HYDROLOGICAL MODELLING USING APEX MODEL FOR AN EXPERIMENTAL AGRICULTURAL WATERSHED IN UPPER YAMUNA BASIN

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by

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CERTIFICATE

This is to certify that the thesis entitled, **"HYDROLOGICAL MODELLING USING APEX MODEL FOR AN EXPERIMENTAL AGRICULTURAL WATERSHED IN UPPER YAMUNA BASIN"** being submitted by **Mr. Ghanshyam Agrawal** to the **Indian Institute of Technology Delhi** for the award of the degree of **DOCTOR OF PHILOSOPHY**, is a record of bona fide research work carried out by him under our supervision and guidance. This thesis work, in my opinion, has reached the standard, fulfilling the requirement of DOCTOR OF PHILOSOPHY degree. The research report and the result presented in this thesis have not been submitted, in part or in full, to any other university or institute, for the award of any degree or diploma.

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ABSTRACT

Land and water are the precious natural resources that are essential for the existence of life. The management of these resources has become most crucial and simultaneously difficult to manage. The development and management of water resources require thorough understanding of basic hydrologic processes and simulation capabilities at a watershed level. An accurate understanding of the hydrological behavior of a watershed is important for effective management. Various hydrological models have been developed to predict runoff, soil loss, and nutrient losses from agricultural watersheds ranging from plot level to basin level. APEX (**A**gricultural **P**olicy/**E**nvironmental e**X**tender) model is one of them which has the capability to model the watershed at both plot and field scale effectively and efficiently.

The overall goal of the present study was to understand various hydrological processes at field or micro watershed level and applicability of APEX model in Indian scenario for simulating runoff, sediment and crop yields and validating them through field experimentation at local level and to study the available hydrologic processes and highlight the shortcomings of the model.

An experimental agricultural watershed at Dr Y S Parmar University of Horticulture & Forestry was selected under the present study. The study area has an area of 0.4 ha in the Research Farm, Department of Soil Science and Water Management, College of Forestry, Dr Y S Parmar University of Horticulture and Forestry, Nauni – Solan, Himachal Pradesh – India. The historical meteorological data and comprehensive information on land and crop management practices for crops grown in the study area were collected for preparing APEX model input files. The various laboratory and field experiments were conducted to determine the accurate values of soil properties of different soil layers to provide the soil properties input values in the

APEX model and also to categorize the soil productivity class of the experimental agricultural watershed.

The soil of experimental agricultural watershed was categorized sandy clay loam at surface and loam at subsurface layer, medium quality soil structure, ideal bulk density, neutral pH, normal EC, medium to high SOC, low to medium available N and available K, medium to high available P, medium CEC, high profile water storage capacity, moderate infiltration rate, moderately slow saturated hydraulic conductivity, erodible soil surface in nature. The physical health rating index (PRI) value for the experimental agricultural watershed was estimated as 0.9025. The experimental agricultural watershed was rated as Productivity Class I, which is very suitable for productive cultivation and capable to provide high yields of the crops grown in the watershed.

An experimental set up comprising a 90^0 V- notch was constructed and installed with an automatic stage level recorder at the outlet for measuring continuous discharge and taking runoff samples for estimating sediment yield from the experimental agricultural watershed. The continuous runoff and sediment yield data were measured during the rainy season from year 2015 to year 2021 for performing calibration and validation of the APEX model.

The mean rainy season rainfall, runoff, ratio of runoff to rainfall and soil loss were observed 732.29 mm, 161.68 mm, 21.99 percent and 2.68 t ha^{-1}, respectively during the entire study period from year 2015 to year 2021 for the experimental agricultural watershed, which is lower than permissible soil loss tolerance limit of the country.

The correlation equation between runoff (Y) and rainfall (X) as $Y = 0.5512X - 8.3443$ ($R^2 = 0.6994$), correlation equation between soil loss (Y) and rainfall (X) as $Y = 0.01X – 0.1594$ ($R^2 = 0.7018$) and correlation equation between soil loss (Y) and runoff (X) as $Y = 0.0164X - 0.0061$ ($R^2 = 0.8352$) were established for the experimental agricultural watershed.

