

SPACE-TIME MODELLING OF GROUNDWATER WITH ASSISTANCE FROM REMOTE SENSING

by

VIJAY KUMAR

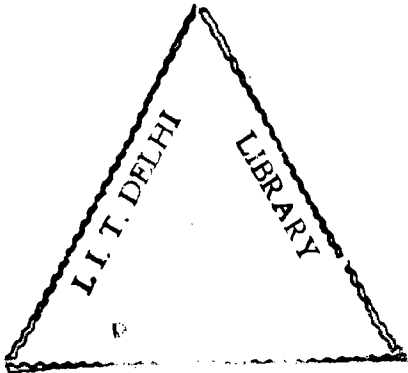
*Thesis submitted
in fulfilment of the requirements for
the award of the degree of
DOCTOR OF PHILOSOPHY*



Department of Civil Engineering
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA
JANUARY, 1996

TH
550.31
VIJ-S

I. I. T. DELHI
LIBRARY
Acc. No. TH-2404



CERTIFICATE

This is to certify that the thesis entitled "**SPACE-TIME MODELLING OF GROUNDWATER WITH ASSISTANCE FROM REMOTE SENSING**", being submitted by **VIJAY KUMAR** for the award of degree of **DOCTOR OF PHILOSOPHY**, is a record of the original bonafide research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of his thesis. The results presented in this thesis have not been submitted in a part or full to any other University or Institute for award of any degree/diploma.

Rema devi

(Dr. (Mrs.) Remadevi)
Associate Professor
Department of Civil Engineering
Indian Institute of Technology
New Delhi- 110 016

ACKNOWLEDGEMENTS

I express my deep sense of gratitude to Dr.(Mrs.) Remadevi, Associate Professor, Indian Institute of Technology Delhi, for her valuable guidance, keen interest and ever available help during this study.

I am grateful to Dr. S.M. Seth, Director, National Institute of Hydrology, Roorkee for giving the permission to continue my doctoral research as a part time student.

This study would not have been possible without the data supplied by the Command Area Development Authority, Government of Rajasthan. The help thus extended is fully acknowledged.

I am thankful to Dr. Arun Kumar, Professor, Delhi College of Engineering, Dr. G.C. Mishra, Scientist 'F', National Institute of Hydrology Roorkee and Dr. B.P. Parida, Assistant Professor, Indian Institute of Technology Delhi, for their constant encouragement during the study.

Thanks are also due to my valuable friends, Praveen, D.S. Khatri, Dheeraj, Atul, Pradeep, Harvinder, Yogender and Raj, who have made my life enjoyable in this world.

I am also thankful to my colleagues at IIT Delhi, especially Dr. Sandhya Rao, my colleagues at NIH, Roorkee and my friends, Anil, Pradeep, Irfan, Amarjeet, Janak, at University of Roorkee for their constant help.

My acknowledgement will be incomplete without a mention of my parents, brother, Bhabhi and sister, whose love and constant inspiration have helped me in all walks of my life.


(Vijay Kumar)

ABSTRACT

Water resources projects, which are often necessary to meet the demands of energy and agriculture, have often brought in some adverse environmental impacts while delivering the targetted benefits. One of the major environmental impacts associated with water resources projects, particularly with irrigation projects, is the rise in groundwater levels, which may lead eventually to waterlogging and perhaps to increased salinization as well. On the other hand, in some areas, where, there is over exploitation of groundwater for various purposes, the continuous depletion of groundwater may lead to lowering of groundwater levels well beyond recharge capabilities. Groundwater resource thus gets depleted and may result in eventual water scarcity. Thus, there exists a strong need to study the spatial and temporal behaviour of groundwater.

The measurement of groundwater level data is the simplest and most economical among the various other groundwater parameters. It is also widely used in the models available related to groundwater studies. In the near future also, groundwater levels are likely to be the major choice of input for estimation of groundwater.

