



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكرو فيلم

بسم الله الرحمن الرحيم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكرو فيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكرو فيلم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



MONA MAGHRABY



EXTENDING THE APPLICATION OF SCS CURVE NUMBER METHOD TO BE USED WITH ANNUAL RAINFALL TO ESTIMATE ANNUAL DIRECT RUNOFF IN ARID REGIONS

By

Ayman Mohamed Mokhtar Ahmed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
IRRIGATION AND HYDRAULICS ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

**EXTENDING THE APPLICATION OF THE SCS CURVE
NUMBER METHOD TO BE USED WITH ANNUAL RAINFALL
TO ESTIMATE ANNUAL DIRECT RUNOFF IN ARID REGIONS**

By

Ayman Mohamed Mokhtar Ahmed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
IRRIGATION AND HYDRAULICS ENGINEERING

Under the Supervision of

Prof. Dr. Abdallah Sadik Bazaraa

Prof. Dr. Ayman G. Awadallah

.....
Professor of Irrigation and Drainage
Irrigation and Hydraulics Department
Faculty of Engineering, Cairo University

.....
Professor of Water Resources Engineering
Civil Engineering Department
Faculty of Engineering, Fayoum University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

**EXTENDING THE APPLICATION OF THE SCS CURVE
NUMBER METHOD TO BE USED WITH ANNUAL RAINFALL
TO ESTIMATE ANNUAL DIRECT RUNOFF IN ARID REGIONS**

By

Ayman Mohamed Mokhtar Ahmed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
IRRIGATION AND HYDRAULICS ENGINEERING

Approved by the
Examining Committee

Prof. Dr. Abdallah Sadik Bazaraa,

Thesis Main Advisor

Prof. Dr. Khaled H. Hamed,

Internal Examiner

Prof. Dr. Karima Mahmoud Attia,
(Professor Emeritus at National Water Research
Center (NWRC))

External Examiner

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

Engineer's Name: Ayman Mohamed Mokhtar Ahmed
Date of Birth: 01/01/1992
Nationality: Egyptian
E-mail: Aymanmokhtar92@gmail.com /
Ayman.Mokhtar@dar.com
Phone: 01224402714
Address: 2 Orkedia Resort Compound, Gezera St.,
5th Settlement, New Cairo, Egypt.
Registration Date: 01/03/2015
Awarding Date: / /2020
Degree: Master of Science
Department: Irrigation and Hydraulics Engineering



Supervisors:

Prof. Dr. Abdallah Sadek Bazaraa
Prof. Dr. Ayman G. Awadallah
(Professor of Water Resources Engineering, Faculty of Engineering,
Fayoum University)

Examiners:

Prof. Dr. Abdallah Sadik Bazaraa (Thesis main advisor)
Prof. Dr. Khaled H. Hamed (Internal examiner)
Prof. Dr. Karima M. Attia (External examiner)
(Professor Emeritus at National Water Research Center
(NWRC))

Title of Thesis:

Extending The Application of SCS Curve Number Method To Be Used With Annual Rainfall To Estimate Annual Direct Runoff In Arid Regions

Key Words:

Hydrology; Rainfall-Runoff Transformation; Soil Conservation Service (SCS); Curve Number; Arid Regions

Summary:

The SCS-CN runoff curve number method is one of the most popular rainfall-runoff transformation method. However, it is considered an event-based method, which creates a problem when the daily rainfall records are not available, and the annual rainfall values are the only available rainfall information. In this respect, this study aimed to propose an approach to provide reasonable estimates of annual direct runoff when daily rainfall records are unavailable. This would be done by developing relationships to relate the total annual rainfall to the runoff depths, using the same SCS-CN methodology and parameters, provided that the difference with the event-based method is tolerable. Study area was divided to 13 regions with their associated rainfall stations, SCS-CN method was applied to calculate the runoff depths using daily and annual rainfall records, then correlation and regression analysis (Simple linear and nonlinear) were used to develop the relationships between the total annual rainfall to the runoff depths at different CN values for each region. Finally, the performance of the developed relationships was evaluated by checking regression coefficients and applying other statistical validation tests on developed relationships.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Ayman Mohamed Mokhtar Ahmed

Date: / /2020

Signature:

Acknowledgments

First and foremost, thanks to Allah. I'm delighted to acknowledge all people who helped and encouraged me through my M.Sc. study.

I would like to express my gratitude and thank my supervisors, Prof. Dr. Abdallah Bazaraa and Prof. Dr. Ayman Awadallah, for their continuous guidance, help and support throughout my research. This research would not have been possible without the support of them.

I would also like to express my special thanks and sincere appreciation to my lovely parents, my sister, and my brother for their endless love, patience, support, and encouragement, without whom I would have never accomplished this study.

