CERTIFICATE

It is certified that the work contained in the thesis titled ***"Aquifer modeling in and around, Varanasi, India"*** by "SHIWANSHU SHEKHAR" has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D. Degree.

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DECLARATION BY THE CANDIDATE

I, ***Shiwanshu Shekhar***, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of ***Dr. Medha Jha*** from July-2014 to December-2021, at the ***Department of Civil Engineering,*** Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma.

I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc, reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

Date : Signature of the Student

Place: Varanasi **(Shiwanshu Shekhar)**

CERTIFICATE BY THE SUPERVISORS

It is certified that the above statement made by the student is correct to the best of my/our knowledge.

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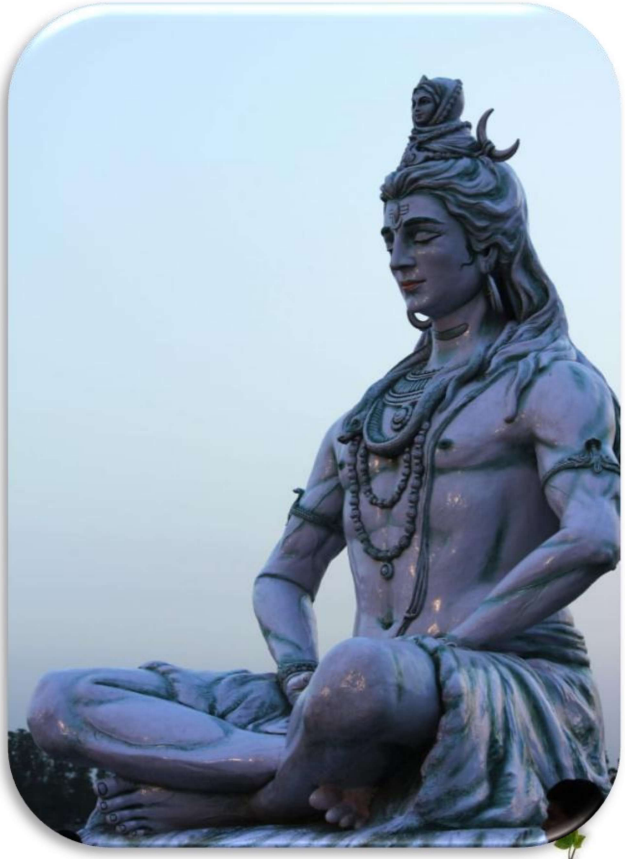
Dedicated

to

My Maa, Papa and Bhaiya

for

Always loving me and supporting me



Har Har Mahadev

ACKNOWLEDGEMENT

At the very outset, I would like to express my heartfelt gratitude and indebtedness to my research supervisor **Dr. Medha Jha**, Department of Civil Engineering, IIT (BHU) to guide me well throughout the research work. Her immense knowledge, motivation and patience have given me more power and spirit to excel in the research writing. Conducting the academic study regarding such a difficult topic couldn't be as simple as she made this for me. She is my mentor and a better advisor for my doctorate study beyond the imagination.

Apart from my Supervisor, I won't forget to express the gratitude to **Prof. P.K.Singh Dikshit,** Head, Department of Civil Engineering, Indian Institute of Technology (BHU), Varanasi for the encouragement and motivation extended to me.

I am also pleased to say thank you to **Prof. Shyam Bihari Dwivedi** and **Dr. Rajesh Rai** who made my access simpler to the research facilities and laboratory and gave an opportunity to become part of their guidance. It wouldn't have been possible to conduct this research without their precious support. They all really mean a lot to me.

I would like to give special thanks to, **Dr. Anurag Ohri** and **Dr. Shishir Gaur** for their help and guidance.

I am highly obliged to **Dr. B.N. Singh** and **Dr. Ajai Srivastava** for their valuable suggestions and also help in thesis writing.

I have a deep sense of gratitude for all Teachers of the Department of Civil Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi, for their cooperation and inspiration

I would like to thank **Mr. Lalji, Mr. Ramanji Jha** of Hydraulics and W.R.E. Laboratory and also **Mr. Akhilesh Kumar Jaiswar,** Engineering Geosciences Laboratory for their help during my research work. I am also grateful to all laboratory staff and all supporting staff of the Department of Civil Engineering, Indian Institute of Technology (Banaras Hindu University) Varanasi, to help in this research work.

