

**ADAPTATION TO CLIMATE CHANGE IMPACTS AT FARM LEVEL
USING SWAT AND APEX MODEL**

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INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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**ADAPTATION TO CLIMATE CHANGE IMPACTS AT FARM LEVEL
USING SWAT AND APEX MODEL**

by

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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy
to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCTOBER, 2018

Certificate

This is to certify that the thesis entitled "**Adaptation to climate change impacts at farm level using SWAT and APEX model**" being submitted by **Rajesh Kumar Rai** to the Department of Civil Engineering, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is a bonafied research work carried out by him under my supervision and guidance. The thesis work in my opinion has reached the requisite standard, fulfilling the requirements for the said degree.

The results contained in this thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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Acknowledgements

Thesis could not exist without the generous support from guide. I am very grateful to **Prof. Ashvani Kumar Gosain** for valuable analysis and criticism.

I wish to thank Evelyn Steglich and Prof. Raghavan Srinivasan (TAMU, US), Dr. Krishna Reddy Kakumanu (IWMI, India), and Prof. Rakesh Khosa (IITD, India).

I acknowledge that the research project was fully sponsored by CLIMAWATER project (Ref: FT/011/050/2009). All contributions from third persons are kindly acknowledged.

I am grateful to my family (father, mother, siblings, my wife Shashikala Rai, my son Shivam Rai, and my daughter Angel), who have provided me through moral and emotional support in my life. I am also grateful to my friends Chakresh Sahu, Nagraj Patil, Duni Chand Thakur, Shobhit Pipil, Anupriya Patel, Harsha Yadav and Satish Kumar who have supported me along the way. I would like to thank all the staff members who were always supportive such as Amit Bundela ji, Rajveer Aggarwal ji, and Tikka Ram ji.

Rajesh Kumar Rai

Abstract

This study aimed to reveal that the computer simulation models play an important role in watershed management and decision making. The SWAT (Soil and Water Assessment Tool) model has been used for the hydrologic (watershed level) simulation and APEX (Agricultural Policy/Environmental eXtender) model has been used for crop growth and irrigation simulation (farm level). Both models have been used to simulate crop water requirement in field condition, but at different scales. To achieve this task the SWAT and the APEX models have been used in GIS (Geographical Information Systems) framework.

The SWAT agro-hydrological simulation have been done for stream water quality and quantity analysis. As it has been found that the upstream water affects the agriculture at downstream by washing out the chemicals and mixing it to the downstream farm and loading the stream with many complex chemical contaminants. A model approach have been used to assess the impact on stream water quality and quantity and future projections have been done using PRECIS (Providing REgional Climates for Impacts Studies) climate model and IPCC (Intergovernmental Panel on Climate Change) futuristic SRES (Special Report on Emissions Scenarios) scenario.

The economic condition of farmers are affected by the crop yield and total crop production. In Indian purview, most farmers have small land-holdings (marginal farmers) and are dependent on weather that in turn have an impact on the crop yield. It is obvious that weather plays an important role in determination of farmer's economy. Therefore, APEX model has been used for farm simulations from economic point of view, and simultaneously, future projections have been done to analyse farm economy at field level.

The study focuses on 1) to develop the watershed and farm scale integrated hydrological model of the Manjira sub-basin, Andhra Pradesh, India, 2) to develop an intelligent agricultural system for a reliable agricultural advisory services based on agro-hydro-climatic indicators, easy to obtain, and representative of the spatial and temporal variation in constituent parameters, 3) to quantify the climate change impact on stream water quality and quantity, and 4) to project the economic impacts of climate change on farm level agriculture using climate change scenarios.

