crosses the chain of Médea (Boughari). Then, following a SE-NW orientation, it crosses the Gantass massif, and finally it flows on an oblique from East to West, until its mouth towards the Mediterranean Sea in Mostaganem. For most of its course, Cheliff meanders at the bottom of a valley parallel to the sea, bordered to the south by the Ouarsenis massif and to the north by the coastal chain of the Dahra and Zaccar mountains.

From Boughzoul to the mouth of the Cheliff, the distance in a straight line is about 250 km and the difference in altitude about 625 m. During all this course, the Cheliff does not receive important tributaries on its right bank except the Ebda and the Ras Ouahrane wadi, but on its left bank, it collects the waters of the Oued Deurdeur, Harreza, Rouina Zeddine, Fodda, Sly, Rhiou, Djediouia and the important tributary more in the West: the Oued Mina which follows a South-North direction.

In general, the layout of the hydrographic network is largely related to the evolution of the structural elements that have affected the region over geological periods, particularly the Quaternary. The hydrographic network practically follows the important accidents that have affected the land and is modified with the evolution of tectonics.

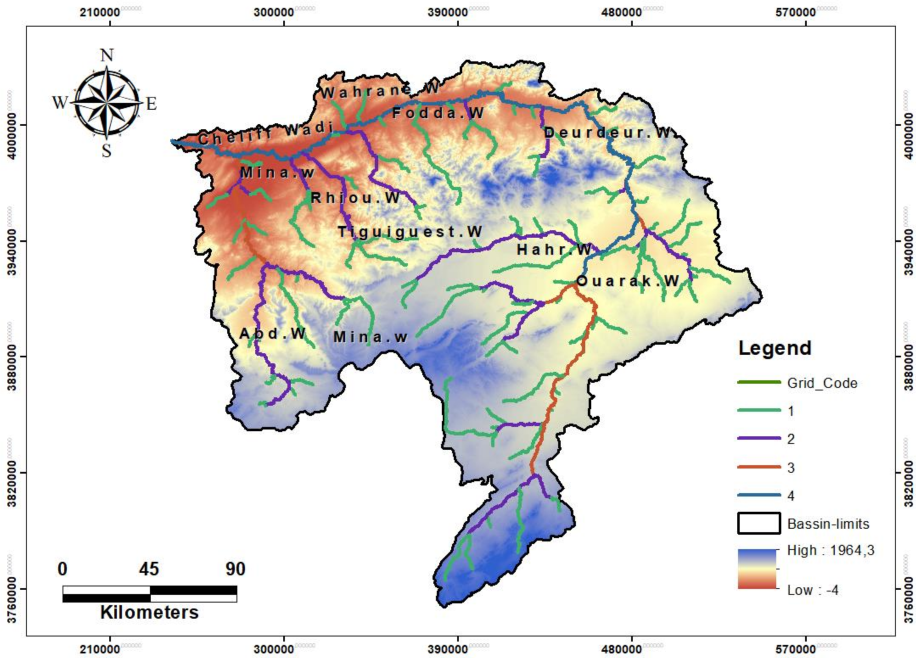


**Figure 3.5 : Stream Network Map of the Cheliff basin.**

### 3.3.3 Soil:

The Cheliff basin has great agricultural potential. Four irrigation perimeters covering 61500 ha, carried out since the thirties (Middle Cheliff put into service in 1936, lower Cheliff put into service in 1937, upper Cheliff in 1937 and Mina in 1941). The soils of the Cheliff basins are composed of five categories according to the classification proposed by ANRH based on physicochemical properties and various natural factors (geomorphology, topography, ...etc).

- Category I: soils do not present major development problems and are to be developed as a priority, they are suitable for all crops.

- Category II: soils have minor development problems (stone removal or surface sanitation). These soils are especially suitable for industrial crops.

- Category III: soils are to be reserved for crops in rotation and whose essential management problems are drainage, after irrigation and desalination.

- Category IV: soils are sometimes salty or hydromorphic with a shallow water table. They present major development problems. The cultivation capacity is often reduced to cereal, forage and market gardening crops. Dry farming is recommended.

- Category V: soils correspond to soils unsuitable for irrigation for various reasons: presence of shallow limestone crusts, halomorphy, very pronounced hydromorphy and unfavorable topography.

According to the pedological studies carried out by ANRH in the Cheliff region, Only category I, II and III soils are considered as irrigable soils, the overall irrigable area is estimated at 241,921 ha.

### 3.3.4 Vegetation:

The vegetation cover of the study area offers a great spatial diversity that is influenced by soil types and climatic differences induced by the proximity of the Sahara and the Mediterranean Sea. The basins of the study area are mostly affected by a semi-arid to arid climatic regime that will determine the vegetation cover.

In the topographically depressed sectors, a predominance of cereal and vegetable crops is limited to the Miocene outcrops, plains and alluvial terraces. These sectors are characterized by rather low slopes (2% to 5%) and are weakly subjected to erosion and steppe areas that are concentrated in the South of the basin. At the level of the upstream parts of the basins where the slopes are relatively strong (10% to 18%) the cultures are unstable essentially installed on the marls and the clays. These formations constitute fragile sub-basements and are very favorable to erosion. The highest regions are dominated by forest cover.

### 3.3.5 Geology:

According to several authors: Pomel, 1881; Gentil, 1895; Brives, 1897; Perrodon, 1957; Mattauer, 1958; Polveche, 1960; Thomas, 1985; Meghraoui, 1982, 1988; Achour, 1997; Remaoun, 2007, the Cheliff basin belongs to the sub-littoral sedimentary basins elongated East-West and set up after the last alpine phase of tangential tectonics. In the north, this depression is separated from the sea by the northern Tellian chain, which is mainly composed of Tertiary, Quaternary, and Permian formations. To the south, it is limited by the "Ouarsenis" mountains, which are formed by Jurassic and Quaternary formations. The Triassic, Ceratosaurus, and Tertiary series overly the eastern part of the Cheliff Basin, which is bounded by the high Cheliff. Tertiary and Jurassic structures, on the other hand, are highly exposed along the western border with the low Cheliff.

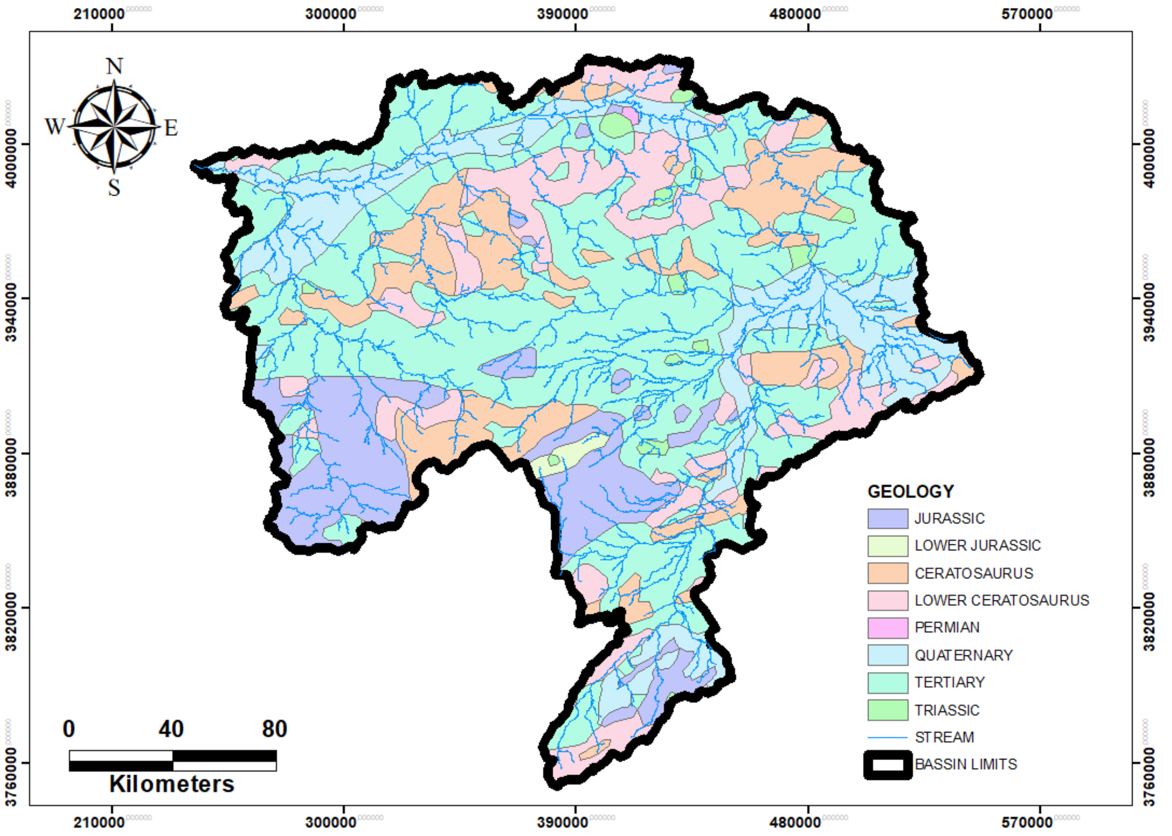


**Figure 3.6: Geological Map of the Study Area.**

### 3.3.6 Hydrogeology:

The study region is composed of two distinct areas:

- In the North, the Cheliff furrow framed by the two Tellian chains (Monts du Dahra in the North and the Ouarsenis Massif in the South).
- In the South, the high plains between the Ouarsenis and the Saharan Atlas.

Many geological formations contain groundwater, the oldest are attributed to the Jurassic and the most recent correspond to the Quaternary alluvium. In the northern part of the basin, the two Tellian chains have poor resources that cannot be exploited directly. The permeable levels (limestones and sandstones) are generally poorly developed and embedded in powerful formations with very low permeability. The Cheliff furrow is subdivided into three basins (Upper, Middle and Lower Cheliff), separated by two thresholds: the Ain Defla threshold and the Oum Drou threshold.

The aquifer formations have a limited extension. The lithology allows to group the geological formations as follows:

- The Jurassic limestones of the massifs, intensely fissured and karstified.
- The basal conglomeratic formations of the lower Miocene and the upper Miocene.
- The reef limestones of the upper Miocene.
- The Pliocene formations with in particular the sandstones and sands (Astien-Villafranchian)
- The alluvial formations of the Quaternary (fine alluvial deposits on the surface, coarse alluvial deposits at depth.

The different aquifer formations in the Cheliff Basin (ABH-CZ, 2004, 2007 and ANRH, 2004, 2009) are illustrated below:

**Wadi Touil region:** Oued Touil is bounded to the north by the Ain Oussara plain and the Sersou plateau, to the west by Jebel Naddor, to the east by the Zahrez plain and to the south by Jebel Amour. The main aquifers are the quaternary alluvium (sands, gravels and clays), the massive Turonian limestones and the Albian sandstones. The potential resource estimated by the rainfall/infiltration method is 9.44 hm3/year.

**Nahr Ouassel plain:** The plain is limited to the North by the marl and limestone formations of Boughari, to the West by the Sersou plateau, and to the South by the limestone of Ain Oussara. The main aquifers of this region are the Quaternary alluvium, the Miocene and Oligocene sandstones, the Turonian limestones, the Albian sandstones and the Barremian dolomites and sandstones. The potential resource is estimated by the rainfall/infiltration method at 23.54 hm3/year.

**Ain Oussera plain:** To the North, these formations are limited by the Nahr-Ouassel plain, to the West by the alluvium of the Oued Touil, to the East by the Relizane Chéraga plain and finally the Djebel Nador to the South. The plain of Ain Oussera is covered over its entire surface by a crust of Quaternary limestone deposits and recent sandy alluvium constituting a small aquifer exploited by traditional wells. The Albian sandstone formations form the main aquifer of the region characterized by an important productivity (10 to 90 l/s from 20 meters depth). The potential annual resource of the Albian sandstones is estimated at 17,17 hm3/year.

**Jebel Benhammad:** This Jebel is limited to the North by the plain of Nahr Ouassel, to the East by the alluvium of oued Touil, to the West and to the South by the Jebel Nador. The fissured limestones and dolomites of the Jurassic and the Cretaceous constitute good aquifers. Boreholes, capturing these formations from 45 m depth, have given flows of 60 to 80 l/s. The total potential resource has been evaluated at 1.75 hm3/year.

**Sersou Plateau:** The Sersou Plateau is limited to the North by the Massif de l'Ouarsenis, to the West by the Oued Nahr Ouassel and the Northern slope of Djebel Nador. It is a vast depression oriented West - East in which several aquifers have been highlighted. On the whole plateau, the coarse deposits of the Plio-Quaternary constitute a shallow aquifer. These deposits can reach 100 m in thickness. The lower Miocene sandstones of low permeability are tapped by numerous wells and boreholes in the northern part of the plateau. They feed a series of springs along the Oued Nahr Ouassel valley. The potential resource has been evaluated at 12.69 hm3/year.

**Mouafkia plain:** This plain forms to the north of Cheliff a depression stretching in a WSW-ENE direction over a length of about 15 km and a little less than 3 km wide. It is limited to the North by the anticline of Medjadjas and to the South by a line of hills formed in major part of villafranchian layers with notably red ochre sandstone. On the southern flank of the Medjadjas Anticline outcrop beige to red calcareous cement sandstones, becoming green at the base (Pradines, 1977).

**Cheliff plain:** The Ponteba sill which separates the wadi Fodda plain upstream from the Cheliff plain is formed by Miocene marls partly covered by Mio- Pliocene sands. The alluvial water table is deep in this area, it consists of gravels located between 57 and 69 m. According to the electrical coring, it contains salt water and its salt content is about 3 g/l. The other layers are coarse alluvium interspersed with more clayey layers. The water table in this area has a mineralization of about 5 g/l. Towards was Ras and north of the Cheliif, the deep formations correspond to coarse alluvium. The groundwater is not very salty compared to the water table.

**Plain of Chlef - Boukadir:** This part of the Cheliff plain is located between the Taflout wadi in the east, the Cheliff in the north, the Kherba hills in the west and the foothills of the lithothamnium limestone in the south. The Boukadir plain constitutes the southwestern end of the Middle Western Cheliff and communicates with the Lower Cheliff through a narrow corridor between the Kherba hills and the lithothamnium limestones.

The Boukadir plain is very flat and very low (altitude around 75 m NGA). In fact, this plain must have constituted for a very long time a lake or a swamp at the downstream end of the

Middle Western Cheliff where fine sediments have accumulated. The phenomenon is accentuated downstream and at the level of the hills of Kherba, the land is essentially clayey from the Cheliff to the limestones with lithothamnias.

## 3.4 Conceptual Research Design:

The research activities included:

- Data collection:

Some data sets such as DEM and satellites images were collected from online databases. The other data such as geology and soil maps were obtained from different institutions and organizations as given under section 3.6.1.

- Generation of the thematic maps:

The groundwater potential conditioning factors were represented in the GIS platform as raster thematic layers through the processing of collected data.

- Artificial neural network Modeling:

Weights for each factor that was generated in the previous step were determined by using the neural net algorithm in the R studio environment.

- Generation of groundwater potential zones:

The estimated weights and the normalized factors maps were then combined through the weighted linear process method to generate the groundwater potential zones map across the Cheliff basin.

## 3.5 Building the Research Geodatabase:

In the study area the generated, collected and digitized data was organized into logical groups of entities concerning geological factors and climatic factors, physiographic factors. Then, individual entities assigned and converted to characteristic spatial representation format in order to make them suitable for analysis in GIS environments. In order to delineate the groundwater potential zones of the study area different thematic maps on 1:50,000 scales and 30m*30m cell size prepared from existing maps. Groundwater potential zone map prepared by artificial neural weight using R studio software and Arc GIS 10.8 software’s.

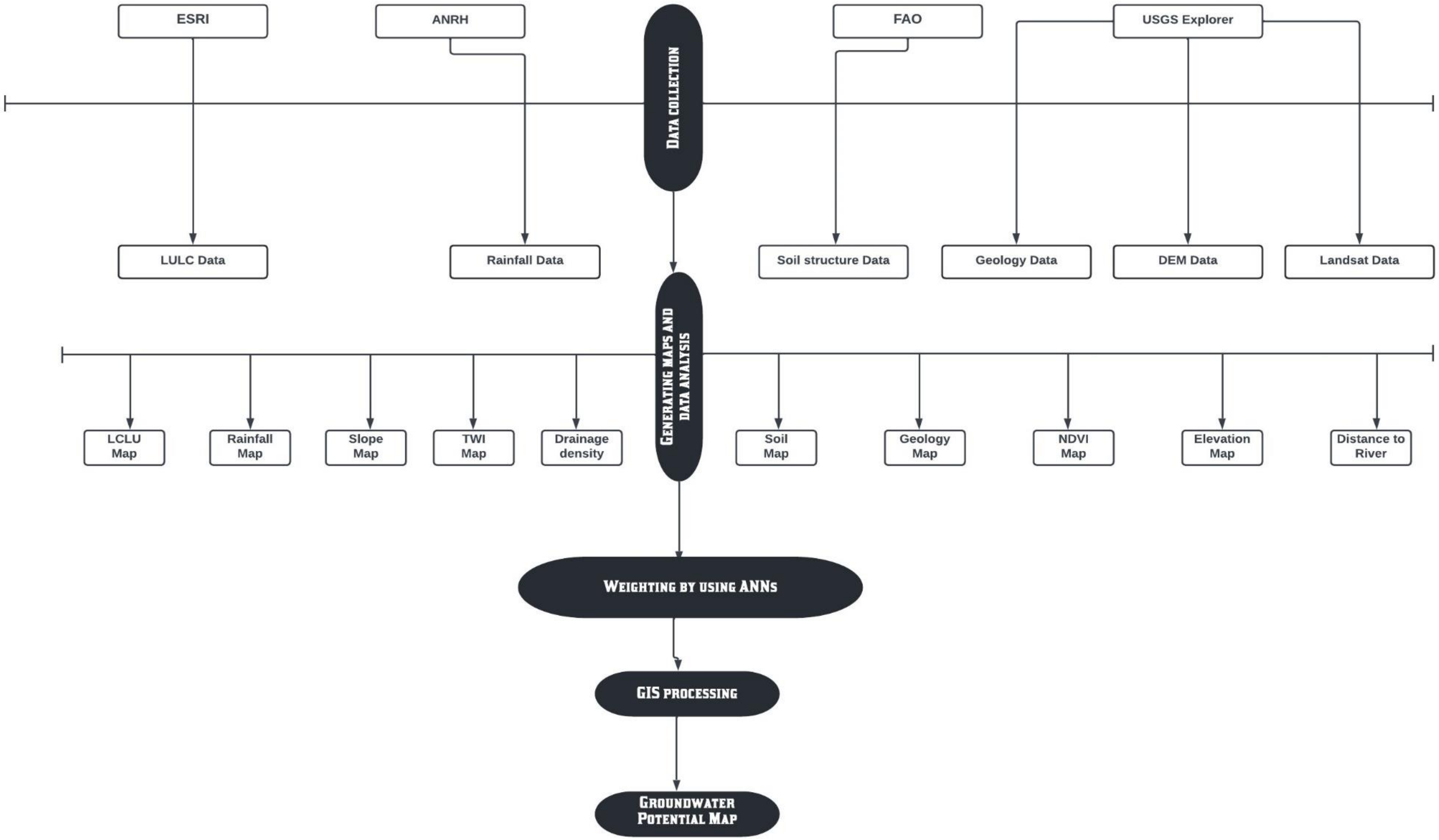


**Figure 3.7: Flowchart for the Delineation of Groundwater Potential Zones.**

## 3.6 Data Sources, Types, Materials:

### 3.6.1 Data Sources:

To achieve objectives of this study, both primary and secondary data are used. Some data used in this research were generated from different sources. The main data used in this study includes Soil data from Food and Agriculture Organization of the United Nations (FAO), Geological Map of study area from United States Geological Survey (USGS) , Rainfall data taken from ANRH, Land use/land cover map that was generated by using data uploaded from Geographic Information Systems Company (Esri) and we used Landsat downloaded from the U.S. Geological Survey Global Visualization Viewer Website without the presence of cloud cover to ensure the accuracy of our data, slope, geomorphology, and drainage pattern were generated by utilizing DEM and Landsat from the USGS earth resource observation system data center (https://earthexplorer.usgs.gov). All of the previously mentioned data were downloaded from Landsat ETM+ in level 1 geotiff format and have a spatial resolution of 30m. the above data is collected and processed in a GIS environment for further analysis on delineating groundwater potential zones by classifying and generating thematic factors.