I am grateful to all the office staff and authorities of the Department of Civil Engineering, Indian Institute of Technology (Banaras Hindu University) Varanasi, for their kind help during my stay to complete the thesis work.

I would like to give special thanks to **Dr. Manvendra Singh Chauhan, Dr. Akash Priyadarshee, Dr. Padam Jee Omar, Dr. Ravi Prakash Tripathi, Dr. C.B.Rai, Dr. Atul Kumar Rahul, Dr.Nikita Shivhare and Nawnit Kumar,** for their help and guidance.Their immense support actually guided me to rectify numerous things that could create major challenges in the acceptance of my paper.

I would always remember my friends **Dr. Arunabh Pandey, Dr. Satyajit Mondal, Dr. Nitesh Gupta, Dr. Ravi Ranjan, Dr. Bablesh Jha, Manish Mandal, Rahul Singh, Bhupindra Singh Rana, Ankit Tevari, Ranveer Kumar, Nikhilesh Singh, Sandeep Maddheshiya ,Sujeet Kumar, Megha Patle, Saurav Sarkar, Surya, Dr. Satyajit Mondal , Satarupa Mitra, Kriti** and **Ketan Solanki** too for the fun-time we spent together, sleepless nights that gave us the courage to complete tasks before deadlines and for stimulating the discussions.

I am thankful to **Dr. Pallav Kumar, Mr. Ashish Kumar, Mr. Santosh Kumar, Mr. Pranav Kumar**, **Mr. Zia Hussain, Mr. Manoj Kumar, Mrs. Shivangi Mishra, Mr. Kumar Utkarsh, Mr. Rishi Kumar** and **Mr. Vijay Kumar,** Asst. Prof., Department of Civil Engineering, MIT, Muzaffarpur, Bihar, for their support, love, and suggestions for a better quality of work.

I would also like to thank **Sonali Kulkarni mam** who was my first mentor in engineering and guided me for this career.

I am also thankful to MHRD for providing financial assistance during my research work.

I would like to express my deep sense of gratitude to my Parents **Mrs.Usha Kiran** (Maa), **Sri Rajeshwar Chaubey** (Papa), **Mr. Himanshu Kumar** (my bhaiya), **Mr. Durgesh Mani Tevari** (in-law), **Nidhi** (Didi) and other family members, friends and relatives for their unwavering support and encouragement.

Lastly, but not the least thank to all those who help directly or indirectly for the completion of the present research work.

Lastly and above all, deeply grateful to the invisible yet present helping hands of **Lord Shiva (Mahadev), Lord Hanuman, Maa Saraswati and Maa Durga** for making my life full of meaning.

Date:

Place: Varanasi **(SHIWANSHU SHEKHAR)**

LIST OF FIGURES

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ABBREVIATIONS

ANN	Artificial Neural Network
ASCII	American Standard Code for Information Interchange
ASR	Aquifer storage recovery
CGWB	Central ground water board
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
ET	Evapotranspiration
FEM	Finite Element Method
GHAT African	Generalised intelligence control with Hybrid Ant colony-Buffalo Optimization
GIC	Generalised intelligence control
GLCF	Global Land Cover Facility
GMS	Groundwater Modelling Software
GP	Genetic Programming
GPS	Global Positioning System
GW	Groundwater
HAC-ABO	Hybrid Ant colony- African Buffalo Optimization
HRU	Hydrological Response Unit
IMD	India Meteorological Department
LULC	Land Use Land Cover
MAR	Managed aquifer recharge
Mha-m	Million hectares meter
MLP-WA	Multilayer perceptron whale algorithm model
MLR	Multiple linear regression

MO	Monsoon
MSL	Mean Sea Level
RBF	River Bank Filtration
RBF-WA	Radial basis function-whale algorithm
SOI	Survey of India
SRTM	Shuttle Radar Topography Mission
SUFI-2	Sequential Uncertainty Fitting version 2
SWAT	Soil and water assessment tool
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WE-GREM	Water enabled groundwater recharge estimation model
WRIS	Water Resource Information System

CONTENTS

PREFACE

The Groundwater is a significant natural resource for several uses, such as domestic industrial, and irrigation purposes. It might be stated that its use offers a number of advantages as compared to the surface water. Groundwater reservoirs do not suffer seepage losses like surface reservoirs. Besides, evapotranspiration losses in the groundwater reservoir are minimum. It could be developed quickly and near the place of use.