The objectives of the thesis is to study the space-time behaviour of the groundwater levels and to explore its use with remote sensing techniques to provide mutually complementary and supplementary information so as to arrive at a more complete and reliable information base on groundwater behaviour.

To achieve the objectives of the study, spatial modelling techniques, namely inverse distance (which are widely used in hydrology) and geostatistical techniques are employed.

Temporal modelling is combined with spatial modelling to achieve space-time modelling. To delineate the water related features on the ground surface, remote sensing interpretation is carried out.

To apply and validate the adopted methodology, it is applied to model the behaviour of groundwater on a real life situation in the command area of a major irrigation project in the north-western part of India. Canal irrigation in this area has led to a general rise in water level of the aquifer in that area. The study area is a part of the desert area in the state of Rajasthan in India and has an areal extent of about 4500 sq km.

The results from the study show that groundwater levels are spatially related in the study area. The geostatistical techniques performed far better than the generally used techniques of inverse linear distance and inverse square distance in spatial modelling of groundwater levels. Also, this technique provides the information regarding the direction of flow of groundwater. Groundwater levels are found to be increasing continuously in most part of the study area. A genre of simple models are found to describe the behaviour of groundwater in the time domain. Spatial interpolation of forecast data using geostatistical techniques is found to be a promising approach towards space-time modelling of groundwater data. Results of the study also indicate the usefulness of remote sensing techniques for delineation of waterlogged areas.

CONTENTS

	Page No.
ABSTRACT	iv
LIST OF FIGURES	vi
LIST OF TABLES	x
LIST OF NOTATIONS	xii
CHAPTER I INTRODUCTION	1
1.1 General	1
1.2 Choice of Input for Estimation of Ground Water	3
1.3 Objectives of the Present Study	4
1.4 Layout of the Thesis	6
CHAPTER II METHODOLOGY	8
2.1 Introduction	8
2.2 Geostatistics	8
2.3 Time Series Analysis	10
2.4 Space-Time Analysis	12
2.5 Remote Sensing	13
2.5.1 Visual Interpretation	18
2.5.2 Digital Image Processing	19
2.6 Approach Adopted	21
CHAPTER III LITERATURE REVIEW	24
3.1 Introduction	24
3.2 Geostatistics	24

3.2.1	Groundwater	25
3.2.2	Soil Science	46
3.2.3	Other Areas	81
3.3	Remote Sensing	96
3.4	Conclusion	102
CHAPTER IV	AREA OF STUDY	103
4.1	Introduction	103
4.2	Study Area	103
4.2.1	Development of Irrigation	105
4.2.2	History of Rise of Ground Water Level	107
4.2.3	Climate	110
4.2.4	Topography	111
4.2.5	Soils	111
4.2.6	Geology	112
4.2.7	Hydrogeology	113
4.2.8	Cropping Pattern	113
CHAPTER V	RESULTS AND DISCUSSION	115
5.1	Introduction	115
5.2	Selection of Observation Data	116
5.3	Spatial Modelling	116
5.3.1	Area I	116
5.3.2	Area II	147
5.3.3	Area III	170

5.3.4	Estimation of Ground Water Volume	191
5.4	Modelling in Time Domain	192
5.5	Space-Time Modelling	200
5.6	Remote Sensing	201
5.6.1	Selection of Data	202
5.6.2	Preliminary Identification of Features	205
5.6.3	Classification	206
5.6.4	Classified Images	209
5.7	Integration of Information on Groundwater	216
5.7.1	Illustration	217
5.7.2	Steps in Integration	221
5.8	Mutual support: Geostatistical modelling and remote sensing	240
CHAPTER VI	CONCLUSIONS	243
6.1	Introduction	243
6.2	Spatial Modelling	244
6.3	Temporal Modelling	247
6.4	Space-Time Modelling	247
6.5	Remote Sensing	248
6.6	Scope of Application	249
6.7	Specific Contributions	250
6.8	Scope for Further Research	251
REFERENCES		252