Table of Contents

DISCLAIMER	i
ACKNOWLEDGMENTS	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vi
LIST OF FIGURES	vii
NOMENCLATURE.....	x
ABSTRACT	xi
CHAPTER 1: INTRODUCTION	1
1.1 Background	1
1.2 Problem Definition.....	2
1.3 Study Objectives	2
1.4 Research Methodology.....	2
1.5 Organization of the thesis.....	3
CHAPTER 2: LITERATURE REVIEW	4
2.1 Introduction	4
2.2 Arid and Semi-Arid Regions.....	4
2.1 Hydrological Cycle and Water Balance	6
2.2 Evapotranspiration Process	8
2.3 Infiltration and Runoff Processes	9
2.4 Estimation of Design Runoff Depth and Volume	11
2.5 The SCS-CN Method Basis	11
2.6 Development of the SCS-CN Equation.....	12
2.7 Hydrologic Soil-Cover Complexes and Curve Number	17
2.8 Estimation of Annual Direct Runoff from Annual Rainfall.....	23
CHAPTER 3: DATA PREPARATION AND STUDY AREA	25
3.1 Study Area.....	25
3.2 Available Data and Data Screening	26
3.2.1 Introduction.....	26
3.2.2 Available Rainfall Records.....	26
3.2.3 Digital Elevation Model.....	35

CHAPTER 4: METHODOLOGY	36
4.1 Methodology Framework.....	36
4.2 SCS-CN Method	38
4.2.1 General.....	38
4.2.2 SCS-CN Method (Applied to Rainfall Event)	39
4.2.3 Extended SCS-CN Approach for Annual Rainfall Records (Approach for Annual Runoff Estimation)	41
4.3 Correlation.....	43
4.4 Regression Analysis	46
4.4.1 Simple Linear Regression (SLR)	46
4.4.2 Nonlinear Regression Analysis	52
4.5 Evaluation and Performance Criteria of the Regression Equations	53
4.5.1 Introduction.....	53
4.5.2 Significance	53
4.5.3 The Durbin Watson Test.....	54
4.5.4 The Nash–Sutcliffe Efficiency.....	55
4.5.5 The Mean Absolute Percentage Error (MAPE)	56
4.5.6 Root Mean Squared Error (RMSE)	56
4.5.7 Leave-One-Out Cross Validation	57
CHAPTER 5: PRESENTATION AND INTERPRETATION OF RESULTS.....	58
5.1 Introduction	58
5.2 Results for Each Region.....	59
5.2.1 ‘Asir Region.....	59
5.2.2 Jizan Region.....	64
5.2.3 Ha’il Region.....	68
5.2.4 Al-Qasseim Region.....	72
5.2.5 Al-Bahah Region	76
5.2.6 Al Jawf, Tabouk & Northern Regions	80
5.2.7 Makkah Region.....	84
5.2.8 Riyadh Region	88
5.2.9 Al-Madinah Region	92
5.2.10 Eastern Region	96

5.2.11 All Regions Compiled	100
CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS.....	105
6.1 Introduction	105
6.2 Summary	105
6.3 Conclusions	106
6.4 Recommendations for Future Research	108
REFERENCES	109
Appendix A: Estimated Runoff Values for Different Rainfall Stations	113

List of Tables

Table 2-1: Classification of Climatic Regimes According To Aridity Index (Φ)	9
Table 2-2: Hydrologic Soil Groups (HSG) For Different Soil Textures (Hawkins et al., 2009)	18
Table 2-3 : Runoff Curve Number For Hydrologic Soil Cover Complexes For Fully Developed Urban Areas (Vegetation Established) (USDA, 1986)	19
Table 2-4: Runoff Curve Number for hydrologic soil cover complexes for agricultural lands (USDA, 1986)	20
Table 2-5: Runoff Curve Number For Hydrologic Soil Cover Complexes For Agricultural Lands (USDA, 1986)- Continued	21
Table 2-6: Runoff Curve Number For Arid And Semi-Arid-Regions (USDA, 1986)	22
Table 3-1: Number of Rainfall Stations in Each Region	28
Table 3-2: Rainfall Stations Used in the Study	28
Table 4-1: Assumptions of linear regression model (Helsel and Hirsch, 2002)	48
Table 4-2: List of equations used in regression analysis (Helsel and Hirsch, 2002)	49
Table 5-1: Simple Linear Regression Analysis Results for ‘Asir Region	61
Table 5-2: Simple Linear Regression Analysis Results for Jizan Region	65
Table 5-3: Simple Linear Regression Analysis Results for Ha’il Region	69
Table 5-4: Simple Linear Regression Analysis Results for Al-Qasseim Region	73
Table 5-5: Simple Linear Regression Analysis Results for Al-Bahah Region	77
Table 5-6: Simple Linear Regression Analysis Results for Al Jawf, Tabouk & Northern Regions	81
Table 5-7: Simple Linear Regression Analysis Results for Makkah Region	85
Table 5-8: Simple Linear Regression Analysis Results for Riyadh Region	89
Table 5-9: Simple Linear Regression Analysis Results for Al-Madinah Region	93
Table 5-10: Simple Linear Regression Analysis Results for Eastern Region	97
Table 5-11: Simple Linear Regression Analysis Results for KSA	101
Table 5-12: The Developed General Equations for Each Region	104
Table 6-1: The Developed General Equations To Predict The Annual Direct Runoff Directly From The Total Annual Rainfall Using Any CN Value For Each Region	106