The APEX model for simulating runoff, sediment yield and crop yield from the experimental agricultural watershed were calibrated for the period of year 2015 – 2018, while the model performance were evaluated by considering a validation period from year 2019- 2021. The water balance components for the experimental agricultural watershed were also simulated using APEX model.

The evaluation of model performance revealed that the APEX model performed very well at field scale for predicting surface runoff, soil loss and crop yields for calibration and validation periods for daily, monthly and seasonal time scales in the Indian perspective due to acceptable values of coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE), Pearson's Correlation coefficient (r), RMSE observations standard deviation ratio (RSR), Index of Agreement (d) and lower values of Percent Bias (PBIAS), Root mean square error (RMSE), Mean absolute error (MAE).

The calibrated and validated APEX model would be helpful to assess the effect of various prevailing land and water management practices on runoff, sediment and crop yield and would be beneficial in agricultural water management as well as various soil and water conservation practice in Indian scenario similar to the study area.

Keywords: APEX model, agricultural watershed, land management, water management, crop management, soil loss.

सारांश

भूमि और जल अनमोल प्राकृतिक संसाधन हैं जो जीवन के अस्तित्व के लिए अतिआवश्यक हैं। इन संसाधनों का प्रबंधन सबसे महत्वपूर्ण हो गया है और साथ ही साथ इनका प्रबंधन करना मुश्किल हो गया है। जल संसाधनों के विकास और प्रबंधन के लिए जलसंभरण (watershed) स्तर पर बुनियादी जल विज्ञान सम्बंधी प्रक्रियाओं और अनुकार क्षमताओं की गहन समझ की आवश्यकता है। प्रभावी प्रबंधन के लिए जलसंभरण के जल विज्ञान संबंधी व्यवहार की यथार्थ समझ महत्वपूर्ण है। प्लॉट स्तर से लेकर बेसिन स्तर तक कृषि जलसंभरों से जल अपवाह, मृदा हानि और पोषक तत्वों की हानि सम्बन्धी पूर्वानुमान के लिए विभिन्न जल विज्ञान सम्बंधी मॉडल विकसित किए गए हैं। APEX (कृषि नीति/पर्यावरण विस्तारक) मॉडल उनमें से एक है जिसमें प्लॉट और क्षेत्र स्तर दोनों पर प्रभावी और कुशलता से जलसंभरण को प्रतिरूपण करने की क्षमता है।

वर्तमान अध्ययन का समग्र लक्ष्य, क्षेत्र या सूक्ष्म जलसंभरण स्तर पर विभिन्न जल विज्ञान संबंधी प्रक्रियाओं को समझना और जल अपवाह (runoff), मृदा तलछट (sediment) और फसल पैदावार का अनुकरण करने के लिए भारतीय परिदृश्य में APEX मॉडल की प्रयोज्यता को समझना और स्थानीय स्तर पर क्षेत्र प्रयोगो के माध्यम से उन्हें सत्यापित करना और उपलब्ध जल विज्ञान संबंधी प्रकमो का अध्ययन करना प्रक्रिया और APEX मॉडल की कमियों को चिन्हांकित करना था।

वर्तमान अध्ययन के अंतर्गत डॉ वाई एस परमार उधानिकी और वानिकी विश्वविद्यालय में एक प्रयोगात्मक कृषि जलसंभरण का चयन किया गया था। एक 0.4 हैक्टेयर क्षेत्रफल का अध्ययन क्षेत्र अनुसंधान फार्म, मृदा विज्ञान और जल प्रबंधन विभाग, वानिकी महाविद्यालय, डॉ वाई एस परमार उधानिकी और वानिकी विश्वविद्यालय, नौणी, हिमाचल प्रदेश, भारत में लिया गया।

APEX मॉडल की आगत (इनपुट) फ़ाइलों को बनाने के लिए ऐतिहासिक मौसम संबंधी आकड़ें, अध्ययन क्षेत्र में उगाई जाने वाली विभिन्न फसलों के लिए प्रयोग में लाई गई सभी भूमि और फसल प्रबंधन संबंधी प्रक्रियाओं पर व्यापक जानकारी एकत्रित की गई। APEX मॉडल में विभिन्न मृदा परतो में मृदा गुणों की आगत मान प्रदान करने के लिए और प्रायोगिक कृषि जलसंभरण की मृदा उत्पादकता श्रेणी वर्गीकृत करने के लिए विभिन्न प्रयोगशाला और अध्ययन क्षेत्र में प्रयोग किए गए।