The major findings of the study may be summarized as: a) it was possible to save 317.5 mm of water in Kharif season and 726.8 mm in Rabi season by exercising model derived irrigation schedule. The model has shown that irrigation schedule could be drastically improved with real time weather data becoming available. b) The model is able to simulate the crop yield very satisfactorily. The observed and simulated Paddy yield ($t\ ha^{-1}$) are found to be as 4.2 and 4.24 for Kharif season; and 5.2 and 5.22 for Rabi season, respectively. c) The impact and adaptation measures have been suggested for farmers who are mainly dependent on rain-fed agriculture and are highly affected by factors such as shift in planting dates, duration of crop growth, plant spacing and many more. d) The impact of the climate change on the mean monthly stream flow of the study area with respect to the baseline flow of $44.35\ m^3\ s^{-1}$ has been quantified as 57.04 for mid-century, and $36.87\ m^3\ s^{-1}$ for end-century.

Keywords: SWAT model, APEX model, Agricultural advisory services; Water management, Farm economics

सार

इस अध्ययन का उद्देश्य यह खुलासा करना है कि कंप्यूटर सिमुलेशन मॉडल वाटरशेड प्रबंधन और निर्णय लेने में एक महत्वपूर्ण भूमिका निभाते हैं। स्वाट (मृदा और जल आकलन उपकरण) मॉडल का उपयोग हाइड्रोलोजिक (वाटरशेड लेवल) सिमुलेशन और एपेक्स (कृषि नीति / पर्यावरण एक्स्टेंडर) मॉडल के लिए किया गया है, जिसका उपयोग फसल विकास और सिंचाई सिमुलेशन (कृषि स्तर) के लिए किया गया है। दोनों मॉडलों का इस्तेमाल क्षेत्र की स्थिति में फसल/जल की आवश्यकता को अनुकरण करने के लिए किया गया है, लेकिन विभिन्न पैमाने पर। इस कार्य को प्राप्त करने के लिए जी. आई. एस. (भौगोलिक सूचना प्रणाली) ढांचे में स्वाट और अपैक्स मॉडल का उपयोग किया गया है।

स्वाट कृषि सिमुलेशन द्वारा जल गुणवत्ता और मात्रा विश्लेषण के लिए किया गया है। जैसा कि यह पाया गया है कि धारा-विरुद्ध पानी रसायनों को धोकर और अनुप्रवाह फार्म में मिलाकर और कई जटिल रासायनिक दूषित पदार्थों के साथ प्रवाह भार करके अनुप्रवाह पर कृषि को प्रभावित करता है। धारा जल गुणवत्ता और मात्रा पर प्रभाव का आकलन करने के लिए एक मॉडल दृष्टिकोण का उपयोग किया गया है और भविष्य के अनुमान प्रेसिस (प्रभाव अध्ययन के लिए क्षेत्रीय क्लाइमेट्स प्रदान करना) जलवायु मॉडल और आईपीसीसी (जलवायु परिवर्तन पर अंतर सरकारी पैनल) भविष्यवादी एस. आर. ई. एस. (उत्सर्जन परिदृश्य पर विशेष रिपोर्ट) का उपयोग करके किया गया है।

किसानों की आर्थिक स्थिति; फसल, उपज और कुल फसल उत्पादन से प्रभावित होती है। भारतीय सीमा में, अधिकांश किसानों के पास छोटे भूमि-अधिग्रहण (सीमांत किसान) होते हैं और मौसम पर निर्भर होते हैं, जो बदले में फसल उपज पर असर डालते हैं। यह स्पष्ट है कि किसान की अर्थव्यवस्था के निर्धारण में मौसम एक महत्वपूर्ण भूमिका निभाता है। इसलिए, एपेक्स मॉडल का उपयोग आर्थिक सिमुलेशन से कृषि सिमुलेशन के लिए किया गया है, और साथ ही, क्षेत्रीय स्तर पर कृषि अर्थव्यवस्था का विश्लेषण करने के लिए भविष्य के अनुमान लगाए गए हैं।