Table 3.2 highlights the spatial datasets used in this study:

(*NA means Not Applicable.)

**Table 3.1 : Datasets and Inputs Used in the Study.**

| Data | Spatial resolution | Format | Source |
|---|---|---|---|
| Soil data | *NA | Vector | Food and Agriculture Organization of the United Nations<br>https://www.fao.org/ |
| Geology Data | NA | Vector | https://certmapper.cr.usgs.gov/ |
| Land-use / Land-cover | NA | Vector | Esri<br>Geographic information system company<br>https://livingatlas.arcgis.com/ |
| SRTM DEM | 30 m | Raster | United States Geological Survey<br>https://earthexplorer.usgs.gov/ |
| Landsat 8 | 30 m | Raster | https://earthexplorer.usgs.gov/ |
| Rainfall data (1936 to 2008 ) | 0.5° x 0.5° | Vector | Algerian National Agency for Hydraulic Resources (ANRH) |

### 3.6.2 Data Types:

#### 3.6.2.1 Primary Data:

The primary data consists of Landsat 8 current land use/land cover of the study area; it was downloaded from the U.S. Geological Survey Global Visualization Viewer Website after making sure that there was no cloud cover. SRTM images with a spatial resolution of 30 m * 30 m were downloaded from the USGS as a Digital Elevation Model (DEM) of the Cheliff basin (ground elevation map), and they were also used to generate slope, distance to river, and drainage density maps. Rainfall data were collected from ANRH to create the spatial distribution of mean annual rainfall across the study area.

#### 3.6.2.2 Secondary Data:

The secondary data used in this study includes the soil map of the study area, which was acquired from FAO, and the geological map of the study area from other secondary data were gathered from reports, journals, and governmental institutions specializing in water resource management.

### 3.6.3 Materials:

The groundwater potential zone site for Cheliff and the surrounding watershed was determined using various instruments and technology in this study. Computer hardware and software are used in this study for data preparation and organization, data analysis, and output generation. A personal computer, a printer, and a digital camera are among the hardware components. The software used for data preprocessing and preparation, data analysis, editing, and output generation was Arc GIS 10.8 and R Studio.

## 3.7 Methods:

### 3.7.1 Data Analysis Methods:

As it is described in the above section this research benefit from combination of data from different sources. Likewise, different data analysis methods and tools will be employed in this study such as methods of GIS operation for suitability analysis. Methods like rectifying, digitizing, reclassify, and weighting are the major ones uses in this study to delineate groundwater potential zone maps. In general this chapter presents methods that are used during the research study.

### 3.7.2 Thematic Map Preparation:

Thematic maps are an important source of GIS information. These tools served to communicate geographic concepts in the form of maps. The thematic maps such as slope, rainfall, ground elevation, land cover/land use, soil type, normalized difference vegetation index (NDVI), topographic wetness index (TWI), and distances from the river, geology, and drainage density are prepared by using digitization and overlay analysis with the appropriate criteria. Once all the required datasets were acquired, they were georeferenced using a projected coordinate system, WGS 1984 UTM Zone 31N. All the layers were converted to raster format and their values reclassified to a common scale of between 0 and 1. The reclassification was guided by literature information and expert knowledge.

Thematic maps for each parameter are prepared as follows:

#### 3.7.2.1 Drainage Density Layer:

Drainage density indicates rock permeability and infiltration capacity, and therefore recharges capacity. They are reflection of the rate that precipitation infiltrated compared to surface runoff. Where rocks are highly permeable, infiltration to groundwater is high, and less water is transported in rivers as surface water; but where rocks have low permeability there is little infiltration and more surface water runoff. Low drainage density is therefore related to higher recharge and higher groundwater potential (M. Thangarajan, 2007). The drainage density is high in the plateau and escarpment and very low in the rift floor (Ayenew, 1998).

The drainage density map of the study area was generated from the SRTM digital elevation model (DEM) using the spatial analyst tool for ArcGIS® 10.8 (ESRI, Redlands California USA). The drainage density was calculated from the total stream's length of the study area per unit area using Equation 3.1 after Raghunath (2006).

$Dd=\sum L/A$…………………………………………………………………………...…..…3.1

Where:

$Dd$ = Drainage density (km/km2).

$\sum L$ = Total length of streams (km) .

$A$ = Surface area of the basin under consideration (km2).

### 3.7.2.2 Slope Data Layer:

In the study area the slope is also another topographical aspect that influences the delineate ground water potential. HsinFuYeh (2016). Slope is one of the majors factors that controlling infiltration of water to the ground and the indicator of groundwater potential suitability. Very high sloping region causes more runoff and less infiltration and have poor groundwater prospects when compared to the low slope region. Low slopping regions causes less runoff and high infiltration rate and has good groundwater potential.

Slope map was prepared from DEM using slope function in ArcGIS 10.8 Spatial Analyst toolbar. For each cell, slope calculates the maximum rate of change in value from that cell to its neighbours. Basically, the maximum change in elevation over the distance between the cell and its eight neighbours identifies the steepest downhill descent from the cell.

### 3.7.2.3 Normalized Difference Vegetation Index NDVI Data Layer:

The vegetation in the study area can provide information about the abundance of groundwater potential. If the amount of groundwater in the study area is high, this will have a positive effect on the vegetation that continues its development on the soil in that area. NDVI values between 0.1 and 0.75, in general, denote vegetation cover, while values greater than 0.75 imply a dense canopy. The NDVI for bare land and soil is close to zero, and negative values indicate water surface such as reservoirs.

The NDVI was calculated from the red and near infrared bands using the following formula :

NDVI = (NIR - RED) / (NIR + RED) (Huajie et al., 2016)…………………………………....3.2

where NIR refers to surface reflectance of band 5 (Landsat-8), and Red refers to surface reflectance of band 4 (Landsat-8).

### 3.7.2.4 Soil Data Layer:

Soil is an important factor for delineating the groundwater potential zones. The climate, physiography, and geology characterize soil and play a significant role in groundwater recharge and runoff. The water holding capacity of the area depends upon the soil types and their permeability (Kumar et.al., 2016).

The soil map of the Cheliff watershed was prepared from the soil data provided FAO as a shape file using the geoprocessing clip tool in Arc GIS 10.8.

### 3.7.2.5 Topographic Wetness Index (TWI) Data Layer:

The topographic wetness index (TWI), also known as the compound topographic index (CTI), is used to demonstrate the spatial pattern of moisture and delineate the impacts of topographic conditions for locating the size of runoff saturated areas. (Razavi-Termeh et al,2019). TWI plays a major role in the transport and accumulation of runoff waters at the soil surface. Greater TWI values demonstrate better GW retention capability of an area. (Kim et al, 2019)

The TWI factor is calculated as:

TWI= $\ln(\alpha /\tan\beta )$ ……………………………………………………………………3.4

where **β** is the cumulative upslope area drained through a particular point (per unit contour length), and **α** is the gradient of the slope in that point

### 3.7.2.6 Geology Data Layer:

Geology influences both the porosity and permeability of aquifer rocks (Yazi et.al. 2010; Chowdhury et.al, 2010). Therefore, it is one of the major factors that play an important role in the distribution and occurrence of groundwater. Geology thus, is an important groundwater controlling parameter which should be considered in groundwater studies.

The geology thematic map of the study area was prepared by using the geology global shapefile produced by USGS. The geology shapefile was clipped by using the clip tool in ArcGIS 10.8 software and classified into eight different geological formations according to the formations which characterize the Cheliff watershed.

### 3.7.2.7 Rainfall Data Layer:

Rainfall plays an important role in the hydrologic cycle and controls groundwater potential. Knowing the nature and characteristics of rainfall would be a useful tool for conceptualizing and predicting its effects on groundwater infiltration and recharge (Ramu et.al., 2010). The amount of rainfall can significantly vary from one region to another depending on the environmental conditions of the place (Ramu et.al., 2010). The possibility of finding groundwater is higher in the regions that receive higher rainfall amounts and vice versa. Rainfall varies not only spatially but also temporally, so determining the impact of rainfall in any region necessitates using a long series of records. Thus, the data used in our thesis comprised rainfall records during the 1936–2008 period from 21 rainfall stations. It was collected from ANRH. In

ArcGIS 10.8 software, an average annual rainfall map for the study area was generated using the inverse distance weighting (IDW) interpolation technique and converted as raster data.

### 3.7.2.8 Land Cover/ Land Use Data Layer:

Land-use land-cover (LULC) data gives information about the use of general landfill. Uses such as settlements, forests and agricultural lands in an area affect the water permeability, soil and surface texture in the area, so LULC may provide indication about the groundwater potential (Mandal et al. 2016).

LULC map prepared from the Land Sat 8 data. Maximum likelihood algorithm was used. The detailed land use/cover map of the area was prepared by supervised classification through ArcGIS 10.8 Software. The obtained LULC map of the study area comprised six categories namely water, trees, corps, built area, bare ground and rangeland.

### 3.7.2.9 Elevation Data Layer:

Elevation is also one of the deciding factors which affects the availability of groundwater in any area. It is known that water tends to be stored at lower topography rather than at higher topography (Ramu et al., 2010). Therefore, the higher the elevation, the lesser the ground water potential and vice versa. Hence, elevation or altitude should be considered in the groundwater potential studies. In this study, the elevation map was developed based on SRTM data. The raw data are corrected in GIS using the fill tool, and then classified into 5 classes, i.e, very high, high, moderately, low, very low.

### 3.7.2.10 Distance from River Data Layer:

Distance from river is important in hydrogeological studies because it is noted that the presence of local alluvial layers is located essentially near the river courses especially in semi-arid region.(Benjmel et al, 2020) Areas close to rivers are favorable for effective infiltration and consequently groundwater recharge. In contrast, it is difficult to find alluvial layers in areas beyond a distance of 600 m from river courses. (Moghaddam et al, 2015)

Distance to river was determined by selecting Spatial Analyst Tools > Map Algebra > Raster Calculator. In the Raster Calculator window, we entered the following command:

Con(”FlowACC.tif” > 4000000, 1)………………………………..…………………………3.5

where Con represents condition, FlowACC.tif represents the flow accumulation and 4,000,000 is a value that enabled us to create the major river courses in the study. The resulting raster file was then converted to lines using the tools Conversion Tools > From Raster > Raster To

Polyline. To classify the distance to major rivers, we used Spatial Analyst Tools > Distance > Euclidean Distance.

### 3.7.3 Weighted Linear Combination Process:

The weighted linear combination method (WLC) is the most common technique for analyzing multi-scale evaluations. This technique also is called a ‘‘scoring method’’. This method is based on the content of the weight average. The analyzer or decision-maker is based on the ‘‘relative importance’’ weighted directly to the scales. By multiplying the relative weight by the feature value, a final measure can be obtained for each option (such as picture element in spatial analysis). After specifying the final value for each option, alternatives, which have higher values, will be the best option for the desired purpose. (Malczewski.,2004)

Determining the proportion for a specific operation or evaluating the potential of a particular occurrence is considered to be a desired purpose. In this method, decision making principles calculated the value of each Ai options using following equation:

$A_i = \sum w_i x_i$………………………………………………………..……………….3.6

In this equation, Wj is the j criterion weight; Xij is a value, which accepted i place in relation to j criterion. In other words, this value can indicate the appropriate degree of the i location in relation to j criterion; n is the total number of criteria and Ai is a value, which will attach to the i location. In this method, the total weight should be equal to 1; otherwise, in last stage Ai should be divided by the total of all weights, thus the Ai output will be between 0 and 1. Higher or lower amounts of output can be due to an appropriate or inappropriate option, weight normalizing can be omitted. In the end, the ideal option will be the one that has higher amount of Ai (Malczewski.,1999).

## 3.8 Data Preparation Methods:

In the present study, different polygons in the thematic layers labeled separately and then they were converted into raster and registered. In the final thematic layer initially each one of the raster qualitatively the final potential groundwater map. The methodology of the present study, a delineation of groundwater potential zone for further hydrogeological investigation selected using GIS and artificial intelligence techniques. The study is carried out in 4 major steps, in which inputting data sets, deriving data sets, reclassifying and standardizing data sets and weighting datasets of the thematic maps are integrating and analysis of all data will be processing. The steps required are discussed as follows:

### 3.8.1 Inputting Dataset:

In this study data sets such as SRTM data, Landsat image and geological data and soil data of the area are identified and used as inputting data sets for further processing. Inputting data sets used for this study is geological data of Africa to extract geological data of the area and Landsat image have been used for the preparation of land use land cover and NDVI as inputting data sets, soil data of africa from soil map of FAO to extract soil data of the area, and SRTM (Shuttle Radar Topographic Mission) 30*30m resolution to generate the rest factors.

### 3.8.2 Deriving Data:

In this step, data analysis is applied to extract new information from existing data or input data to get a thematic map. slope, rainfall, ground elevation, land cover/land use, soil type, normalized difference vegetation index (NDVI), topographic wetness index (TWI), and distances from the river, geology, and drainage density data are analysis to show the ground water potential zone delineation.

### 3.8.3 Reclassifying and Standardizing Datasets:

The data extracted from the thematic maps is reclassified and standardized by using the standardization technique, which is used to translate various inputs of a decision problem to a common scale, to allow comparison and overcome the immeasurability of the data (Rahman et al, 2009), because the training algorithm is very sensitive to scaling data. Thus, the input and output values of the data set should be standardized. For the most part, input and output data was set up to the scale scopes of either (– 1, 1), (0.1, 0.9), or (0, 1) (Khademi et al., 2016).

Our feature layers for mapping possible groundwater regions have been developed in a variety of units and at a variety of measurement levels. For this reason, the standardization step has been described as the best way to rescale factor values between 1 and 0. Therefore, we adopt the fuzzy membership method as a standardization method as it demonstrates its effectiveness in the mapping of potential groundwater. Consequently, all groundwater influence factors have been in the range from poor potential (o) to high potential (1) due to the utilization of the linear fuzzy membership tool in ArcGIS 10.8.

### 3.8.4 Artificial Neural Network Weighting:

Inspired by human nervous system, the Artificial Neural Network (ANN) is a computational model that acquire, represent, and compute a mapping from one multivariate space of information to another, given a set of data representing that mapping. (Wasserman.,1989)

ANN can learn associative patterns and approximate the functional link between a set of inputs (independent variables) and outputs (dependent variables). The purpose of an ANN is to generate a model of the data-generation process so that the network can generalize and anticipate outcomes from inputs it has never seen before.

The multilayer perceptron (MLP) trained by the back-propagation algorithm is one of the most widely implemented neural network topologies. This training uses a set of examples of associated input and output values. This learning algorithm is a multi-layered neural network which consists of an input layer, hidden layers, and an output layer. The hidden and output layer neurons process their inputs by multiplying each input by a corresponding weight, summing the product, and then processing the sum using a nonlinear transfer function to produce a result (Temgoua et al, 2005).

The network used in this study consisted of three layers (Figure 3.9). The first layer is the input layer, where the nodes were thematic maps of 10 variables controlling groundwater potential occurrence. The second layer is the internal or "hidden" layer. The third layer is the output layer that presents the output data. This data consists of groundwater potential areas (training sites). Each node in the hidden layer is interconnected to nodes in both the preceding and following layers by weighted connections (Lee et al, 2012).

For this study, ANN were simulated in the neural network module of R studio. The algorithm was applied to calculate the weights between the input and hidden layers and between the hidden and output layers. We first randomly divided the point data (100 locations) into two sets such that one set with 70% of locations (~70) was used for training the models and the remaining locations (~30% = 30 locations) were used for the validation. The final weights between layers acquired during training of the neural network and the contribution or importance of each of the 10 factors was used to predict groundwater potentials. Finally, the weights were applied to the entire study area, and groundwater potential map was created. The values were classified and grouped into five classes (poor, low, moderate, high and very high) for visual interpretation.

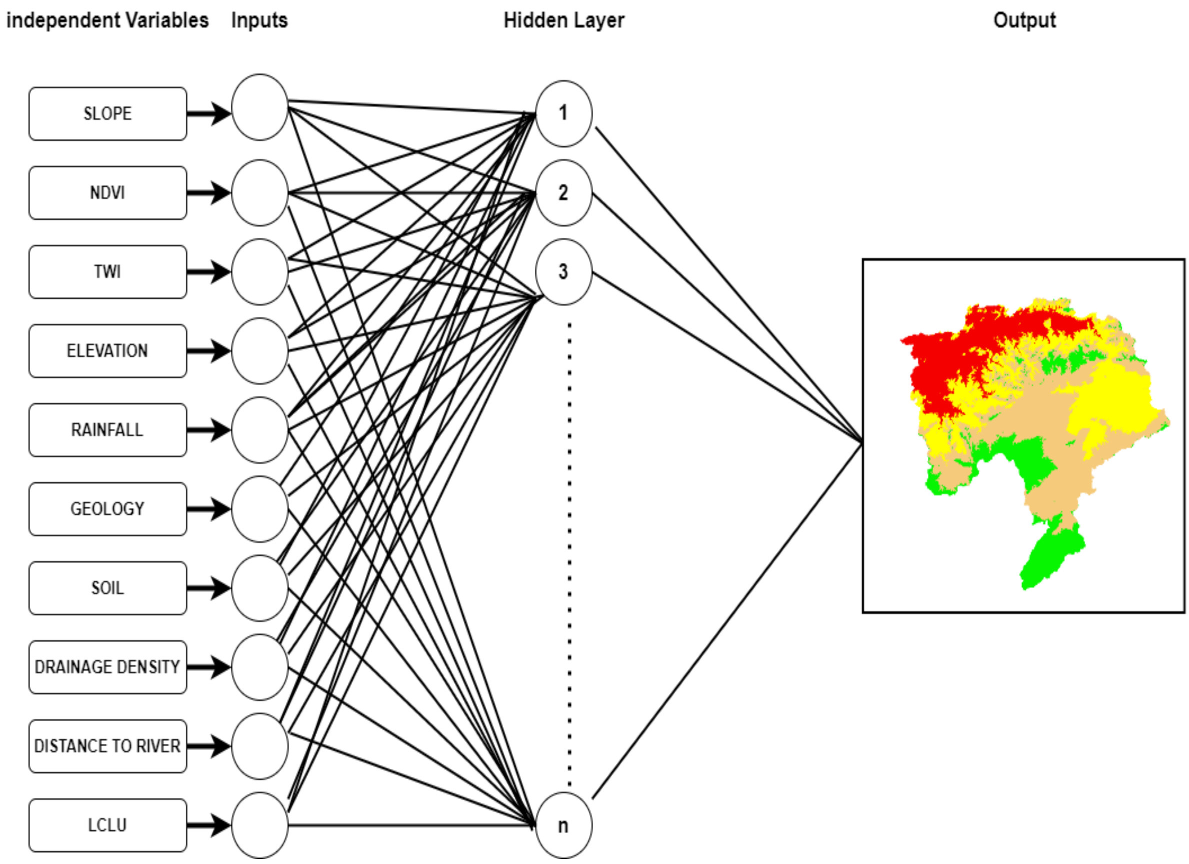


**Figure 3.8: Artificial Neural Network Architecture.**

## 3.9 Identification of Groundwater Potential Zones:

The watershed's groundwater potential zones (GWPZ) were obtained by integrating feature maps into the ArcGIS platform. The weighted linear combination (WLC) aggregation method was used to determine the GWPZ, as indicated below in Groundwater potential index (GWPI) Equation:

$$GWPZ = \sum_{j=1}^{m} \sum_{i=1}^{n} (w_j * w_i)$$

(GWPI) is a unitless value that expresses the GWPZ in a particular area, where, $x_i$ and $w_j$ are the normalized weights of the $i^{th}$ and $j^{th}$ classes of thematic layers. $m$ represents the count of the total thematic layer and $n$ represents the count of whole classes in each thematic layer. (Malczewski 1999; Agarwal & Garg 2016). The GWPZI value was calculated in ArcGIS 10.8 using the map algebra tool.

## 3.10 Model Validation:

A map of the well distribution around the study area is essentially required for validating predictive models of groundwater potential in the Cheliff basin. In this respect, a validation map was developed using the Hydrographic Basin Agency (ABH) water points distribution dataset (See Appendix C).