List of Figures

Figure 2.1: Arid and Semi-Arid Regions Distribution Map (Meigs, 1952)	5
Figure 2.2: The Hydrological Cycle (USDA, 1972).....	6
Figure 2.3: Water Balance Scheme.....	7
Figure 2.4: Evapotranspiration Ratio Curves Predicted By Budyko (1948)	8
Figure 2.5: Effect of watershed shape on the runoff peak discharge (NEH, 2004).....	10
Figure 2.6 : Horton's Overland Flow Mechanism for Surface Runoff.....	12
Figure 2.7: Rainfall-Runoff Depths Plot For 482 Rainfall Events in Nebraska (Hawkins et al., 2009)	13
Figure 2.8: Relationship between the Initial Abstraction (Ia) and the Potential Retention (S) (NRCS, 2004b)	15
Figure 2.9: Graphical Solution of the Runoff Equation $Q = (P - 0.2S)^2(P + 0.8S)$ (NRCS, 2004b)	16
Figure 3.1: Kingdom of Saudi Arabia Main Regions	25
Figure 3.2: Spatial Distribution of Rainfall Stations over the Study Area	27
Figure 3.3: ALOS 30m DEM for the Study Area.....	35
Figure 4.1: Methodology Framework	37
Figure 4.2: Monotonic (linear) correlation between X and Y (Helsel and Hirsch, 2002) ...	44
Figure 4.3: Monotonic (nonlinear) correlation between X and Y (Helsel and Hirsch, 2002).....	44
Figure 4.4: Non-monotonic relationship between X and Y (Helsel and Hirsch, 2002)	45
Figure 4.5: True linear relation between x and y , and 10 resultant measurements (Helsel and Hirsch, 2002)	47
Figure 4.6: 'Asir Region Linear Regression Equations at Different CN Values.....	51
Figure 4.7: Nonlinear Regression Equation for 'Asir Region	52
Figure 4.8: Cross Validation Schematic Idea	57
Figure 5.1: Rainfall Stations in 'Asir Region	59
Figure 5.2: 'Asir Region Regression Equations for Different CN Values	60
Figure 5.3: Regression Analysis between Coefficients (b_1) and CN.....	61
Figure 5.4: Box and Whisker Plots for the Regression Coefficients (b_1)	63
Figure 5.5: Rainfall Stations in Jizan Region	64
Figure 5.6: Jizan Region Regression Equations for Different CN Values	65

Figure 5.7: Regression Analysis between Coefficients (b_1) and CN	66
Figure 5.8: Box and Whisker Plots for the Regression Coefficients (b_1)	67
Figure 5.9: Rainfall Stations in Ha'il Region	68
Figure 5.10: Ha'il Region Regression Equations for Different CN Values	69
Figure 5.11: Regression Analysis between Coefficients (b_1) and CN	70
Figure 5.12: Box and Whisker Plots for the Regression Coefficients (b_1)	71
Figure 5.13: Rainfall Stations in Al-Qasseim Region	72
Figure 5.14: Al-Qasseim Region Regression Equations for Different CN Values	73
Figure 5.15: Regression Analysis between Coefficients (b_1) and CN	74
Figure 5.16: Box and Whisker Plots for the Regression Coefficients (b_1)	75
Figure 5.17: Rainfall Stations in Al-Bahah Region	76
Figure 5.18: Al-Bahah Region Regression Equations for Different CN Values	77
Figure 5.19: Regression Analysis between Coefficients (b_1) and CN	78
Figure 5.20: Box and Whisker Plots for the Regression Coefficients (b_1)	79
Figure 5.21: Rainfall Stations in Al-Jawf, Tabouk & Northern Regions	80
Figure 5.22: Al-Jawf, Tabouk & Northern Regions Regression Equations for Different CN Values	81
Figure 5.23: Regression Analysis between Coefficients (b_1) and CN	82
Figure 5.24: Box and Whisker Plots for the Regression Coefficients (b_1)	83
Figure 5.25: Rainfall Stations in Makkah Region	84
Figure 5.26: Makkah Region Regression Equations for Different CN Values.....	85
Figure 5.27: Regression Analysis between Coefficients (b_1) and CN	86
Figure 5.28: Box and Whisker Plots for the Regression Coefficients (b_1)	87
Figure 5.29: Rainfall Stations in Riyadh Region	88
Figure 5.30: Riyadh Region Regression Equations for Different CN Values	89
Figure 5.31: Regression Analysis between Coefficients (b_1) and CN	90
Figure 5.32: Box and Whisker Plots for the Regression Coefficients (b_1)	91
Figure 5.33: Rainfall Stations in Al-Madinah Region	92
Figure 5.34: Al-Madinah Region Regression Equations for Different CN Values	93
Figure 5.35: Regression Analysis between Coefficients (b_1) and CN	94
Figure 5.36: Box and Whisker Plots for the Regression Coefficients (b_1)	95
Figure 5.37: Rainfall Stations in Eastern Region	96