However, there is plenty of water on the earth surface, the supply of fresh water is limited. That is why it is essential to have a ground water reservoir. Keeping in view of this, management of groundwater is required much as the needs for the water resources are increasing day by day. Its management calls for proper and systematic monitoring of level; which fluctuates with time and space. No doubt, groundwater is an important source of water for several purposes in the country at present. Groundwater caters for about 40% of the gross irrigated area in our country. The role of groundwater is all the more important in Ganga basin, which has a vast reservoir of groundwater, replenished every year at a very high rate. The Indo-Gangetic aquifer is one of the world's most valuable transboundary water resources, as well as the world's most frequently used aquifer. About 45% of the total countries resource is located in the Ganga basin alone. Within the basin, the gross annual groundwater recharge has been estimated to be to 212.8 million cubic metres and the exploitable resource comes 149 billion cubic metres per annum. In some areas of the alluvial region, especially in the upper and middle gangetic plain, groundwater is being too heavenly drawn upon, causing grave concern.

Varanasi, a millennia old city and an important city lying in the middle Ganga plain has been chosen for aquifer modelling in order to acquaint with state-of -the-art of groundwater level, its budget and yield capacity. Because of diminishing recharge and expanded interest in groundwater, it is very important to analyse the groundwater level. Estimation of groundwater recharge rate is a fundamental requirement for the proficient management of the groundwater resources and is specifically vital in the area and semi-arid sites where those assets are frequently the way to the financial growth. Excessive removal of groundwater to cater the need of ever growing population in the area chosen has resulted in the land subsidence in past causing a decline of water head. Permanent decline in the water table has been observed due to excessive groundwater withdrawal in the city of Varanasi, the lowering of groundwater has been 7 feet (213 cm) approximately in the preceding years.

In the present study daily meteorological data from the year 1996 to 2020, Digital elevation model (DEM), Soil lithology and Landsat 8 satellite data, Arc-GIS, SWAT-CUP and MATLAB were employed. Besides, the flow of groundwater in the study area covering 293 km^2, has been discussed with the help of GMS-MODFLOW (a widely use Groundwater modelling Tool). The study focused on the groundwater level head fluctuation, identifying the water status in entire study area. Primarily, the locations of wells in the area have been identified with the use of differential global positioning system (DGPS).The investigation of the watershed has been performed in the modelling process. Data from IMD has been taken as input and validation. Arc-GIS SWAT software was used to perform the hydrological analysis. After, the SWAT analysis of the area, MODFLOW software has been used for assessing the water budget scenario. Further, the groundwater levels of the Varanasi wells were measured during

the years from 1996 to 2019 that could be employed for training and testing. Hence, the novel GIC (Generalised intelligence control) with HAC-ABO (Hybrid Ant colony-African Buffalo Optimization) termed as GHAT was developed for forecasting the groundwater level in wells during Post and Pre-monsoon season. The GIC model is used for training the dataset to the MATLAB and the parameters of HAC-ABO model is combined with the GIC classification layer for forecasting the groundwater level and enhancing the performance. A prediction for the groundwater status for next 30 years has been drawn from the present study. So, the proposed approach predicts the groundwater level for next 30 years. Also, it attained high prediction accuracy and lower error rate than other models. The MODFLOW framework and artificial recharge system is broadly explained in fifth and seventh chapters.

In addition to above, an inventory of ponds and water bodies, an important source of groundwater reservoir has been made with utmost interest and passion .The ponds and its ecosystem have come under great pressure in the recent year due to unbridled organisation and encroachment of its surrounding lands. Out of the 118 ponds and tanks in the city the records of 39 are missing in the documents of the Nagar Nigam. As the city is suffering a severe water crisis, Ponds need to be developed. On the basis of these findings, suggestions for sustaining and augmenting the groundwater level in the city have been made, which could prove a milestone in the overall development process as envisaged by the government and also in the path of shaping this millennia old city as a ‘Smart City’.