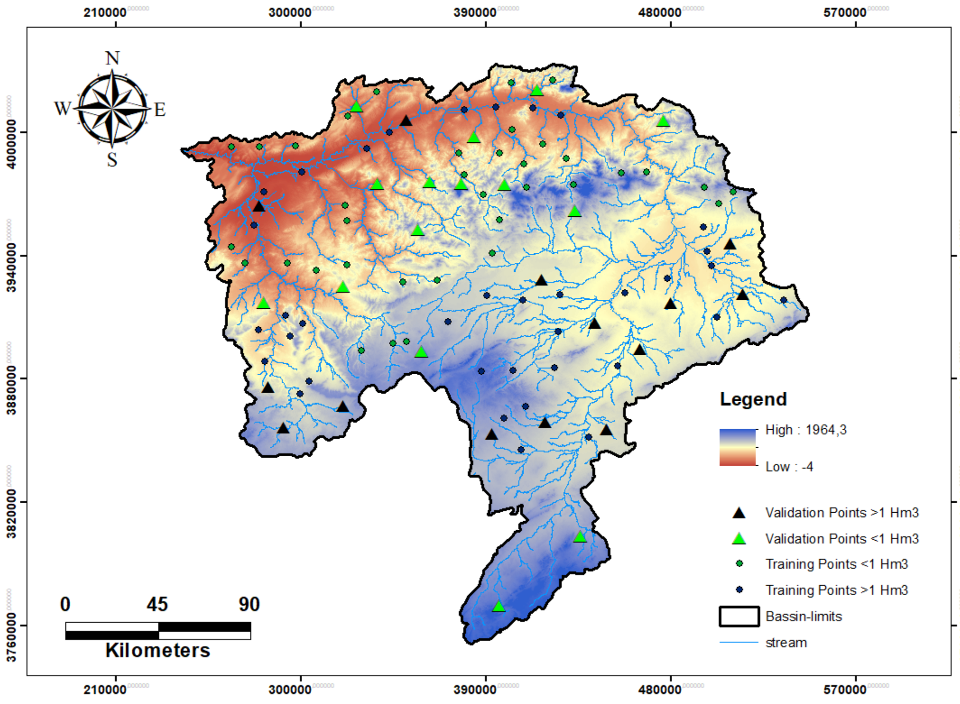


**Figure 3.9: Validation Map of Cheliff Basin.**

Validation methods should be used to evaluate the performance of the models in addition to comparing the inventory map and the produced map. This step is critical in determining how much the model fits. Two statistical indices were utilized to validate the model used in this study: the Root Mean Squared Error (RMSE) and the area under the curve (AUC).

The RMSE is a statistical metric used to evaluate disparities between the prediction and target values. RMSE is a useful metric for comparing model performances, and it is calculated as follows:

RMSE=1N∑i=1N(yi−y¯i)2

where N is the number of samples in the dataset, $y_i$ is the predicted value of the $i^{th}$ sample, and y¯i is the measured value of the $i^{th}$ sample.

On other hand, ROC (Receiver Operator Characteristic) is a graph commonly used in the validation of binary classification models. This curve is created by expressing sensitivity and specificity. Therefore, the ROC curve will show the relationship, the trade-off and the significance of choosing an appropriate model of sensitivity and false alarm rate. Area under the ROC curve, called AUC, is often utilized quantitatively to validate and compare predictive capability of the models, which is calculated as follows:

$$AUC=(\sum TC+\sum TD)(A+B)$$

where TC is the number of points correctly classified, TD is the number of points incorrectly classified, A is the total number of groundwater points, B is the total number of non-groundwater points.

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Introduction:

This study was conducted in the Cheliff Basin to delineate groundwater potential zones in the area. The following section presents the results of the thematic mapping of groundwater potential zones in the study area, which is the first objective of the study. Firstly, an interpretation of different thematic layers maps is provided. This is in order to provide a more comprehensive understanding of the characteristics that influence the occurrence of groundwater. The maps were then standardized using the fuzzy membership function in ArcGIS software. In addition, different weightages were assigned as per their groundwater potential controlling capacity within the study area, and reclassification of each map was done based on the weight values produced. Last but not least, the maps were integrated using GIS software to delineate groundwater potential zones for the Cheliff Basin by using the GIS capability and weighting results of the artificial neural network algorithm. The generated map was subsequently validated by comparing it against the available inventory map.

## 4.2 Thematic Layer Mapping:

To evaluate the different groundwater potential zones, parameters that were considered to influence the occurrence of groundwater were prepared for each layer based off previous literature. The salient aspects of these thematic maps are described below :

### 4.2.1 Slope Map:

The slope is an important factor in groundwater potential mapping as this aspect determines the rate of infiltration of surface water in an area. It is therefore expected to observe low levels of recharge in steep slopes as water flows rapidly downwards, providing insufficient time for infiltration, while flat terrains facilitate groundwater recharge due to extensive retention of rainfall (Arkoprovo et al., 2012). In this study, the slope of the study area was generated from DEM and analyzed using Arc-GIS technology. The identified slope category varies from (0-318,06%) in the study area and the area is classified into four classes like (0 - 8,73%) gentle, (8,74 - 21,2%) moderate, (21,21 - 39,91%) high, (39,92 - 318,06%) steep. While gentle slopes (0-8.73%) indicate the presence of very high groundwater potential zones, steep slopes (> 39.92%) show the presence of low groundwater potential zones as water runs rapidly off the surface and does not have sufficient time to infiltrate the surface, keeping other parameters constant.

The majority of the study area displayed a gentle slope (0 - 8,73%). This flat to gentle slope area is categorized by a very high category for groundwater storage due to the nearly flat terrain and slow surface runoff, which allows more time for rainwater to percolate (Prasad et al. 2008). The area with a slope (8,74 - 21,2%) is considered moderate, which is categorized as high groundwater potential. The area with a steep slope towards the southern and northeastern parts of the cheliff wadi is considered to have low groundwater potential due to high slope, higher runoff, low infiltration, and low rainfall recharge zones. The details are shown in figure 4.1 below:

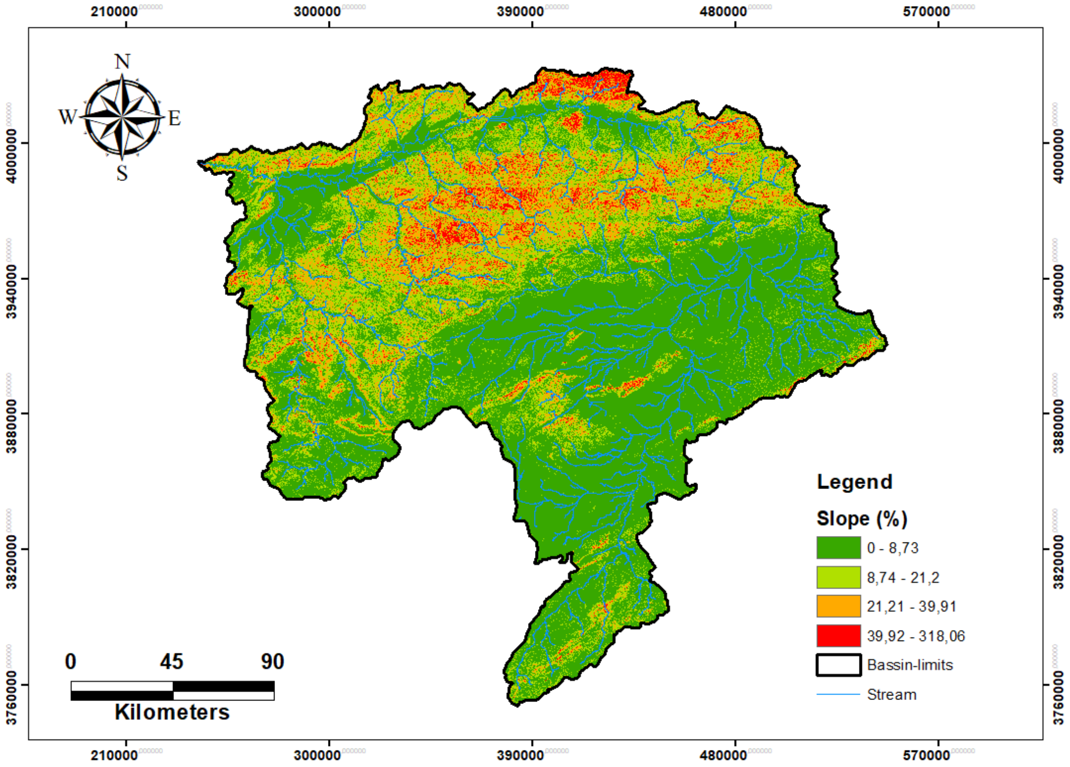


**Figure 4.1: Slope Map of the Study Area.**

### 4.2.2 Land Use/Land Cover Map:

Land use/ Land cover is an important characteristic of the runoff process that affects infiltration, erosion and flow of water. The land use/cover map of the area was generated from the worldwide land use/ land cover map with the help of the ArcGIS 10.8 software. The land use/land cover is one of the important features considered while assessing the groundwater potential of a specific location. It contributes widely in the amount of water infiltration into the soil which is the main source of groundwater recharge. Classification of land use/cover for analysis was done based on their character to infiltrate water in to the ground and to hold water on the ground. There is a various land use/ land cover classes in the study area which used to delineated groundwater potential zone. The various classes in the study area are:  Water, Trees, crops, built area, bare ground and Rangeland (Scurb).

The most abundant cover in the study area is Rangland. This is reasonable since the study area is located in the areas where the main activity is agriculture. The corps is the second largest sub-class and is mostly located along with the Cheliff wadi, the tree area, which is mainly in the middle part of the Cheliff basin. It is mainly located in areas with moderate slopes and sometimes closer to water bodies. On the other hand, the water bodies are located mainly in the northern part, near the southern border with the Tellian atlas. Finally, built-up and bare ground land features that are densely populated in the high plateau area where the slope is typically high or steep.

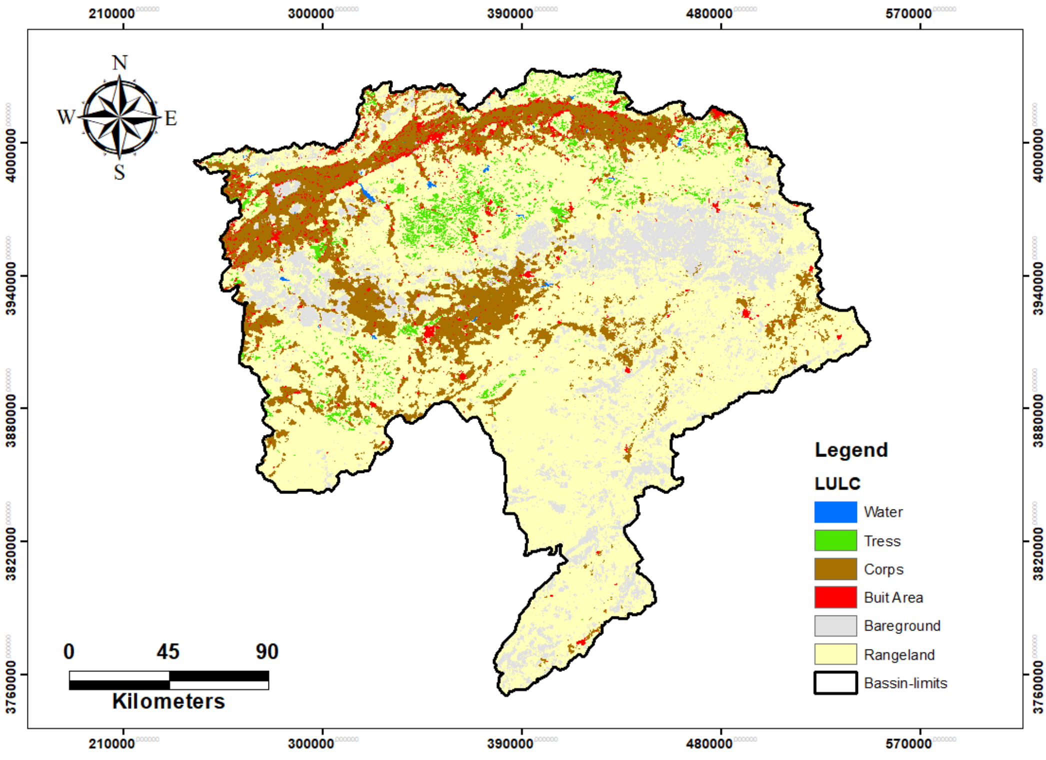


**Figure 4.2: LULC Map of the Study Area.**

### 4.2.3 Drainage Density Map:

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin is calculated as a ratio of the sum of stream lengths to the size of the area of the grid. It is one of the major factors which determine the degree to which water infiltrates and the runoff distribution occurs. The drainage density of the study area was produced from the SRTM global elevation data through in ArcGIS 10.8.

Figure 4.3 below shows the drainage density of the Cheliff basin to be within the range of (0-0.492). According to the map, it is observed that the drainage density of the basin is mostly very low (0- 0.123) to low (0.124- 0.246), but we can easily notice some rises in the drainage density in the middle of the basin along with the Cheliff wadi stream to the south east of our basin values ranging between (0.247- 0,369) to (0,37 - 0,492). However, studies have revealed that the drainage density is inversely proportional to soil permeability and infiltration capacities and then inversely related to groundwater potential (Gouri *et al.*, 2014; Das and Mukhopadhyay, 2018). As a result, when the drainage density is high, the probability of groundwater occurrence is lower and vice-versa.

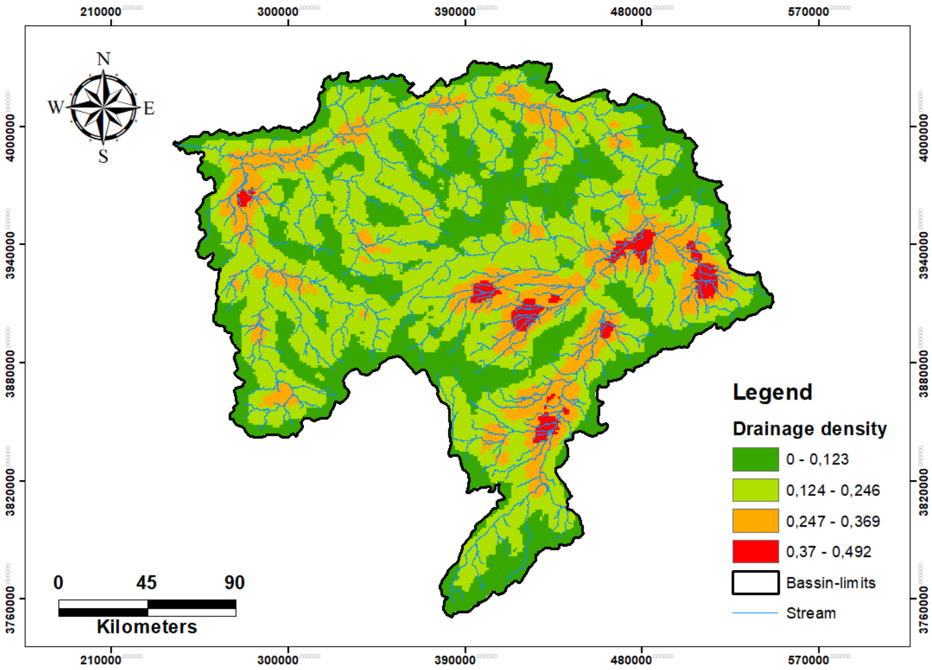


**Figure 4.3 : Drainage Density Map of the Study Area.**

### 4.2.4 Geology Map:

The geology is another heaviest factor in the groundwater potential identification due to its high influence in groundwater storage, movement and occurrence. Examining various types of rocks in a particular location was usually necessary to reveal characteristics of hydrological crosssection structure, porosity values, permeability nature, geological structure, geomorphology, and spatial heterogeneity of flow and transport parameters.

The geology of the study area is attributed to the Atlas Domaine of northern Africa. Different types of geological formations have been found in the province, which have been categorized into eight (8) classes depending on their different characteristics and influences on groundwater prospects. We can easily observe from the map that the quaternary sediment is tightly bound to the stream courses, which are characterized by high permeability. On the other hand, some Permian and Tertiary rocks that are exposed within the north and south of Cheliff Wadi are frequently weathered and faulted. These rocks bear witness to recent volcanic activity in the region. Besides that, we have successfully identified a complex mixture of other sedimentary rocks to the south of the basin, including lower Ceratosaurus, Jurassic, and Ceratosaurus. withal, The Jurassic rocks are well represented in the western parts of the region. On the one hand, the eastern part of the Cheliff basin is distinguished by a mixture of volcanic and sedimentary rocks, such as Tertiary, Ceratosaurus, and Triassic.

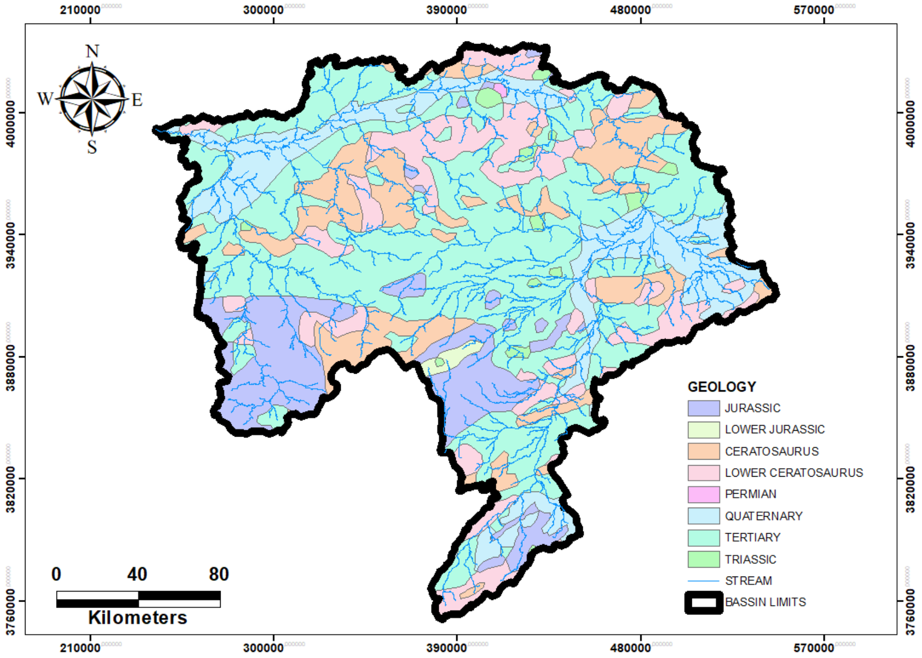


**Figure 4.4: Geological Map of the Study Area.**

### 4.2.5 Soil Map:

Soils are highly affected the movement and infiltration of ground water (Hornsby, 1986, Maurice and Courteny, 1990). It is the world’s natural resource and a soil map is a spatial representation of these resources. Soil map is fundamental starting point when ground water potential zone delineation processed.

In this research, classification of soil types in relation to groundwater potential control was done based on FAO soil texture classification. The analysis of the soil type reveals that there are three major types of soil in our study area, which are calcic Cambisols, calcic Yermosols, and calcic Xerosols. The Calcic Cambisol is found in the study area in the northern part of the basin, specifically in the Tellian atlas to the high pleateaux areas. It has a loamy texture, like clay. Calcic Yermosols are soils dominant in the south of the basin. They are usually characterized by having a weak ochric A horizon and an aridic moisture regime. Moreover, the Calcic Xerosol rock is located in the central part of the basin, and possesses the same properties as the Calcic Yermosols. On the other hand, Calcaric Fluvisols and Chromic Cambisols are mostly close tie to the stream courses. Finally, we can observe from the map that various types of rocks, such as Calcaric Regosols, Lithosol and Orthic Solonchaks, Calcaric Fluvisols, and Xerosols, are dispersed across the basin in modest quantities.