अध्ययन 1) मंजिरा उप-बेसिन, आंध्र प्रदेश, भारत के वाटरशेड और फार्म स्केल एकीकृत हाइड्रोलॉजिकल मॉडल को विकसित करने के लिए 2) कृषि-जल-जलवायु संकेतकों के आधार पर एक विश्वसनीय कृषि सलाहकार सेवाओं के लिए एक बुद्धिमान कृषि प्रणाली विकसित करना , जो की प्राप्त करने में आसान हो, और घटक पैरामीटर में स्थानिक और लौकिक भिन्नता के प्रतिनिधि हो, 3) धारा जल गुणवत्ता और मात्रा पर जलवायु परिवर्तन प्रभाव को मापने के लिए, और 4) जलवायु परिवर्तन का उपयोग कर कृषि स्तर पर जलवायु परिवर्तन के आर्थिक प्रभावों को प्रोजेक्ट करने के लिए परिदृश्यों पर आधारित हो।

अध्ययन के प्रमुख निष्कर्षों को संक्षेप में सारांशित किया जा सकता है: अ) खरीफ सीजन में 317.5 मि.मी. पानी और मॉडल व्युत्पन्न सिंचाई कार्यक्रम का उपयोग करके रबी सीजन में 726.8 मि.मी. बचा सकता है। मॉडल ने दिखाया है कि वास्तविक काल मौसम तथ्य उपलब्ध होने के साथ सिंचाई कार्यक्रम में काफी सुधार किया जा सकता है। ब) मॉडल फसल उपज को बहुत संतोषजनक ढंग से अनुकरण करने में सक्षम है। खरीफ सीजन के लिए प्राप्त और अनुकृत धान उपज (टन प्रति हेक्टेयर) 4.2 और 4.24 के रूप में पाया जाता है; और रबी मौसम के लिए 5.2 और 5.22 क्रमशः (टन प्रति हेक्टेयर) | स) उन किसानों के लिए प्रभाव और अनुकूलन उपायों का सुझाव दिया गया है जो मुख्य रूप से बारिश से कृषि पर निर्भर हैं जैसे रोपण की तारीखों में बदलाव, फसल की वृद्धि की अवधि, पौधे की दूरी और कई अन्य कारकों से प्रभावित होते हैं। द) 44.35 घन मीटर प्रति सेकेंड के बेसलाइन प्रवाह के संबंध में अध्ययन क्षेत्र के औसत मासिक धारा प्रवाह पर जलवायु परिवर्तन का प्रभाव मध्य शताब्दी के लिए 57.04 के रूप में और अंततः सदी के लिए 36.87 घन मीटर प्रति सेकेंड के रूप में प्रमाणित किया गया है ।

कीवर्ड: स्वाट मॉडल, एपेक्स मॉडल, कृषि सलाहकार सेवाएं; जल प्रबंधन, कृषि अर्थशास्त्र

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Acronyms and Abbreviations

APEX	Agricultural Policy/Environmental eXtender
ArcAPEX	APEX model with ArcGIS framework
ArcGIS	ESRI's software of geographic information system
ArcSWAT	SWAT model with ArcGIS framework
CACP	Commission for Agricultural Costs and Prices
CGWB	Central Ground Water Board
CRRRI	Central Rice Research Institute
CWC	Central Water Commission
DEM	Digital Elevation Model
DES	Directorate of Economics and Statistics
EPA	Environmental Protection Agency
EPIC	Environmental Policy Integrated Climate (Originally—Erosion Productivity Impact Calculator)
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organisation
GHG	Green House Gases
GIS	Geographic Information System
GLCF	Global Land Cover Facility
GPS	Geographic Positioning System
HadCM3	Hadley centre Coupled Model, version 3
IITD	Indian Institute of Technology Delhi
IITM	Indian Institute of Tropical Meteorology
IMD	India Meteorological Department

IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
MSP	Minimum Support Price
NAAS	National Academy of Agricultural Sciences
NIPCC	Non-governmental Panel on Climate Change
NSE	Nash-Sutcliffe Efficiency coefficient
NWDA	National Water Development Agency
PRECIS	Providing REgional Climates for Impacts Studies
SRES	Special Report on Emissions Scenarios
SRTM	Shuttle Radar Topography Mission
SWAP	Soil-Water-Air-Plant
SWAPP	SWAT-APEX Programme
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT-Calibration and Uncertainty Procedures
TAMU	Texas Agricultural and Mechanical University
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WRIS	Water Resources Information System