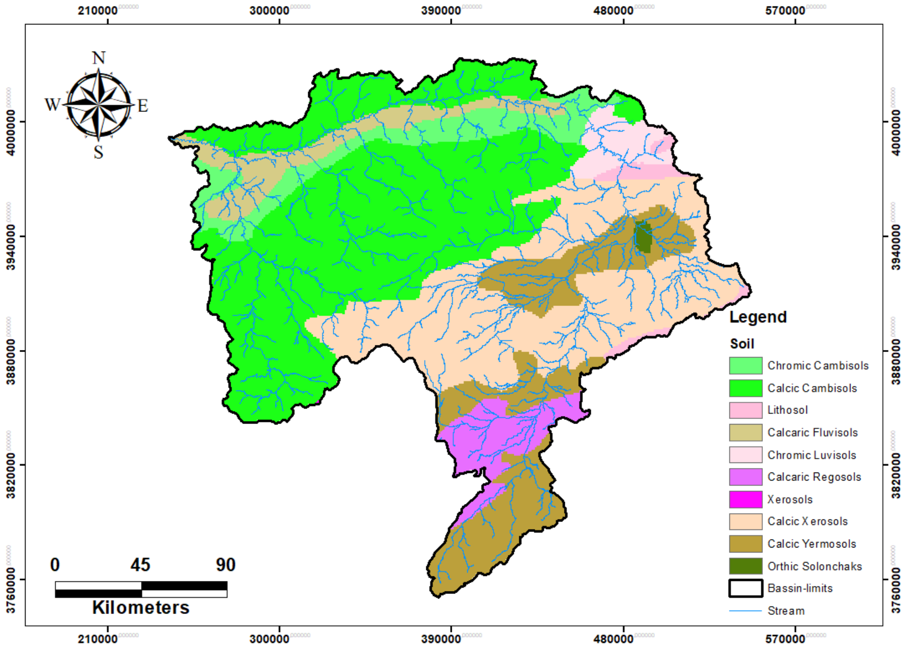


Figure 4.5: Soil Map of the Study Area.

### 4.2.6 Rainfall Map:

Rainfall is one of the crucial factors for the formation of groundwater potential. It plays an important role in the hydrologic cycle, which controls groundwater potential. Knowing the nature and characteristics of precipitation, we can conceptualize and predict its effects on runoff, infiltration, evapotranspiration, and water yield. Therefore, for delineating groundwater potential zones, it is important to know the areal distribution of precipitation.

The figure represents the precipitation map of the research area (Figure 4.6). The northeastern part of the study area receives very high precipitation in the range of 573-742 mm/yr, while precipitation in the northwest and southwest ranges from low precipitation of 255-338 mm/yr to low precipitation of 123-254 mm/yr. On the other hand, from the north-central to the central part of the study area, parts of the study area get moderate precipitation of 339-440 mm/year. On the other hand, from east-central to southwest, the precipitation is low, in the range of 255-338 mm/yr. The southeastern part of the study area finally has very low precipitation, 123-254 mm/year.

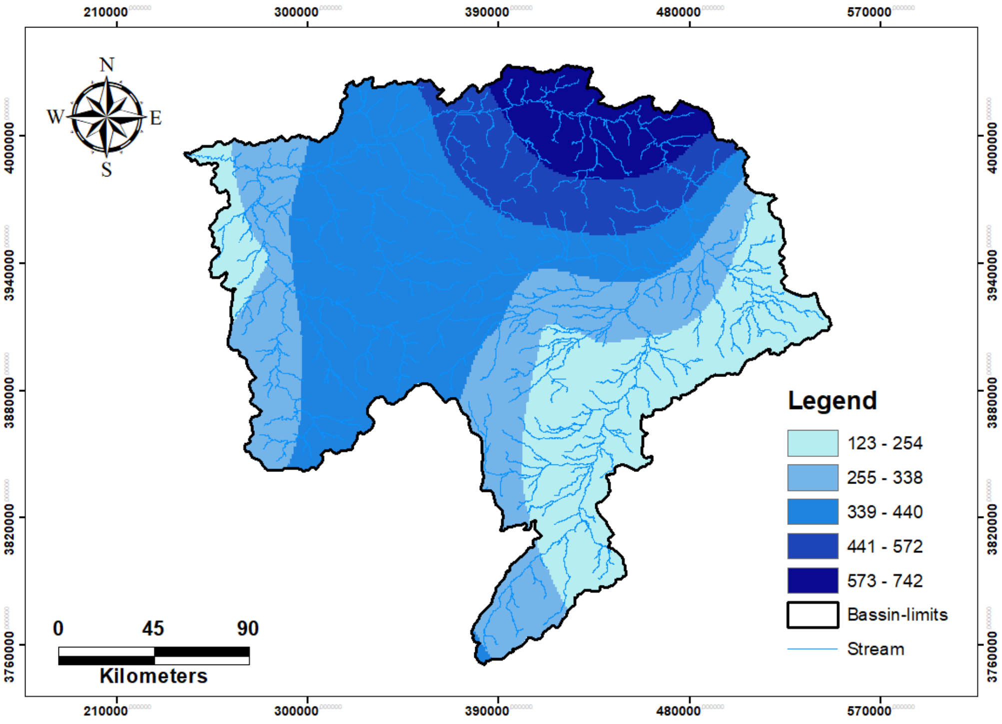


Figure 4.6: Rainfall Map of the Study Area.

### 4.2.7 Elevation Map:

The relief of the province was generated from the digital elevation model of the area, which was downloaded from the US Earth Explorer website. Relief is another very important factor to consider in groundwater potential detection. According to many researchers, the highest recharge occurred generally in the valleys and the lowest recharge in the hills.

In the Cheliff basin, the elevation is relatively higher in the south and the southwestern parts, while it is lower in the other directions. The highest and lowest elevations range from (1160–1960 m) and (-4-390 m) respectively. The map was divided into five (5) categories: low elevation (-3 – 390m), moderate elevation (684–907m), high elevation (908–1 150m), and very high elevation (1 160–1 960m). The two lowest elevation ranges were found to have a large surface area, greater than a quarter of the study area and mostly located in the northern part of the basin. The map shows that the largest area of the Cheliff basin is covered by the moderate elevation generally settled in the central area of the basin. The high elevation of the region is dominantly situated in the south-western and southern regions. while the greatest elevation of the province is mainly occupied on the southern edge of the basin. (Figure 4.7)

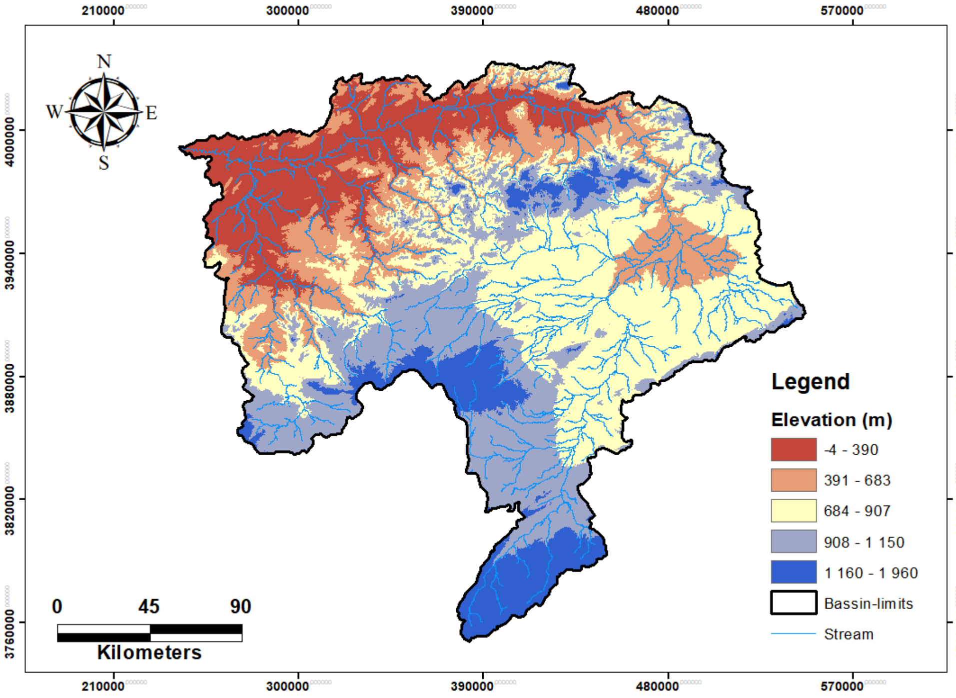


Figure 4.7: Elevation Map of the Study Area.

### 4.2.8 Normalized Different Vegetation Index Map (NDVI):

The vegetation condition derived from NDVI is used as an indicator of groundwater presence beneath the earth's surface. Tucker created this indicator, which ranges from -1 to 1, with values less than 0 indicating no vegetation cover and greater than 0 indicating available vegetation cover. The presence of healthy vegetation in a given area appears to be linked to adequate groundwater recharge. As a result, the greater the vegetation, the more groundwater is present there and vice-versa.

Our study areas NDVI has been grouped into five categories in the thematic mapping, namely, water bodies (-0,44--0,1) are largely inhabited in the basin's northwest part with small abundance. Built-up areas (0.011–0.00) are scattered throughout the basin; no vegetation areas (wasteland) (0,049–0,2) occupy the largest area of the total surface area, from the north eastern to the south and south western of the Cheliff basin; and moderately healthy vegetation (0,21–0,37), which represents the second largest area in the basin and is mostly found in the basin's north western to north central region, along with stream courses. Finally, we can notice from the map that there are healthy vegetation regions (0,38–0,51) with low densities, especially in the basin's center towards the moderate healthy vegetation. (Figure 4.8)

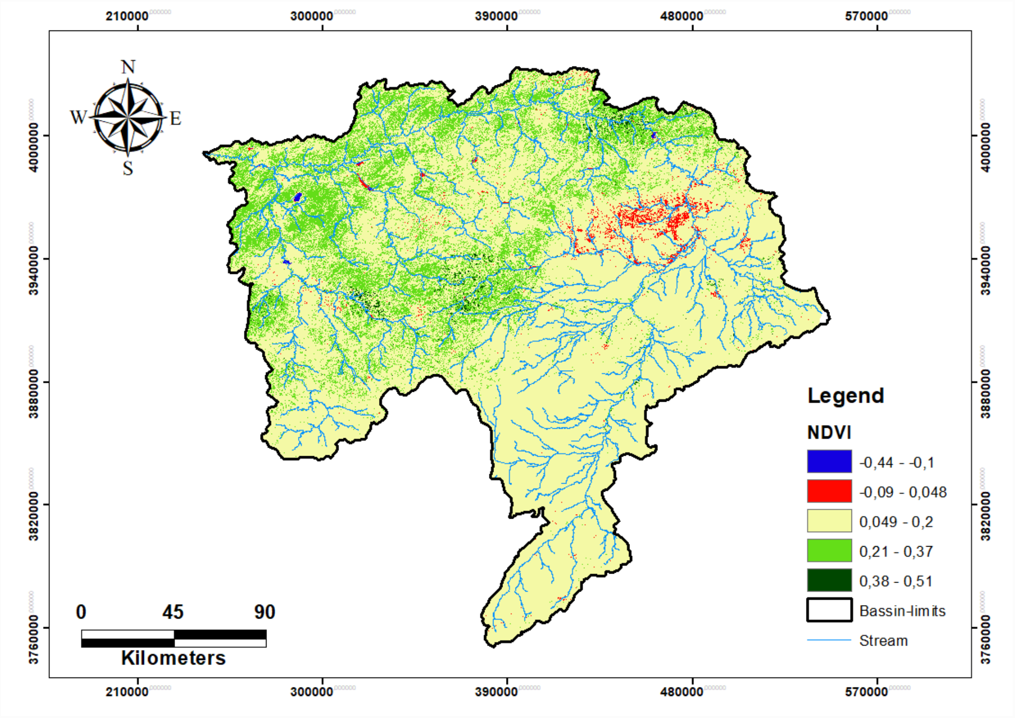


**Figure 4. 8: NDVI Map of the Study Area.**

### 4.2.9 Topographic Wetness Index Map (TWI):

The topographic wetness index (TWI) is used to quantify topographic control on hydrological processes and indicates the potential groundwater infiltration induced by the impacts of topography. Accordingly, TWI is an important parameter for determining the groundwater potential zone. In a regional topography, TWI represents the geographical distribution of wetness conditions. It controls the water's tendency to accumulate as well as the water's tendency to flow down the slope under gravity.

The TWI value in our study area ranges from -7,41 to 33,4. The values were divided into five groups. These are the following: -7,41–5,55 were classified as extremely poor; they occupied a significant area of the total area and were dominant in the areas with high slopes; 5,56–7,47 were classified as poor; they occupied the second largest area of the total area and were mostly located in the regions where the slope is classified as gentle; 7,48–10 moderate TWI was generally located in the zones where the slope is classified as gentle as well; 10,1–14 and 14,1-33,4 occupied the least area of the entire area classified as good and excellent respectively. (Figure 4.9)

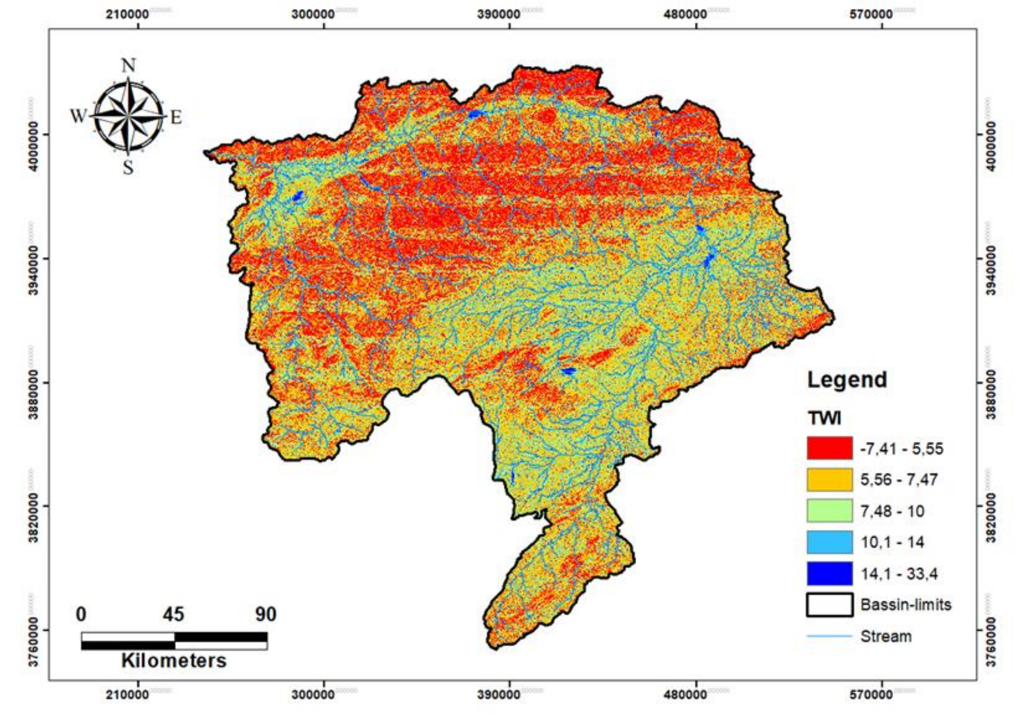


**Figure 4.9: TWI Map of the Study Area.**

### 4.2.10 Distance from River Map:

Rivers are the principal origin of groundwater recharge in semiarid regions. Hence, distance from rivers is one of the major hydrological elements affecting groundwater potential. According to Pham et al., distance from the river substantially affects groundwater levels. This effect appears to be positive, especially in flat areas. The distance from the river was calculated in ArcGIS 10.8 using the Euclidean distance function. In this specific research, the distance from the river ranges from 0 to 11300 m. It is categorized into five classes. The first class (i.e., 0–2260m) and the second class (i.e., 2270–4520m) cover the majority of the basin area. On the other hand, the other three classes (i.e., 4530–6780m, 6790–9040m, and 9050–11300m) represent a smaller area compared to the two preceding classes. (Figure 4.10)

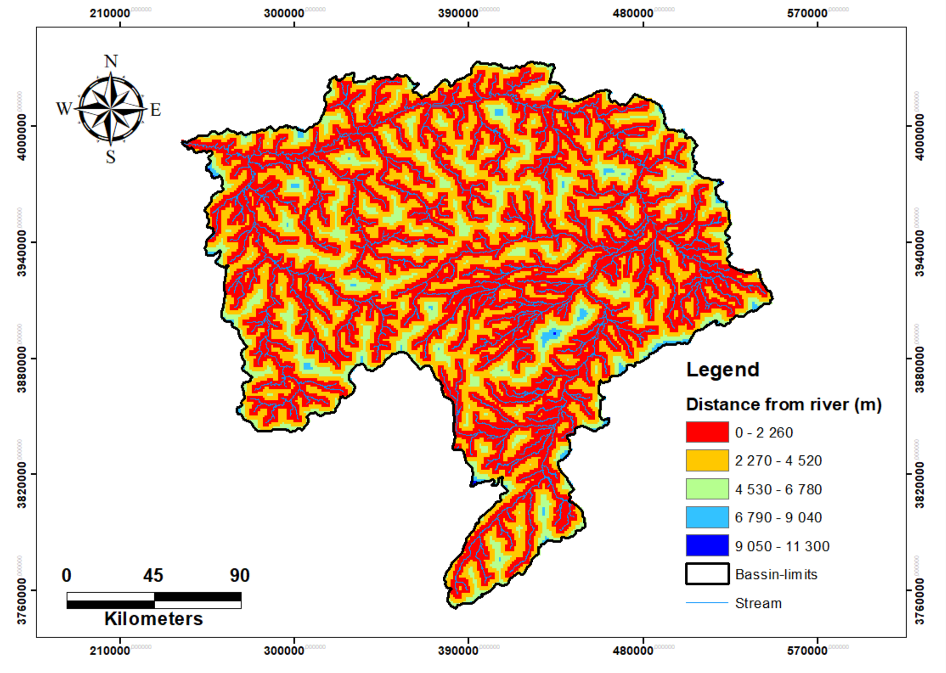


**Figure 4.10: Distance from River Map of the Study Area.**

## 4.3 Data Integration Analysis in GIS Environment:

The present study delineates different groundwater potential zones by considered essential parameters and the maps were prepared for each layer. Theses maps were converted to raster data sets having the same pixels size and get standardized, then different weightage were assigned as per their groundwater potential controlling capacity within the study area and reclassification of each map was done based on the weight values produced.

### 4.3.1 Standardizing Map Layers:

To locate and compound maps, layers should be standardized. This implies that decision-making techniques should be applied to transform layers into scales that allow all layers to be integrated. In this case, the WLC method was used. The map layers were standardized using the fuzzy approach that was relevant to this research. Prior to applying the fuzzy membership function in the GIS environment, all the map layers were digitized or imported and converted to a raster format with the same pixel size. The results of this standardization are depicted in the following figures.

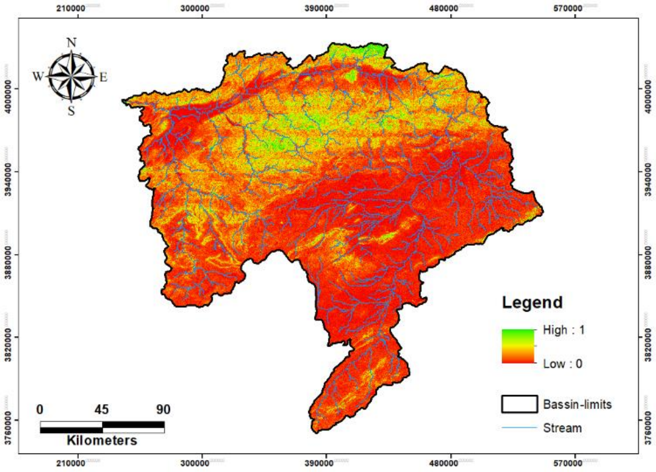


Figure 4.11: Standardized Slope Map of the Area.

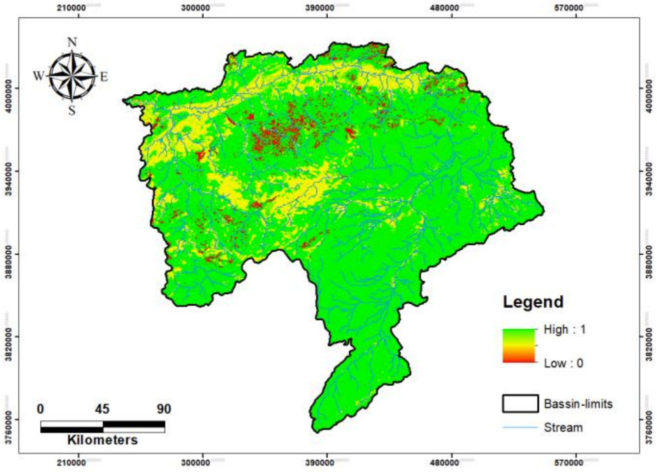


Figure 4.12: Standardized LULC* Map of the Area.

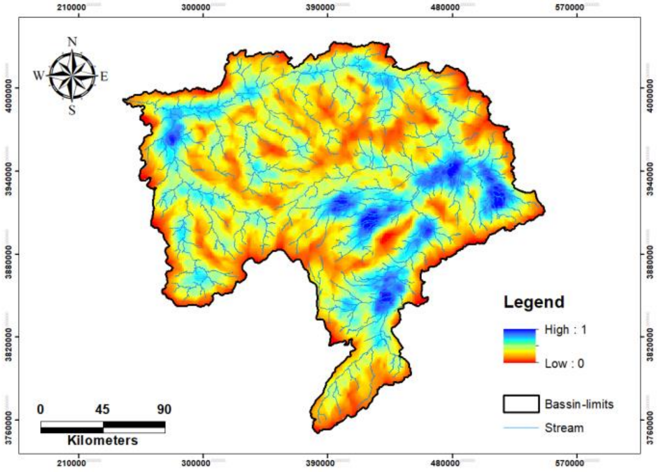


Figure 4.13: Standardized Drainage Density Map of the Area.

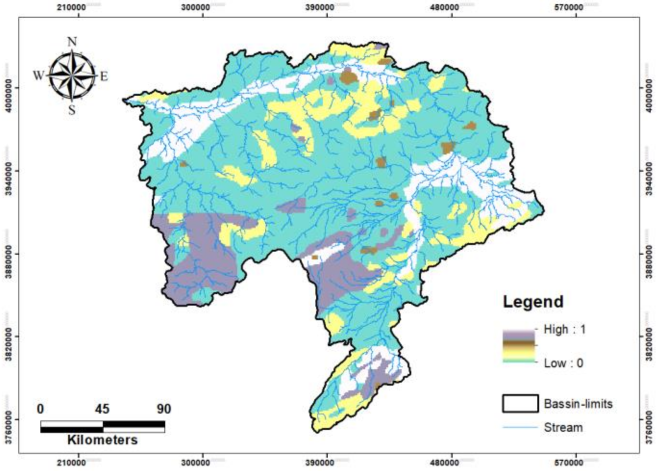


Figure 4.14 : Standardized Geology Map of the Area.

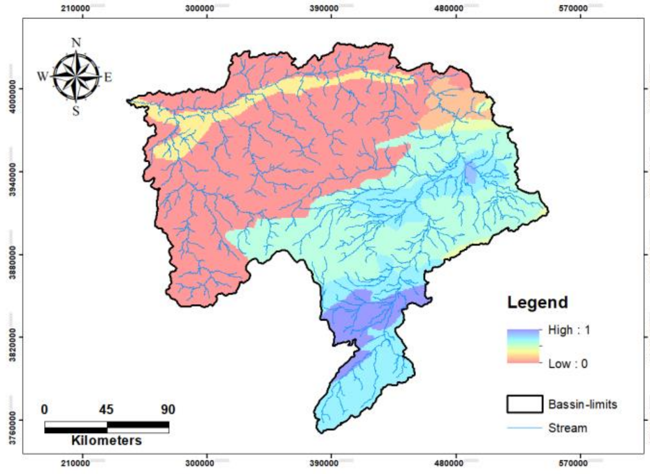


Figure 4.15: Standardized Soil Map of the Area.

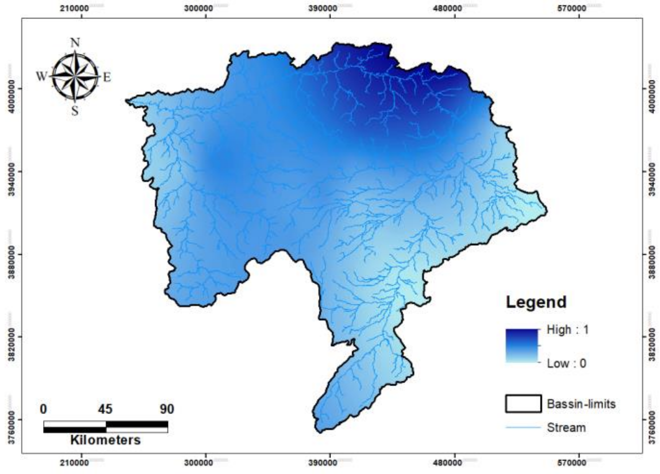


Figure 4.16: Standardized Rainfall Map of the Area.

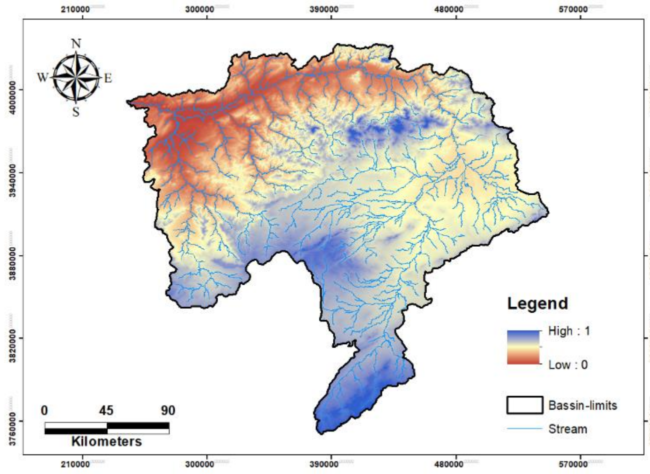


Figure 4.17: Standardized Elevation Map of the Area.

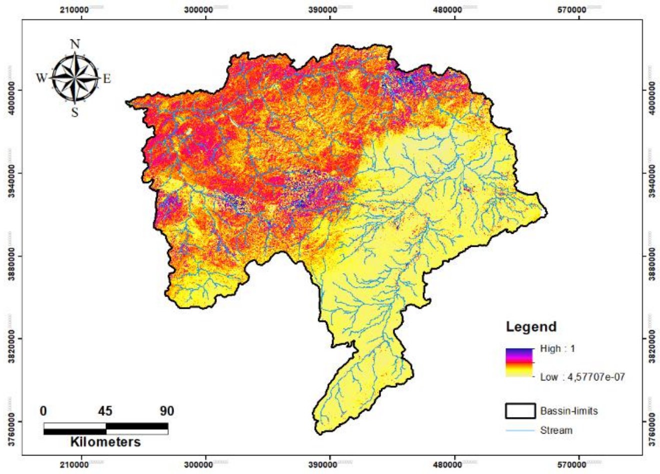


Figure 4.18: Standardized NDVI* Map of the Area.

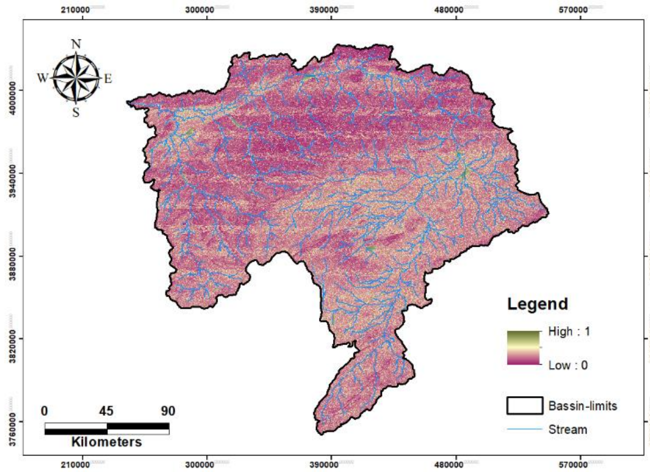


Figure 4.19: Standardized TWI* Map of the Area.

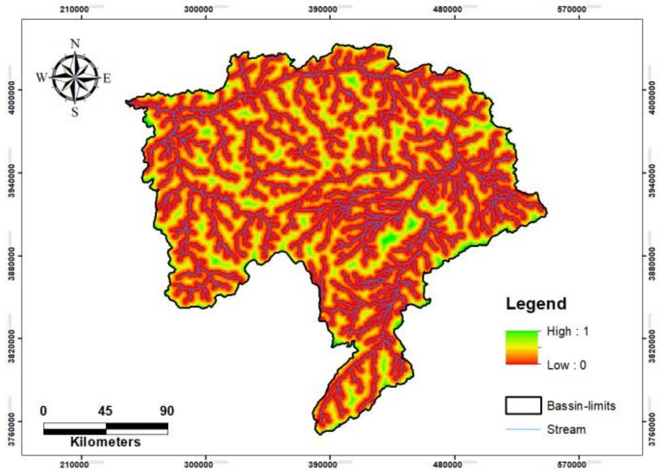


Figure 4.20: Standardized DSI* Map of the Area.

**LULC*: Land Cover/Land Use.**

**NDVI*: Normalized Different Vegetation Index.**

**DSI*: Distance from river.**

**TWI*: Topographic Wetness Index.**

### 4.3.2 Weight Analysis for the Thematic Layers:

Since each thematic layer in the model influences the potential aquifer recharge differently, weightage was applied to consider the importance of each factor in relation to the other one. Hence, the more a factor influences groundwater potential, the greater its importance, resulting in a large weight. The weighted linear combination method was used in this study as a decision-aiding method to finalize the weights assigned to different themes and their respective features used in deciphering groundwater potential.

We first randomly divided the point data (100 locations) into two sets such that one set with 70% of locations (~70) was used for training the models and the remaining points (~30% = 30 locations) were used for validation. A multi-layer perceptron (MLP) structure was selected in this study. Based on the number of input parameters assigned in input nodes, which is ten (10), a total of three (3) hidden layers were used as an output layer. To start the training process, the input values were already normalized using the fuzzy membership technique in ArcGIS 10.8 software. The weight values assigned to the input nodes were multiplied with the normalized and spatially distributed input parameters. The weighted sum of the inputs and weights were activated in hidden nodes. Where X is the pixel value in the vector point data, Xmin and Xmax are the minimum and maximum values in the point-based point values. Feedforward is the process by which the one-sided sum of weights and inputs parameters are pushed forward to get a rough result in the output node. The result of weights were initially assigned between the input nodes and the hidden nodes, and between hidden nodes and the output node.

The values of weights taken after the training processes are shown below:

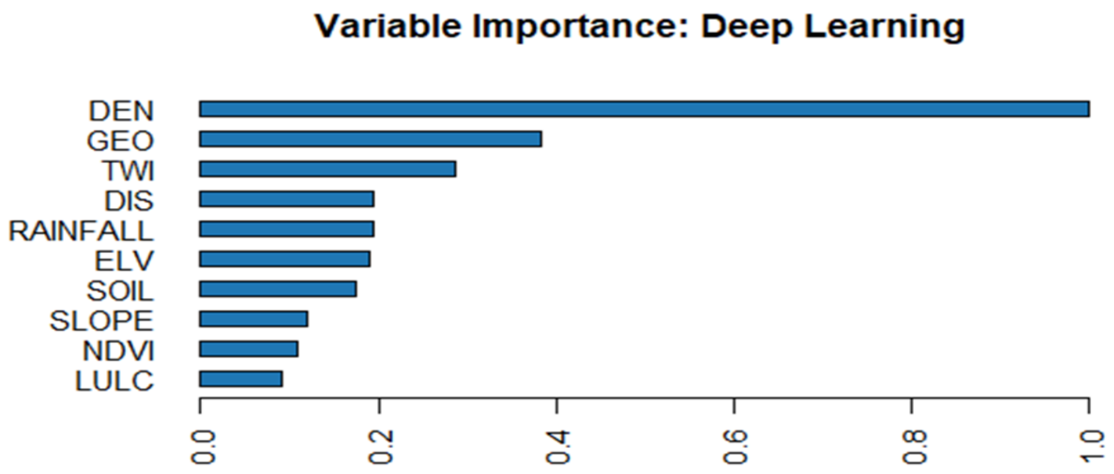


Figure 4.21: Importance of Thematic Factors.

**Table 4.1: Weights of the Thematic Maps of the Potential Groundwater.**

| N | Themes | Weights (%) |
|---|---|---|
| 1 | Drainage Density | 0.364667 |
| 2 | Geology | 0.139333 |
| 3 | Topographic wetness index | 0.104335 |
| 4 | Distance from river | 0.070927 |
| 5 | Rainfall | 0.070650 |
| 6 | Elevation | 0.069552 |
| 7 | Soil | 0.063983 |
| 8 | Slope | 0.043417 |
| 9 | Normalized Difference Vegetation Index | 0.039899 |
| 10 | Land use/ Land cover | 0.033238 |

The drainage density, geology, and topographic wetness index hold the highest weighted values compared to the other parameters. On the other hand, land use/land cover hold the least weighted value. As a result, the weight assigned for drainage density was better than the heaviness of others, which influenced the occurrence of groundwater potential zones more than other parameters.

### 4.3.3 Groundwater Potential Zone:

After reclassification, all the reclassified thematic layers were integrated using ArcGIS 10.8 software to generate the groundwater potential index (GWPI) for the study area. The index was computed by a weighted linear combination method using the equation stated below:

$$\mathbf{GWPI=DEN_r*DEN_w+GEO_r*GEO_w+TWI_r*TWI_w+DIS_r*DIS_w+R_r*R_w+ELV_r*ELV_w+S_r*S_w+SL_r*SL_w+NDVI_r*NDVI_w+LULC_r*LULC_w}$$

where GPWI is the resulting Groundwater Potential Index, DEN is the Drainage density, GEO is the Geology, TWI is the Topographic wetness index, DIS is the Distance from river, R is the Rainfall and ELV the Elevation. S is the soil type, SL is the slope, NDVI is the Normalized Difference Vegetation Index and LULC is the land use/cover. The subscripts w and r refer to the weight of each thematic layer and the rank of individual features of a thematic layer, respectively. (Figure 4.22)

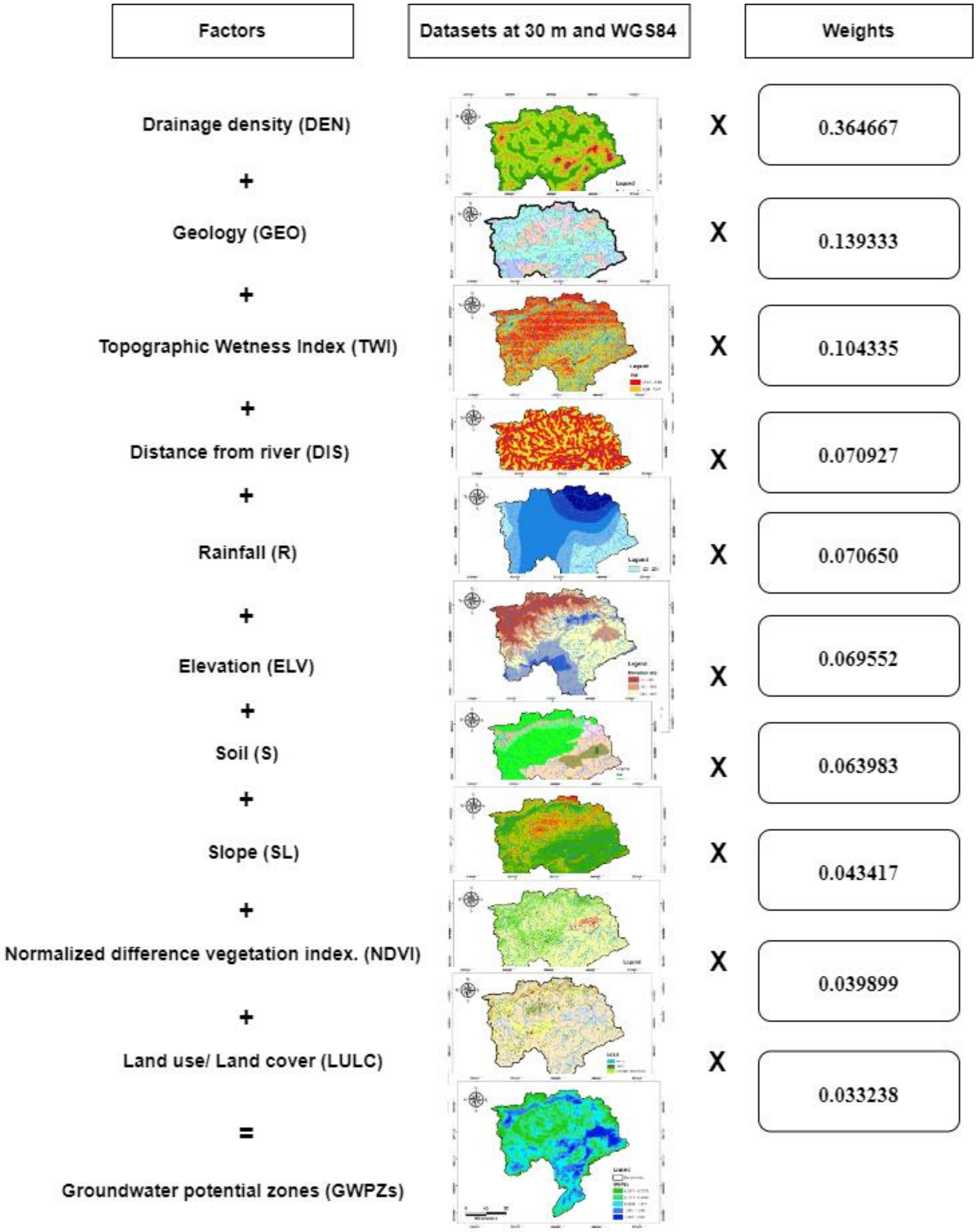


**Figure 4.22: Overlaid Superposition of the Analyzed Thematic Layers to Derive Ground Water Potential Zones (GWP).**

The GWPI result allows delineating GWP zones. For this study, groundwater potential zones were categorized into five classes. The classes were namely "very high", "high", "moderate", "low" and "poor", where "very high" indicated the highest probability of groundwater occurrence and "poor" the lowest probability of occurrence. The prospect map describing the ground water potential zone in the study area was identified and presented in Figure 4.23.

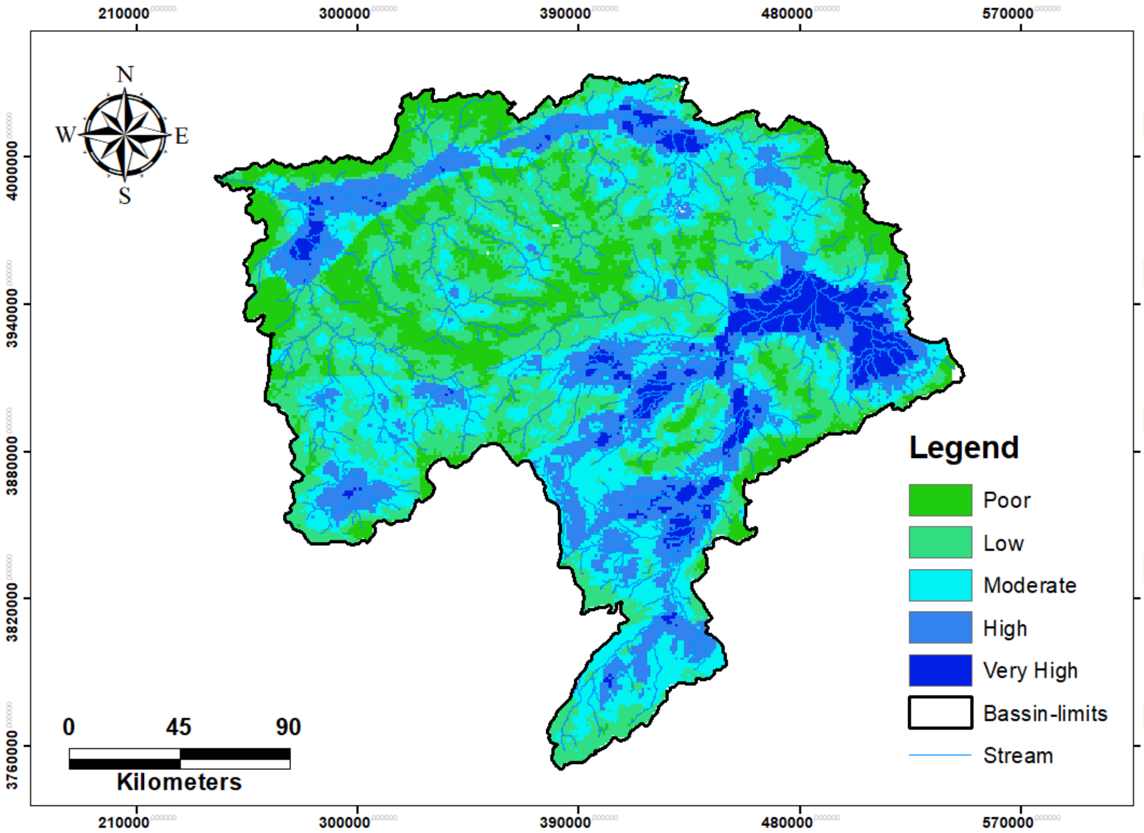


**Figure 4.23: Groundwater Potential Zone Map of the Study Area.**

As previously stated, groundwater potential zones in this study region were classified into five types: poor (18%), low (33%), moderate (26%), high (17%), and very high (6%). The most suitable areas were identified in the south-east to the south of our basin and some areas in the north-central near the stream course of the Cheliff Wadi. The map indicated that maximum plain areas were identified as poor to low prospective zones (51%).

**Table 4.2 : Groundwater Potential area and Percentage of the Study Area.**

| Sr. No | Groundwater potential zones | Area (Km2) | Percentage (%) |
|---|---|---|---|
| 1 | Poor | 7640.065 | 18 |
| 2 | Low | 14267.040 | 33 |
| 3 | Moderate | 11367.291 | 26 |
| 4 | High | 7364.194 | 17 |
| 5 | Very high | 2685.919 | 6 |
| Total | / | 43324.510 | 100 |

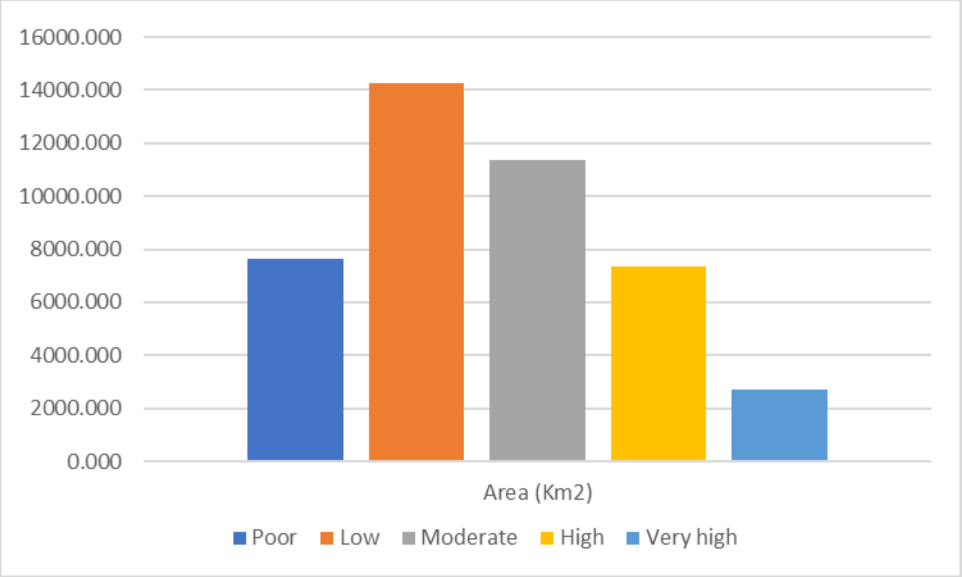


**Figure 4.24: Groundwater Potential Zones Area Coverage Of the Study Area.**

A closer analysis of the map indicates that the distribution is a considerable consequence of the drainage density and geological influence. The very good and good GWPZs mainly encompass units that have low drainage density sediments, and the areas where quaternary and tertiary rocks dominate are the most promising areas for groundwater storage. Similarly, the topographic wetness index (TWI) factor, which is widely documented to have a remarkable impact on groundwater recharge, displayed a reasonable control on groundwater potential distribution in the current study. The area that has moderate TWI in the southeast and south parts of the basin is most likely contributing to the high groundwater potential in such parts. In addition, low slope areas in the same zones mentioned before can rationalize the identified good groundwater potential in this part.

Likewise, the closer distances to the rivers can enhance the groundwater potential in the basin. The impact of the close distances to the rivers can be observed in the southeastern part, which has very good groundwater potential. Our results, however, show that the close distances to the rivers in the other parts of the basin have almost no effect on groundwater potential zones, and this can be attributed to the offset by the other parameters (e.g., TWI , slope, drainage density, and Geology) that have low groundwater potential ratings in such parts.

The regions where corps and bare land use prevail, on the other hand, are most likely contributing to the higher groundwater potential. This is plainly seen in the south-east and south regions of our basin, as well as in the north-central parts. When it comes to the effects of soil type and elevation, we can notice from the map that high groundwater potential zones are those where calcic xerosols and calcaric fluvisol soils predominate, and where elevation ranges from low to moderate. However, the NDVI has no substantial impact on groundwater potential recharging in our zone because the area with a high percentage of wasteland is also the area with a moderate to high groundwater potential.

Finally, the rainfall impact can only be observed in some areas of the northwestern part, which has a high groundwater potential and moderate rainfall average. However, the northeastern parts have low groundwater potential despite the high rainfall amounts that these parts receive, and this can be ascribed to the other parameters mentioned above that have classes with high groundwater potential in these parts.

### 4.3.4 Validation of the Potential Zones:

The final composite map is intended to provide a clear image of the groundwater status in the study area. Therefore, the accuracy of the delineated groundwater potential zones is essential.

The validity of the model developed is checked against the inventory map, which reflects the actual groundwater yield that was created by using the data collected from the Hydrographic Basin Agency (ABH). The total number of locations was 100 locations, and out of these, only 50 locations have a potential yield superior to 1 Hm3 and the rest are inferior to 1 Hm3. Since the prediction of the potential zones is a probability, it is mandatory to evaluate the accuracy of the identified zones based on field points. According to the validated potential zones presented in Figure 4.24, out of 100 point locations, 90 locations accurately match, and 10 locations do not match with the groundwater potential map zonation.

the comparison method of the map is not sufficient for judging the accuracy and performance of a model. Due to this, two methods were used, namely AUC and RMSE, to test the performance of models and the accuracy of the map generated. Both training (goodness of fit) and validation (prediction accuracy) datasets have been used for judging the capability of models in producing the GWPMs of the study area. Considering the training dataset, ROC curves showed an AUC value of 0.950 and the RMSE value was 0.302. In the validation data context, the AUC value was 1. On the other hand, the RMSE value was 0.246. Thus, all the statistical techniques used in this study to evaluate the performance of the model have judged the model as perfectly sufficient for mapping the groundwater potentiality in this area.

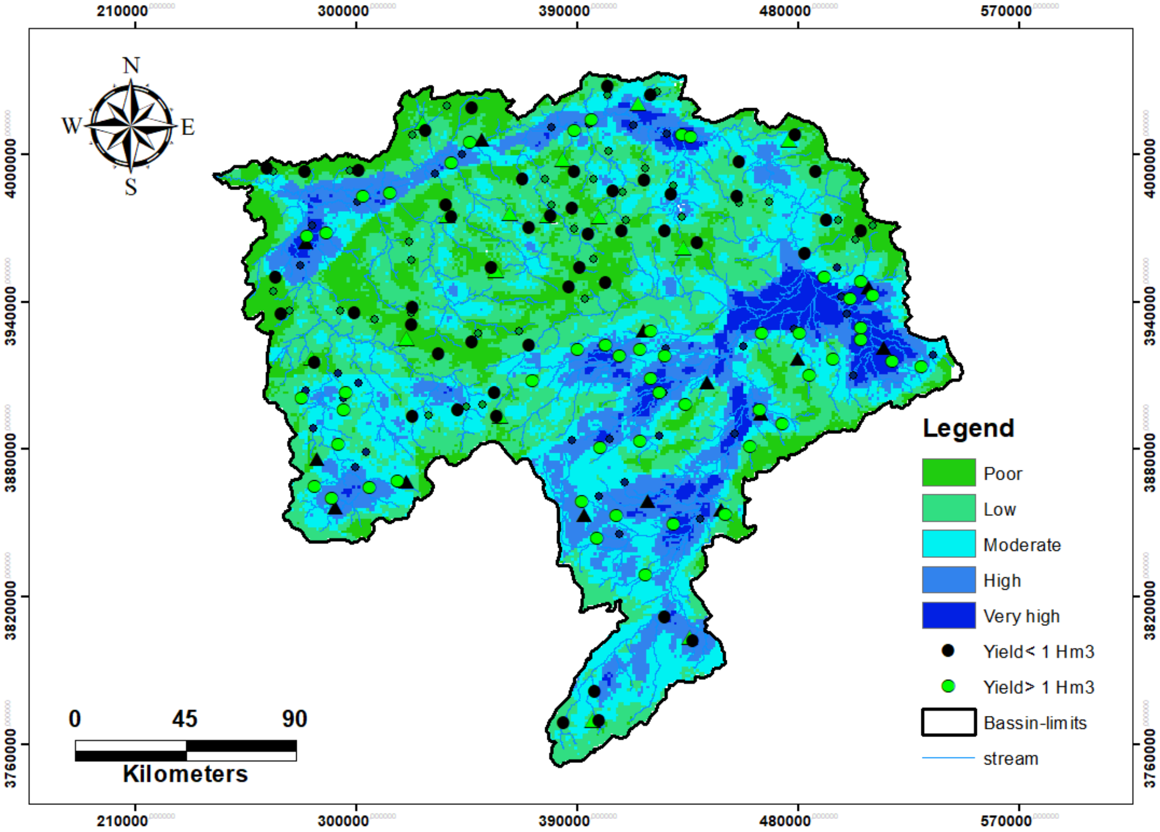


Figure 4.25: Distribution of Points Locations in Groundwater Potential Zones.

## 4.4 Limitations:

The groundwater potential zone of this study was constructed using available data of the study area and satellite imagery. Therefore, the point discharge data would not actually determine the exact potential of locations.

The majority of the GIS data sets are currently represented in vector format, which is convenient due to strong efficiency but can be difficult to manipulate analytically. The processes involved in vectorization as well as rasterization manifest errors in a given GIS system.

Single step in the process of integrating input parameters may contain uncertainties ranging from data acquisition to model resolution to result visualization. As far as I am aware, there are currently no effective methods for dealing with and communicating these uncertainties step by step until the final results.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion:

Groundwater demand in the Cheliff Basin has been rapidly increasing due to population increase, fast urbanization, industrialization, and agricultural expansion, causing its unscientific exploitation and creating a water stress situation. Lack of proper water planning and sewage management, lack of awareness, and non-implementation of appropriate measures are leading to fresh water scarcity. Proper estimation and budgeting of groundwater resources based on spatio-temporal distribution, its allocation for meeting the competing demands for irrigation, industrial and domestic usage, and conjunctive use of surface and groundwater resources are therefore essential for optimal utilization of available groundwater on a sustained basis**.**

While artificial neural networks demonstrate their efficiency and accuracy in prediction, notably in groundwater modeling. Geographical Information Systems (GIS) facilitate integrated and conjunctive analysis of large volumes of multi-disciplinary data. In the recent past, various methods combining ANNs and GIS techniques have been applied for groundwater studies. The integrated approach provides convergent analysis of large spatial data sets and decision making for groundwater studies.

The Cheliff wadi serves some of the Cheliff basin's drinking water needs, as well as the drinking and irrigation needs of the areas along its course. The basin lies in the northwest of Algeria and covers an area of 43750 Km2. The expanding urban population, shortage of rainfall, weather changes, over-exploitation of groundwater, competition for water between agriculture and drinking water supply requirements are some of the problems being faced by the basin.

The present study focuses on using artificial neural networks and GIS techniques for the assessment, evaluation, and analysis of the spatial distribution of groundwater potential zones in the Cheliff basin. The delineation of groundwater potential zones in the basin was carried out through the development of the Groundwater Potential Index (GWPI) map of the basin. To identify suitable locations for groundwater exploitation in the basin, slope, drainage density, geology, soil type, topographic wetness index (TWI), rainfall, distance from river, elevation, normalized different vegetation index map (NDVI), and landuse/land cover were used as thematic factors. The ANNs, were adapted to provide weight values for each parameter.

The delineated Groundwater potential were classified into five zones namely, ‘Poor’, ‘low’, ‘moderate’, ‘high’ and ‘very high’. poor zone shows that the low suitable area for groundwater prospect. Whereas very high zone indicates the most suitable area for groundwater prospect. High potential areas are present mostly in the southeast to southern part of the basin, which coincides with the low slope and low drainage density of the study area. Very low groundwater potential falls in the central area of the basin, which has a high slope and high drainage density. The acceptable results were done by comparing the inventory map with the groundwater potential zone map of the study area.

The most effective parameters in the area for groundwater potential are drainage density, topographic wetness index, distance from the river, geology, and slope. The neural network algorithms indicate that all the previous parameters are significant. The majority of the area, approximately 33%, is classified as low groundwater potential, followed by moderate groundwater potential (26%), poor groundwater potential (18%), and the remaining areas are classified as high to very high groundwater potential 17% and 6%, respectively. The validation clearly highlights the efficacy of the integration of Geographic Information Systems and Artificial Neural Networks with values of the RMSE for training and validation are equal to 0.302 and 0,246, respectively. And, The evaluation results of the ROC curve indicated that the AUC was 95,0 and 100%. Therefore, the performance of the combination of ANN and GIS techniques in delineating the potential zones was extremely beneficial.

Finally, it is concluded that the integration of ANNs and GIS techniques is an effective tool for the delineation of groundwater prospective zones, and this thesis will recommend that future research will focus on their implementation for the delineation of potential groundwater zones for the region where skilled manpower and financial affordability are very limited.

## 5.2 Recommandations:

Depending on this finding, the following recommendations were forwarded.

The study suggested that, depending on the finding, the delineated groundwater potential map along with other thematic map forms serves as a resource information database which can be updated from time to time by adding new information.

The delineated groundwater potential zone information will be useful for effective identification of suitable locations for extraction of water, which is used for different purposes. Furthermore, it can be said that the present methodology can be used as a guideline for further research.

In the present study, integrated GIS technique and artificial neural network were very helpful, time and cost effective tools for the identification and delineation of groundwater potential and analysis. For fast, cost effective and accurate result in delineation of groundwater potential zones investigations integrated Artificial neural network and GIS approach is highly recommended.

The study suggested that the GWPZs generated will serve as useful guidelines for planners, engineers and decision makers providing quick decision- making in the management of groundwater resources, on delineate/identify Groundwater potential occurrence zone.

# REFERENCES

Adeyeye, O.A.; Ikpokonte, E.A.; Arabi, S.A. GIS-Based Groundwater Potential Mapping within Dengi Area, North Central Nigeria. Egypt. J. Remote Sens. Space Sci. 2018.

Adiat, K. A. N., Olayanju, G. M., Omosuyi, G. O & Ako, B. D. (2009). Electromagnetic profiling and electrical resistivity soundings in groundwater investigation of a typical Basement Complex-a case study of Oda Town Southwestern Nigeria. Ozean Journal of Applied Sciences, 2(4), 333-359.

Adiat K N, Nawawi M N M, Abdullah K (2012) Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool - A case of predicting potential zonesof sustainable groundwater resources. Journal of Hydrology, 440(1), 75–89.

Agarwal R, Garg PK (2016) Remote sensing and GIS based ground-water potential & recharge zones mapping using multi-criteria decision making technique. Water Resour Manag 30(1):243–260.

Ako, B. D & Olorunfemi, M. O. (1989). Geoelectric survey for groundwater in the Newer Basalts of Vom, Plateau State. Journal of Mining and Geology, 25(1), 247-250.

Al-Ruzouq, R.; Shanableh, A.; Yilmaz, A.G.; Idris, A.; Mukherjee, S.; Khalil, M.A.; Gibril, M.B.A. Dam Site Suitability Mapping and Analysis Using an Integrated GIS and Machine Learning Approach. Water 2019, 11, 1880.

Al-Saud M. 2008. Using ASTER images to analyze geologic linear features in Wadi Aurnah basin, western Saudi Arabia. The Open Remote Sensing Journal 1: 17–25.

Amadi, U. M. P & Nurudeen, S. I. (1990). Electromagnetic survey and the search for groundwater in the crystalline basement complex of Nigeria. Journal of Mining Geology, 26(1), 45-53.

Amos, B.J., and Greenbaum, D., 1989. Alteration detection using TM imagery: The effects of supergene weathering in arid climate. Int. J. Remote Sensing, 10, pp. 515-527.

Aniya, M. (1985). Landslide-susceptibility mapping in the Amahata river basin, Japan. Annual Association American Geographers, 75, 102–114.

Arnold, W.S., White, M.W., Norris, H.A & Berrigan, M.E. (2000). Hard clam (Mercenaria spp.) aquaculture in Florida, USA: Geographic information system applications to lease site selection. Aquacultural Engineering 23, 203–231.

Aronoff, S. (1989) Geographic Information Systems: A Management Perspective. WDL pub., Ottawa.

Ayazi, M.H., Pirasteh, S., Arvin, A.K.P., Pradhan, B., Nikouravan,B., Mansor, S., 2010. Disasters and risk reduction in groundwater.

Ayenew T. (1998). The hydrogeological system of the Lake District basin, Central Main Ethiopian Rift. The Netherlands,259pp: PhD thesis (ISBN.9061641586), Free University of Amsterdam,.

Basavarajappa, H.T.; Dinakar, S.; Manjunatha, M.C. Validation of Derived Groundwater Potential Zones (Gwpz) Using Geoinformatics and Actual Yield From Well Points in Parts of Upper Cauvery Basin of Mysuru and Chamarajanagara Districts, Karntaka, India. Int. J. Civ. Eng. Technol. (IJCIET) 2016, 7, 141–161.

Bear, J., Verruijt, A., 1987. Modeling Groundwater Flow and Pollution. D. Reidel Publishing Company, Dordecht, Holland.

Bekkoussa B, Meddi M, Jourde H (2008) Climatic and anthropic forc- ing on groundwater resources in a semiarid area: The case of the Ghriss plain, north western Algeria. Sécheresse 19(3):173.

Benjmel K, Amraoui F, Boutaleb S, Ouchchen M, Tahiri A, Touab A (2020) Mapping of groundwater potential zones in crystalline terrain using remote sensing, GIS techniques, and multicriteria data analysis (case of the Ighrem Region, Western Anti-Atlas, Morocco). Water 12:471.

Beven, K. J. and Kirkby, M. J.: A physically based, variable contributing area model of basin hydrology, Hydrolological Sciences Bulletin, 24, 43–69, 1979.

Beven, K. J., Wood, E. F., and Sivapalan, M.: On hydrological heterogeneity – catchment morphology and catchment response, J. Hydrol., 100, 353–375, 1988.

Bouchekima B, D. Bechki, H. Bouguettaia, S. Boughali, M.T. Meftah, The underground brackish waters in south Algeria: potential and viable resources, in: 13th IWRA World Water Congress, Montpellier, France, 1–4 September, 2008.

Boucefiane A (2006) Cartographie automatique des précipitations du bassin Chéllif-Zahrez. Centre Universitaire de Khemis Miliana, Algérie, Mémoire de Magistère.

Botzen WJW, Aerts JCJH, van den Bergh JCJM (2013) Individual preferences for reducing flood risk to near zero through elevation. Mitig Adapt Strateg Glob Chang 18:229–244.

Burrough, P.A. (1986) Principles of Geographical Information Systems for Land Resources Assessment. Oxford University Press, Oxford.

Chowdhury, A., Jha, M., & Chowdary, V. (2010). Delineation of ground water recharge zones and identification of artificial recharge sites in West Medinipur District, West Bengal using RS, GIS and MCDM techniques. Environ Earth Sci, 59(6):1209–1222.

Condon LE, Maxwell RM (2015) Evaluating the relationship between topography and groundwater using outputs from a continental-scale integrated hydrology model. Water Resour Res 51:6602–6621.

Courtney, R. G., and Timpson, J. P. (2005). Reclamation of fine fraction bauxite processing residue (red mud) amended with coarse fraction residue and gypsum. Water, air, and soil pollution, 164(1-4), 91-102.

Das, N.; Mukhopadhyay, S. Application of multi-criteria decision making technique for the assessment of groundwater potential zones: A study on Birbhum district, West Bengal, India. Environ. Dev. Sustain. 2020, 22, 931–955.

Deering, D. W. (1978). Rangeland reflectance characteristics measured by aircraft and spacecraft sensor. Texas A&M University.

Derdous O, Bouamrane A, Mrad D (2020) Spatiotemporal analysis of meteorological drought in a Mediterranean dry land: case of the Cheliff basin–Algeria. Model Earth Syst Environ.

Dubey, S. K., Pranuthi, G., & Tripathi, S. K. (2012). Assessing the Relation Between NDVI and Rainfall over India. International Journal of Water Resources and Arid Environments, 2(4), 108-114.

Edet, A., Okereke, C., SC.Teme, & Esu, E. (1998). Application of remote-sensing data to groundwater exploration: a case study of the Cross River State, southeastern Nigeria. Hydrogeol J., 6:394–404.

Elmeddahi Y, (2016) Les changements climatiques et leurs impacts sur les ressources en eau , cas du bassin du Chelliff. Dissertation, University of Hassiba Ben Bouali-Algeria.

E. Temgoua, T. H. Djeuda, E. Tanawa, C. Guenat et H. R. Pfeifer, «Groundwater fluctuations and footslope ferricrete soils in the humid tropical zone of southern Cameroon,» Hydrol. Process, vol. 19, 2005.

FAO, 2003. Review of world water resources by country. In: Water Reports, vol. 23, Rome, Italy.

Famiglietti, J. S. and Wood, E. F.: Evapotranspiration and runoff from large land areas – land surface hydrology for atmospheric general-circulation models, Surv. Geophys., 12, 179–204, 1991.

FAO, 2004. Aquastat.

Farmer, D., Slvapalan, M., & Jothltyangkoon, C. (2003). Climate, soil, and vegetation controls upon the variability of water balance in temperature and semiarid landscapes: Downward approach to water balance analysis. Water Resources Research

Fashae, O. A., Tijani, M. N., Talabi, A. O., and Adedeji, O. I.: Delineation of groundwater potential zones in the crystalline basement terrain of SW-Nigeria: an integrated GIS and remote sensing approach, Applied Water Science, 4, 19-38, 2014.

Fetter, C.W (1994).Applied Hydrogeology, 4th ed. Prentice Hall, Englewood Cliffs, NJ, 543–591.

Fitts, C. Groundwater Science; Elsevier: Amsterdam, The Netherlands, 2002.

Greenbaum, D., 1992. Structural influences on the occurrence of groundwater in SE Zimbabwe. In: Geological Society London, vol 66, pp. 77–85, Special Publications.

Godebo TR (2005) Application of remote sensing and GIS for geological investigation and groundwater potential zone identification, Southeastern Ethiopian Plateau, Bale Mountains and the surrounding areas. ADDIS ABABA UNIVERSITY, Dissertation.

Gouri, B.S., Samanta, S., Pal, D.K & Pal, B (2012). Assessment of Groundwater Potential Zone in Paschim Medinipur District, West Bengal–A Meso-scale study using GIS and Remote Sensing Approach. Journal of Environment and Earth Science. 2(5), 41-59.

Kim, J.C.; Jung, H.S.; Lee, S. Spatial mapping of the groundwater potential of the Geum River basin using ensemble models based on remote sensing images. Remote Sens. 2019, 11, 2285.

Kumar, P., Gopinath, G., Seralathan, O., 2007. Application of remote sensing and GIS for the demarcation of groundwater potential areas of a river basin in Kerala, southwest coast of India. Int. J. Remote Sens. 28, 5583–5601.

Kumar, P., Herath, S., Avtar, R., & Takeuchi, K. (2016). Mapping of groundwater potential zones in Killinochi area,. Sustainable Water Resources Management.

Khelfi MEA, Touaibia B, Guastaldi E (2017) Regionalisation of the "intensity-duration-frequency" curves in Northern Algeria. Arab J Geosci 10.

Harkat, S. & Kisi, O. 2021 Trend analysis of precipitation records using an innovative trend methodology in a semi-arid Mediterranean environment: Cheliff Watershed Case (Northern Algeria). Theoretical and Applied Climatology 144 (3), 1001–1015.

Hassini, N. ; Abderrahmani, B.; Dobbi, A.Trends of Precipitation and Drought on the Algerian Littoral: Impact on the Water Reserves. International Journal of Water Resources and Arid Environments, 1(4) (2011) 271-276.

Hornsby, A. G. (1986). A microcomputer-based management tool for chemical movement in soil. Applied agricultural research, 1(1), 50-56.

Hsin-Fu Yeh, C.-H. L.-C.-H. (2016). "GIS for assessment of the groundwater recharge potential zone". Environmental Geology, 58:185-195.

Huajie, Duan, Deng Zhengdong, and Deng Feifan. "Classification of Groundwater Potential in Chaoyang Area Based on QUEST Algorithm." 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 2016.

Hyun-Joo O, Yong-Sung K, Jong-Kuk C, Eungyu P, Saro L (2011) GIS mapping of regional probabilistic groundwater potential in the area of Pohang City. Korea J Hydrol 399(3–4):158–172.

Indhulekha, K.; Chandra Mondal, K.; Jhariya, D.C. Groundwater prospect mapping using remote sensing, GIS and resistivity survey techniques in Chhokra Nala Raipur district, Chhattisgarh, India. J. Water Supply Res. Technol. 2019, 68, 595–606.

Jaturon, Konkul, Wiewwiwun, Rojborwornwittaya, Srilert, Chotpanarat, 2014. Hydrogeologic characteristics and groundwater potentiality mapping using potential surface analysis in the Huay Sai area, Phetchaburi province, Thailand. Geosci. J. 18 (1), 89–103.

Jha, M. K., Chowdary, V. M. & Chowdhury, A. Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. Hydrogeol. J. 18, 1713–1728.

Jha, M.K., Chowdhury, A., Chowdary, V.M & Peiffer, S (2007). Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. Water Resources Management, 21 (2), 427–467.

Leduc, C., Favreau, G., Schroeter, P., 2001. Long-term rise in a Sahelian water-table: the Continental Terminal in south-west Niger. Journal of hydrology, 243: 43–54.

Lehr, J H, Keeley, J.W., Lehr, K.K &. Kingery, T.B. 2005. Water encyclopedia.

Madan, K.J., Chowdary, V.M. & Chowdhury, A. (2010.) Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. Hydrogeology Journal, 18(7), 1713–1728.

Magesh, N.; Chandrasekar, N.; Soundranayagam, J.P. Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geosci. Front. 2012, 3, 189–196.

Manap, M.A., Sulaiman, W.N.A., Ramli, M.F., Pradhan, B., Surip, N., 2013. A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia. Arab. J. Geosci. 6, 1621–1637.

Mandal, Uday, Satiprasad Sahoo, Selva Balaji Munusamy, Anirban Dhar, Sudhindra N. Panda, Amlanjyoti Kar, and Prasanta K. Mishra. "Delineation of Groundwater Potential Zones of Coastal Groundwater Basin Using Multi-Criteria Decision Making Technique." Water Resources Management30, no. 12 (July 04, 2016).

Malczewski J (2004) GIS-based land-use suitability analysis: a critical overview. Prog plan 62(1):3–65.

Malczewski J (1999) GIS and multicriteria decision analysis. Wiley, London.

Masih I, Maskey S, Mussá FEF, Trambauer P (2014) A review of droughts in the African continent: a geospatial and long-term perspective. Hydrol Earth Syst Sci 11(3):2679–2718.

Maurice, D. R., and Courtney, T. H. (1990). The physics of mechanical alloying: a first report. Metallurgical Transactions, 21(1), 289-303.

Meddi M, Boucefiane A (2008) Impact of climate change on the renewal of underground water resources (case hydrographic basin ChéliffZahrez). Groundwater & Climate in Africa, Kampala, Uganda, 2008.

Meddi M, Hubert P (2003) Impact of rainfall regime change on water resources in Northwestern Algeria. Hydrol Mediterr Semiarid Reg 278:229–235.

Meijerink, A.M.J (2007). Remote sensing applications to groundwater IHP-VI, Series on Groundwater No. 16, UNESCO, Paris.

Mehaiguene M (2005) Bilan hydrologique et ressources en eau de surface du bassin Chelif-Zahrez. Dissertation, University of Hassiba Ben Bouali-Algeria.

Moghaddam DD, Rezaei M, Pourghasemi HR, Pourtaghie ZS, Pradhan B (2015) Groundwater spring potential mapping using bivariate statistical model and GIS in the Taleghan watershed, Iran. Arab J Geosci 8(2):913–929.

Mitiche R, Metaiche M, Kettab A et al (2010) Desalination in Algeria: current situation and development programs. Desalin Water Treat 14(1–3):259–264.

M. Thangarajan. (2007). Groundwater Resource Evaluation, Augmentation, Contamination, Restoration, Modeling and Management.

Nampak, H., Pradhan, B., and Manap, M. A.: Application of GIS based data driven evidential belief function model to predict groundwater potential zonation, Journal of Hydrology, 513, 283-300, 2014.

Nag SK (2005) Application of lineament density and hydrogeomorphology to delineate groundwater potential zones of Baghmundi block in Purulia district, West Bengal. J Indian Soc Remote Sens 33(4):522–529.

Naumburg, E., Mata-gonzalez, R., Hunter, R., Mclendon, T. & Martin, D. (2005). Phreatophytic Vegetation and Groundwater Fluctuations: A Review of Current Research and

Application of Ecosystem Response Modeling with an Emphasis on Great Basin Vegetation. Environmental Management, 35(6).

Neshat, A., Pradhan, B., Pirasteh, S., Shafri, H.Z.M., 2013. Estimating groundwater vulnerability to pollution using a modified DRASTIC model in the Kerman agricultural area. Iran. Environ. Earth Sci, 1– 13.

Olayinka, A.I & Olayiwola, M.A. (2001). Integrated use of geoelectrical imaging and hydrochemical methods in delineating limits of polluted surface and groundwater at a landfill site in Ibadan area, southwestern Nigeria. Journal of Mining and Geology 37 (1), 53-68.

Olorunfemi, M.O., Dan-Hassan, M.A. & Ojo, J.S. (1995).On the scope and limitations of the electromagnetic methods in groundwater prospecting in a Precambrian basement terrain a Nigerian case study. Journal of African Earth Sciences, 20 (2), 151–160.

Olusegun, C., & Adeyewa, Z. (2013). Spatial and Temporal Variation of Normalized Difference Vegetation Index (NDVI) and Rainfall in the North East Arid Zone of Nigeria. Atmospheric and Climate Sciences, 3(4), 421-426.

Ozdemir A (2011a) Using a binary logistic regression method and GIS for evaluating and mapping the gorundwarer spring potential in the Sultan Mountians (Aksehir, Turkey). J Hydrol 405:123–136.2011.05.015.

Ozdemir A (2011b) GIS-based groundwater spring potential mapping in the Sultan Mountains (Konya, Turkey) using frequency ratio, weights of evidence and logistic regression methods and their comparison. J Hydrol 411:290–308.

Pan, Y. X., Wang, X. P., Jia, R. L., Chen, Y. W., & He, M. Z. (2008). Spatial variability of surface soil moisture content in a re-vegetated desert area in Shapotou, northern China. Journal of Arid Environment, 72(9)(Environment).

Prasad, R. M. (2008). Deciphering potential groundwater zone in hard rock through the application GIS. Environmental Geology, vol. 55, pp. 467–475.

Pradhan, B., 2009. Groundwater potential zonation for basaltic watersheds using satellite remote sensing data and GIS techniques. Cent. Eur. J. Geosci 1 (1), 120–129.

Pratap K, Ravindran K V & Prabakaran B, Groundwater prospect zoning using remote sensing and geographical information system: a case study in Dala-Renukoot area, Sonbhadra District, Uttar Pradesh, J Indian Soc Remote Sens, 28 (4) (2000) 249-263.

Raghunath H.M (2006). Hydrology: Principles, Analysis, Design, Second edition. New Age International (P) Limited, Publishers, Manipal, Karnataka, India. Pp 477.

Rahman, H.A., 2001. Evaluation of groundwater resources in lower cretaceous aquifer system in Sinai. Water Resour. Manag. 15, 187−202.

Ramu, Mahalingam, B., & Vinay, M. (2010). Identification of ground water potential zones using GIS and Remote Sensing Techniques: A case study of Mysore taluk - Karnataka. International Journal of Geomatics and Geosciences, Volume5, No 3, 2014.

Ramu, Mahalingam, B., & Vinay, M. (2010). Identification of ground water potential zones using GIS and Remote Sensing Techniques: A case study of Mysore taluk - Karnataka. International Journal of Geomatics and Geosciences, Volume5, No 3, 2014.

Rashman. (2016). Identification of Groundwater recharge potentaial zones. International Journal science.

Razavi-Termeh, S.V.; Sadeghi-Niaraki, A.; Choi, S.-M. Groundwater Potential Mapping Using an Integrated Ensemble of Three Bivariate Statistical Models with Random Forest and Logistic Model Tree Models. Water 2019, 11, 1596.

Remini .B, (2005), «La problématique de l’eau en Algérie ».

Rhind, D., Openshaw, S., and Green, N. (1989) The analysis of geographical data: data rich, technology adequate, Proceedings of the IV International Working Conference on Statistical and Scientific Data Base Management, Rome, Italy, Lecture notes in Computer Science, 339, 425–454.

Rodriguez-Iturbe, I. (2000). Ecohydrology: A hydrologic perspective of climate-soil-vegetation dynamies. Water Resources Research, 36(1), 3-9.

Roscoe, M C (1990). Handbook of Ground Water Development. Wiley, New York, pp 34–51.

Robson, A., Beven, K., and Neal, C.: Towards identifying sources of subsurface flow: a comparison of components identified by a physically based runoff model and those determined by chemical mixing techniques, Hydrol. Process., 6, 199–214, 1992.

S. Lee, Y. S. Kim et H. J. Oh, «Application of a weights-of-evidence method and GIS to regional groundwater productivity potential mapping,» J. Environ. Manag., vol. 96, pp. 91 - 105, 2012a.

Sadi A (2004) Seawater desalination share among water and market policy changes in Algeria. Desalination 165:99–104.

Saud, M.A., 2010. Mapping potential areas for groundwater storage in Wadi Aurnah Basin, western Arabian Peninsula, using remote sensing and geographic information system techniques. Hydrogeol. J. 18, 1481–1495.

Saraf AK, Choudhury PR (1997) Integrated application of remote sensing and GIS groundwater exploration in hard rock terrain In: Proceedings of International Symposium on Emerging trends in Hydrology, Department of Hydrology, Roorkee, September 25–27, 1:435–442.

Selvam, S.; Farooq, A.; Magesh, N.; Singaraja, C.; Venkatramanan, S.; Chung, S. Application of remote sensing and GIS for delineating groundwater recharge potential zones of Kovilpatti Municipality, Tamil Nadu using IF technique. Earth Sci. Inf. 2016, 9, 137–150.

Selvarani AG, Elangovan K, Kumar CS (2016) Evaluation of groundwater potential zones using electrical resistivity and GIS in Noyyal River basin, Tamil Nadu. J Geol Soc India 87:573–582.

Sener, E., Davraz, A., Ozcelik, M., 2005. An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. Hydrogeology Journal 13 (5–6), 826–834.

Shamuyarira, K. K. (2017). Determination of recharge and groundwater potential zones in Mhinga Area, South Africa. Master of Earth Sciences in Hydrology and Water Resources MESHWR, University of Venda, South Africa.

Sivapalan, M. and Wood, E. F.: A multidimensional model of nonstationary space-time rainfall at the catchment scale, Water Resour. Res., 23, 1289–1299, 1987.

Sivapalan, M., Wood, E. F., and Beven, K. J.: On hydrologic similarity. 3. A dimensionless flood frequency model using a generalized geomorphologic unit hydrograph and partial area runoff generation, Water Resour. Res., 26, 43–58, 1990.

Senthil Kumar, G.R., Shankar, K., 2014. Assessment of groundwater potential zones using GIS. Front. Geosci. 2 (1), 1–10.

Stromberg, J. C., Tiller, R. & Richter, B. (1996). Effects of Groundwater Decline on Riparian Vegetation of Semiarid Regions: The San Pedro, Arizona. Ecological Society of America, Ecological Application), 113-131.

Thurgood, I.D and J.S Bethel: Geographic Information Systems, Civil Engineering Handbook, CRC Press, Indiana.

Todd DK, M. L. (2005). Groundwater hydrology, 3rd edn. Wiley,. Nation Journal, p 636.

Touchan R, Anchukaitis KJ, Meko DM, Attalah S, Baisan C, Aloui A (2008) Long term context for recent drought in northwestern Africa. Geophys Res Lett 8(13):35.

Wang, P., Zhang, Y., Yu, J., Fu, G., & Ao, F. (2011). Vegetation dynamics induced by groundwater fluctuations in the lower Heihe River Basin, northwestern China. Journal of Plant Ecology, 4(1-2).

Yazi, A., Pirasteh, S., Arvin, A., Pradhan, B., Nikouravan, B., & Mansor, S. (2010). Disasters and risk reduction in groundwater: Zagros Mountain Southwest Iran using geoinformatics techniques. Dis Adv 3(1):51–57.

Yeh, H.F., Cheng, Y.S., Lin, H.I & Lee, C.H. (2016). Mapping groundwater recharge potential zone using a GIS approach in Hualian River, Taiwan. Sustainable Environment Research, 26(1) 33-43.

## Websites:

**FAO:** https://www.fao.org/.

**USGS earth explorer:** https://earthexplorer.usgs.gov/ .

**Google earth:** https://www.google.com/intl/fr/earth/versions/.

**Esri:** https://www.esri.com/.

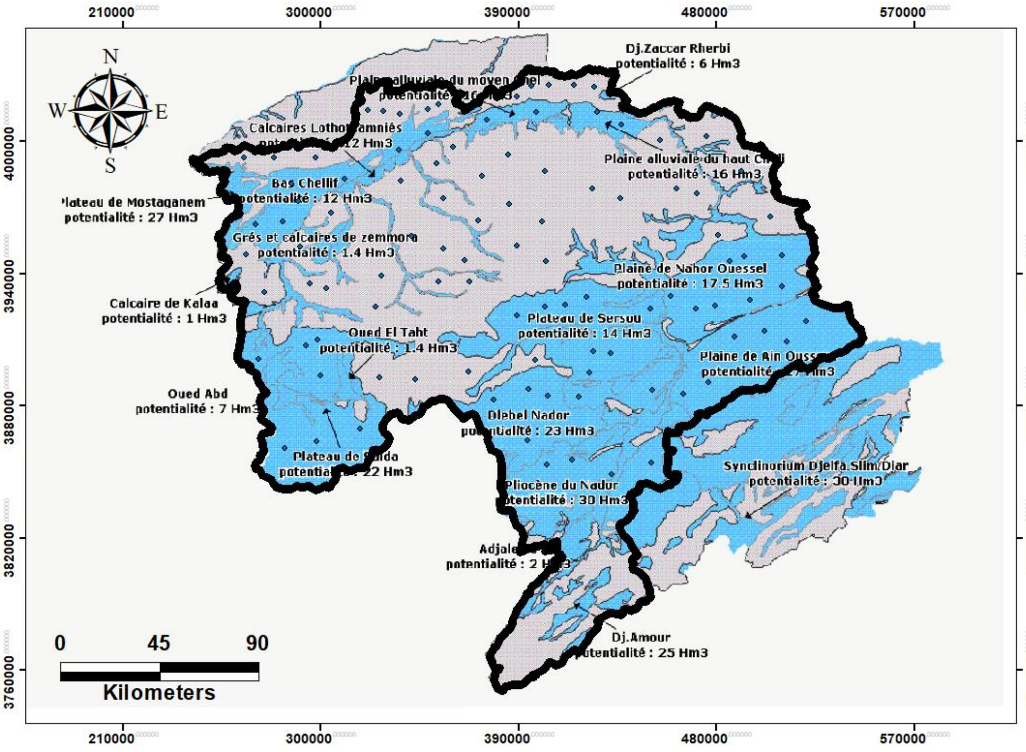
# APPENDIX

Appendix A: Characteristics of Rainfall Stations in the Cheliff Basin. (Derdous et al, 2020).

| Code | Station name | Latitude | Longitude | Elevation (m) | Minima (mm) | Maxima (mm) | Mean (mm) | Standard deviation | Variation coeff |
|---|---|---|---|---|---|---|---|---|---|
| 10502 | Zmalet-El-Amir- | 34.9 | 2.31 | 820 | 11.3 | 555.6 | 170.84 | 92.65 | 0.54 |
| 10703 | Rechaiga | 35.4 | 1.97 | 830 | 107.2 | 494.5 | 267.94 | 84.85 | 0.32 |
| 10704 | Ksar-Chellala | 35.21 | 2.32 | 860 | 51.6 | 677.39 | 244.12 | 99.91 | 0.41 |
| 10803 | Mehdia | 35.42 | 1.75 | 903 | 161.6 | 735.2 | 371.54 | 101.55 | 0.27 |
| 10901 | Sougueur | 35.19 | 1.5 | 1120 | 115.5 | 730.5 | 361.95 | 116.89 | 0.32 |
| 11003 | Colonel-Bou- | 35.55 | 1.97 | 820 | 162.5 | 525.6 | 330.18 | 76.77 | 0.23 |
| 11004 | Khemisti | 35.66 | 1.97 | 928 | 37.75 | 929.47 | 370.74 | 176.29 | 0.48 |
| 11101 | Guelt-Es-Stel | 35.15 | 3.02 | 940 | 78.7 | 335.48 | 195.19 | 58.8 | 0.3 |
| 11104 | Ain-Boucif | 35.88 | 3.14 | 1250 | 102 | 442.01 | 244.81 | 81.86 | 0.33 |
| 11302 | Derrag | 35.9 | 2.4 | 1160 | 190.66 | 1152.85 | 539.51 | 157 | 0.29 |
| 11404 | Zoubiria-Mon- | 36.11 | 2.85 | 1000 | 238.4 | 937.2 | 527.33 | 138.81 | 0.26 |
| 11505 | Medea-CFPA | 36.26 | 2.78 | 900 | 388.25 | 1292.11 | 718.28 | 187.87 | 0.26 |
| 11605 | Theniet-El-Had | 35.88 | 2.02 | 1160 | 83.4 | 799.87 | 526.31 | 138.61 | 0.26 |
| 11803 | Sidi-Medjahed | 36.33 | 2.17 | 850 | 370.1 | 1208.1 | 699.47 | 185.74 | 0.27 |
| 12207 | Chlef | 36.21 | 1.33 | 100 | 199.3 | 795.3 | 415.16 | 118.74 | 0.29 |
| 12503 | Sidi-Hosni | 35.46 | 1.52 | 790 | 128.4 | 805.47 | 355.02 | 136.36 | 0.38 |
| 12505 | Oued-Lili-MN | 35.5 | 1.26 | 570 | 192.3 | 617.7 | 376.24 | 106.91 | 0.28 |
| 12703 | Kenenda-Ferme | 35.64 | 0.82 | 590 | 102.9 | 894 | 411.58 | 166.67 | 0.4 |
| 12804 | DNE-Sidi- | 35.97 | 0.68 | 55 | 153.4 | 786.3 | 319.74 | 113.04 | 0.35 |
| 13004 | Ain-El-Haddid | 35.05 | 0.87 | 829 | 194.8 | 605.7 | 350.09 | 104.91 | 0.3 |
| 13404 | Si-Benaouda- | 35.6 | 0.59 | 130 | 141.4 | 423.02 | 253.92 | 69.31 | 0.27 |

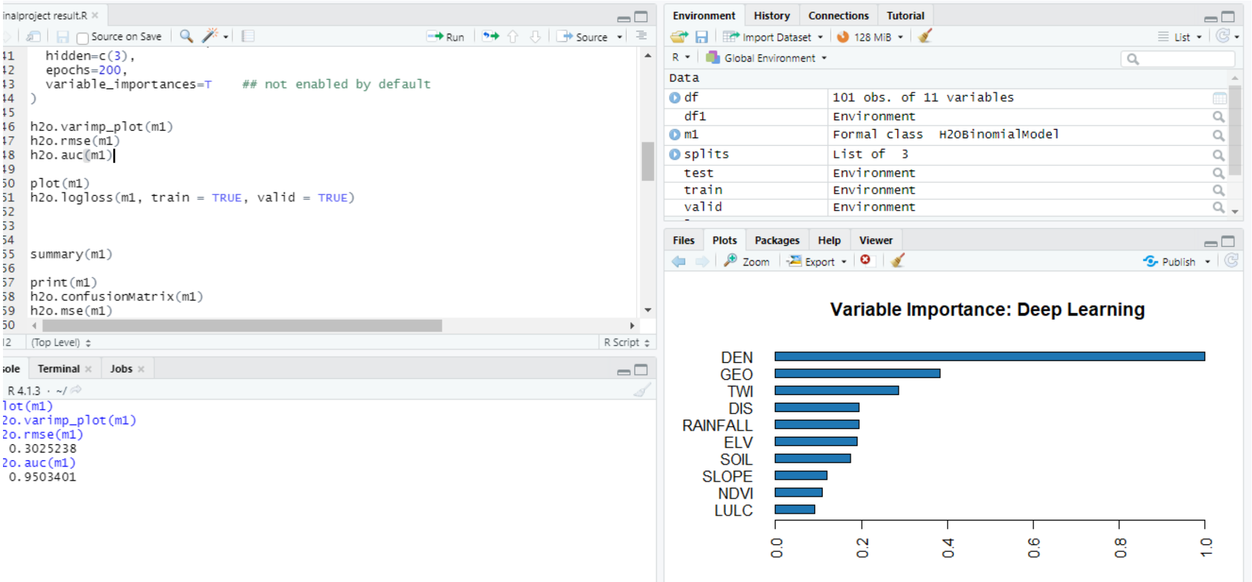
Appendix B: Average Monthly and Annual Temperatures (C°) for 2002.(Mehaiguene,2005)

| Basin | Station | Jun | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bougzoul Downstream | Chlef | 9,6 | 10,9 | 13,4 | 16,4 | 20,8 | 25,6 | 29,6 | 29,8 | 25,3 | 19,4 | 13,9 | 10,1 | 18,7 |
|  | El Abadia | 9,1 | 10,3 | 12,6 | 15,3 | 19,0 | 24,0 | 28,5 | 28,9 | 25,4 | 19,1 | 13,9 | 9,7 | 17,9 |
|  | Chlef ONM | 9,4 | 10,7 | 12,9 | 15,4 | 20,1 | 24,0 | 28,9 | 29,4 | 25,4 | 19,8 | 13,8 | 10,1 | 18,3 |
|  | Ain Defla | 8,9 | 9,8 | 12,6 | 16 | 20,5 | 26,0 | 30,6 | 30,3 | 25,9 | 20,4 | 13,7 | 9,9 | 18,7 |
|  | Miliana | 8,9 | 10,3 | 11,8 | 13,8 | 18,0 | 22,7 | 26,7 | 27,3 | 23,3 | 18,3 | 13,0 | 9,9 | 17,0 |
|  | Ghrib Bge | 8,2 | 9,3 | 12,3 | 13,3 | 17,6 | 22,3 | 26,1 | 27,0 | 21,9 | 17,5 | 12,7 | 8,8 | 16,4 |
|  | Medea | 6,8 | 6,7 | 9,8 | 12,3 | 15,4 | 20,4 | 24,6 | 24,4 | 20,8 | 15,4 | 11,0 | 6,4 | 14,5 |
|  | Merdja | 11,5 | 13,3 | 15,7 | 16,2 | 21,0 | 23,6 | 26,3 | 27,8 | 24,8 | 20,2 | 17,1 | 13,0 | 19,2 |
|  | Sidi Slimane | 7,3 | 8,1 | 9,9 | 12,6 | 17,2 | 21,0 | 26,5 | 27,1 | 22,3 | 16,8 | 10,9 | 7,7 | 15,6 |
|  | Theniet El Had | 4,7 | 5,8 | 8,5 | 11,3 | 15,2 | 20,3 | 23,8 | 24,1 | 19,6 | 14,8 | 8,9 | 6,0 | 13,5 |
|  | Ammi Moussa | 9,1 | 10,8 | 12,9 | 15,6 | 19,4 | 24,4 | 28,2 | 28,5 | 24,7 | 19,0 | 13,6 | 9,6 | 17,9 |
|  | Ksar El Boukhari | 5,7 | 7,1 | 9,9 | 13,1 | 17,0 | 21,5 | 26,3 | 25,3 | 21,5 | 16,0 | 10,4 | 6,2 | 15,0 |
|  | Zoubiria Mongorno | 5,1 | 6,4 | 9,1 | 12,0 | 15,9 | 20,4 | 24,7 | 24,7 | 20,6 | 15,6 | 9,9 | 6,0 | 14,2 |
|  | Ouzera | 4,6 | 6,2 | 8,4 | 10,9 | 15,7 | 20,0 | 25,6 | 25,3 | 19,5 | 14,6 | 8,5 | 5,7 | 13,7 |
|  | Relizane | 9,9 | 11,3 | 13,4 | 16,3 | 20,0 | 23,6 | 27,9 | 28,7 | 25,0 | 19,6 | 14,5 | 10,8 | 18,4 |
|  | Sidi Med B. Aouda | 11 | 12,1 | 15,9 | 17,2 | 22,1 | 24,5 | 29,0 | 29,5 | 25,2 | 20,3 | 16,3 | 13,1 | 19,6 |
|  | Ain Kermes | 6,5 | 7,6 | 9,8 | 11,9 | 16,9 | 22,0 | 26,4 | 25,4 | 20,8 | 16,3 | 11,3 | 7,7 | 15,2 |
|  | Bekhada | 9,7 | 10,7 | 14,1 | 14,2 | 19,5 | 23,7 | 28,6 | 28,2 | 24,3 | 18,4 | 14,8 | 10,3 | 18,0 |
|  | Guertoufa | 6,1 | 6,9 | 9,1 | 12,1 | 16,1 | 21,0 | 25,9 | 26,0 | 21,7 | 15,9 | 10,3 | 6,6 | 14,8 |
|  | Tissemsilt | 5,8 | 5,4 | 8,7 | 11 | 16,5 | 20,5 | 25,4 | 25,3 | 21 | 15,1 | 9,9 | 6 | 14,2 |
| Boughezoul Upstream | Dahmounia | 6,4 | 8,1 | 10,3 | 12 | 16,5 | 21 | 26,5 | 25,3 | 22,2 | 17,3 | 12,1 | 8,1 | 15,5 |
|  | ksar Chellala | 6,8 | 8,3 | 10,9 | 14 | 18,4 | 23 | 27,1 | 27,4 | 23,3 | 16,6 | 11,1 | 7,4 | 16,2 |
|  | Aflou | 4,3 | 3,5 | 8,3 | 11 | 16,7 | 20,4 | 24 | 24 | 19 | 13,9 | 8,5 | 4,8 | 13,2 |



Appendix C: Potential Levels Map. (ABH)

# Weighting Results in Rstudio:

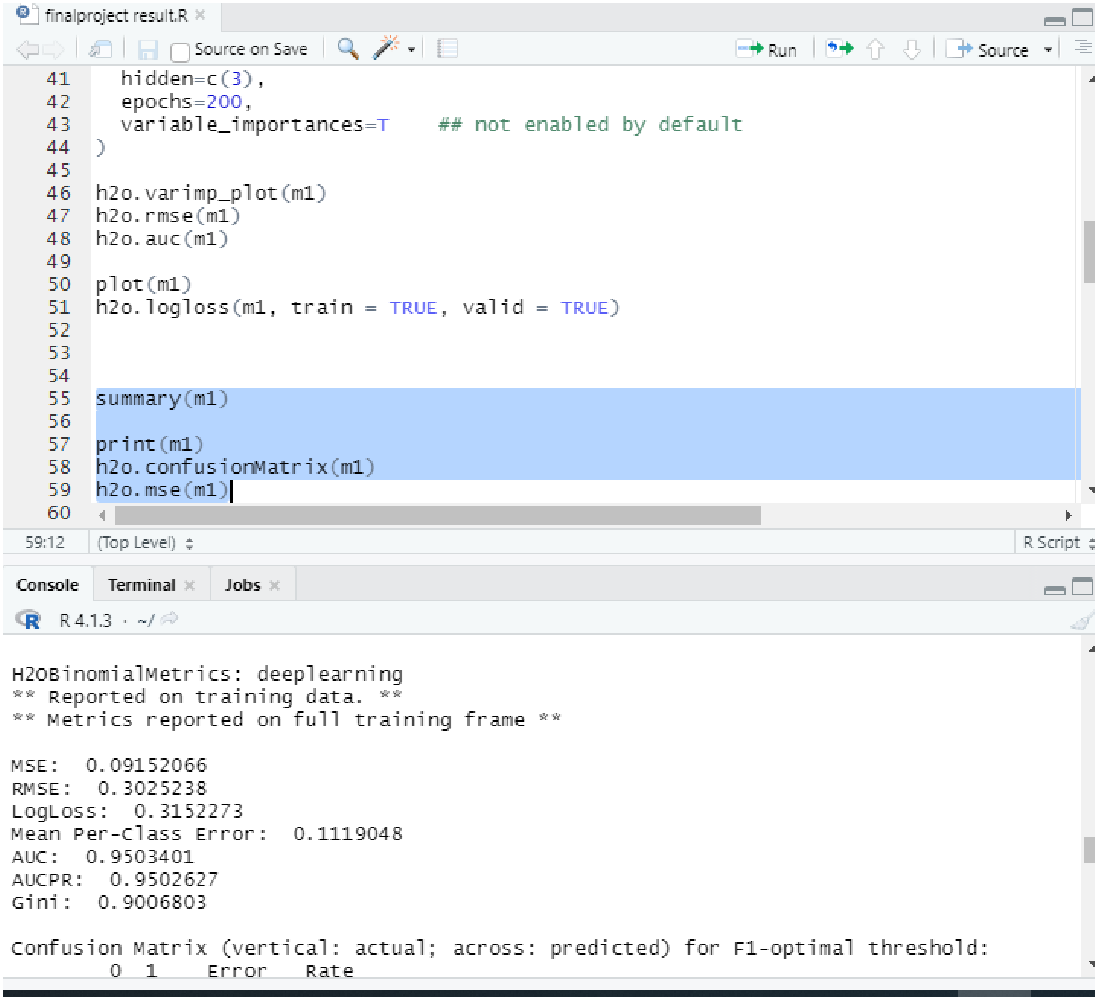


```r
  hidden=c(3),
  epochs=200,
  variable_importances=T    ## not enabled by default
)

h2o.varimp_plot(m1)
h2o.rmse(m1)
h2o.auc(m1)

plot(m1)
h2o.logloss(m1, train = TRUE, valid = TRUE)



summary(m1)

print(m1)
h2o.confusionMatrix(m1)
h2o.mse(m1)
```

```
lot(m1)
2o.varimp_plot(m1)
2o.rmse(m1)
 0.3025238
2o.auc(m1)
 0.9503401
```

```
Data
df       101 obs. of 11 variables
df1      Environment
m1       Formal class  H2OBinomialModel
splits   List of  3
test     Environment
train    Environment
valid    Environment
```

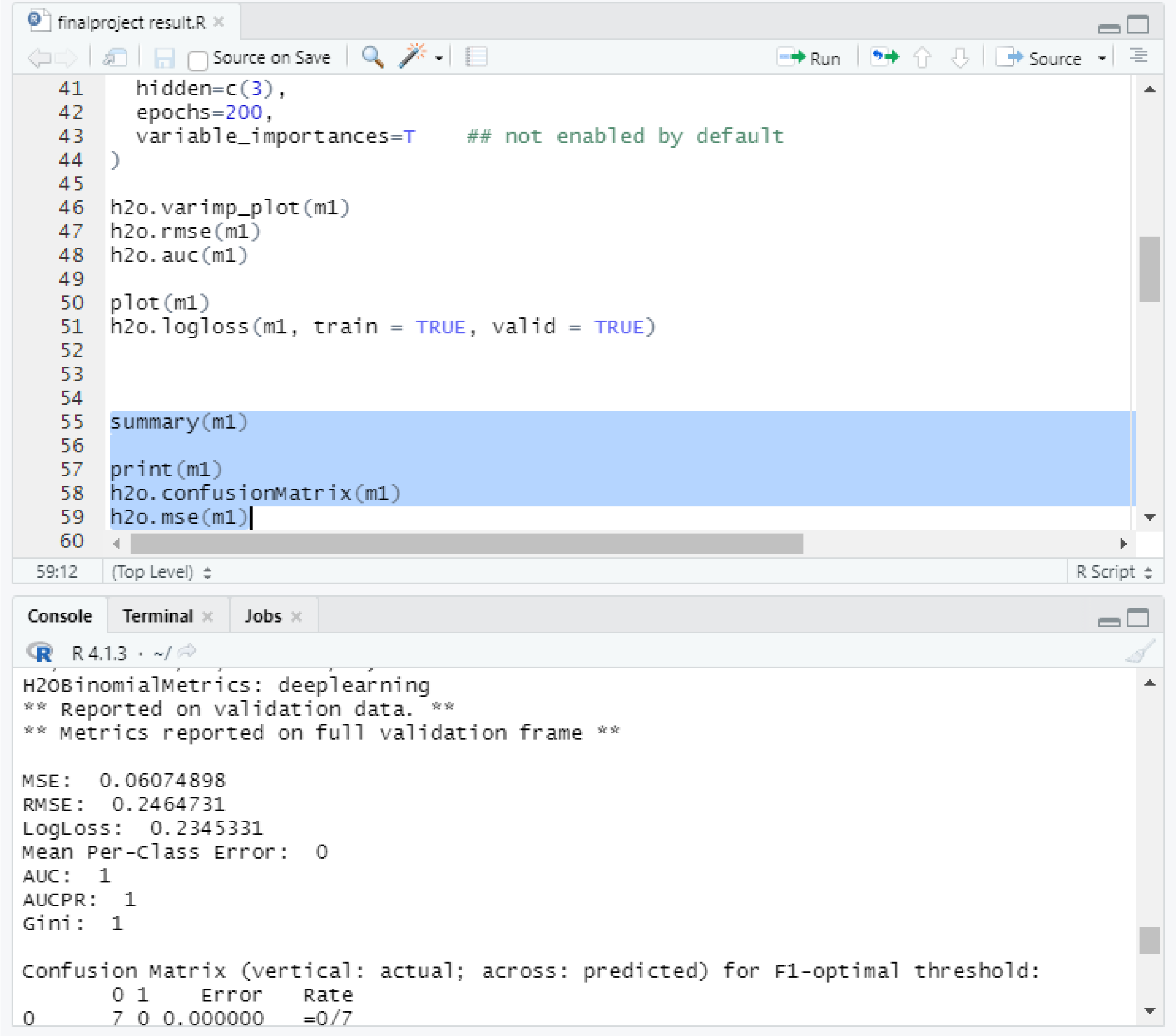
# Training Results in Rstudio:



```r
  hidden=c(3),
  epochs=200,
  variable_importances=T    ## not enabled by default
)

h2o.varimp_plot(m1)
h2o.rmse(m1)
h2o.auc(m1)

plot(m1)
h2o.logloss(m1, train = TRUE, valid = TRUE)



summary(m1)

print(m1)
h2o.confusionMatrix(m1)
h2o.mse(m1)
```

```
H2OBinomialMetrics: deeplearning
** Reported on training data. **
** Metrics reported on full training frame **

MSE:  0.09152066
RMSE:  0.3025238
LogLoss:  0.3152273
Mean Per-Class Error:  0.1119048
AUC:  0.9503401
AUCPR:  0.9502627
Gini:  0.9006803

Confusion Matrix (vertical: actual; across: predicted) for F1-optimal threshold:
        0  1    Error    Rate
```

## Validation Results in Rstudio:



```r
  hidden=c(3),
  epochs=200,
  variable_importances=T    ## not enabled by default
)

h2o.varimp_plot(m1)
h2o.rmse(m1)
h2o.auc(m1)

plot(m1)
h2o.logloss(m1, train = TRUE, valid = TRUE)



summary(m1)

print(m1)
h2o.confusionMatrix(m1)
h2o.mse(m1)

```

```
H2OBinomialMetrics: deeplearning
** Reported on validation data. **
** Metrics reported on full validation frame **

MSE:  0.06074898
RMSE:  0.2464731
LogLoss:  0.2345331
Mean Per-Class Error:  0
AUC:  1
AUCPR:  1
Gini:  1

Confusion Matrix (vertical: actual; across: predicted) for F1-optimal threshold:
       0 1    Error    Rate
0      7 0 0.000000    =0/7
```