प्रायोगिक कृषि जलसंभरण की मृदा को सतह पर रेतीली चिकनी दोमट और उपसतह परत पर दोमट मिट्टी, मध्यम गुणवत्ता वाली मृदा संरचना, आदर्श थोक घनत्व (bulk density), उदासीन पीएच, सामान्य विधयुत चालकता (EC), मध्यम से उच्च मृदा जैविक कार्बन (SOC), निम्न से मध्यम उपलब्ध नाइट्रोजन (N) और उपलब्ध पोटेशियम (K), मध्यम से उच्च उपलब्ध फास्फोरस (P), मध्यम धनात्मक आदान प्रदान क्षमता (CEC), उच्च प्रोफ़ाइल जल भंडारण क्षमता, मध्यम रिसाव दर (Infiltration rate), मध्यम धीमी संतृप्त जलीय चालकता (hydraulic conductivity), प्रकृति में अपरदन योग्य मृदा सतह पाई गई। प्रायोगिक कृषि जलसंभरण के लिए भौतिक स्वास्थ्य श्रेणी सूचकांक (PRI) मान 0.9025 अनुमानित किया गया था। प्रायोगिक कृषि जलसंभरण को उत्पादकता वर्ग प्रथम का दर्जा दिया गया, जो उत्पादक खेती के लिए बहुत उपयुक्त है और जलसंभरण में उगाई जाने वाली फसलों की उच्च पैदावार प्रदान करने में सक्षम है।

प्रायोगिक कृषि जलसंभरण से निरंतर जल अपवाह को मापने और मृदा तलछट उपज को आंकलित करने के लिए जल अपवाह के नमूने लेने के लिए जलसंभरण निकास पर एक प्रायोगिक सेट स्थापित किया गया जिसमे की एक 90^0 V- नॉच (notch) का निर्माण किया गया और एक स्वचालित स्टेज लेवल रिकॉर्डर लगाया गया। APEX प्रतिरूप को अंशांकित (calibrated) एवं

सत्यापित (validated) करने के लिए वर्ष 2015 - 2021 में वर्षा ऋतु के दौरान सतत जल अपवाह और मृदा तलछट उपज के आकडे लिए गए।

प्रायोगिक कृषि जलसंभरण के लिए संपूर्ण अध्ययन अवधि वर्ष 2015 से वर्ष 2021 में मानसून के दौरान औसत वर्षा, जल अपवाह, जल अपवाह और वर्षा अनुपात एवं मृदा हानि क्रमश: 732.29 मिमी, 161.68 मिमी, 21.99 प्रतिशत एवं 2.68 टन प्रति हैक्टेयर आंकलित की गई, जो कि देश की अनुमेय मृदा हानि सहनशीलता सीमा से कम है।

प्रायोगिक कृषि जलसंभरण के लिए जल अपवाह (Y) एवं वर्षा (X) के बीच सहसंबंध समीकरण $Y = 0.5512X - 8.3443$ ($R^2 = 0.6994$), मृदा हानि (Y) एवं वर्षा (X) के बीच सहसंबंध समीकरण $Y = 0.01X - 0.1594$ ($R^2 = 0.7018$) और मृदा हानि (Y) एवं जल अपवाह (X) के बीच सहसंबंध समीकरण $Y = 0.0164X - 0.0061$ ($R^2 = 0.8352$) स्थापित किए गए।

प्रायोगिक कृषि जलसंभरण के लिए APEX मॉडल को जल अपवाह, मृदा तलछट उपज और फसल पैदावार मानों को अनुकरित करने के लिए अवधि वर्ष 2015 - 2018 के लिए अंशांकित किया गया जबकि मॉडल दक्षता का मूल्यांकन करने के लिए वर्ष 2019 - 2021 के लिए प्रतिरूप को सत्यापित किया गया। प्रायोगिक कृषि जलसंभरण के लिए APEX मॉडल का उपयोग करके विभिन्न जल संतुलन घटको के मानों को अनुकरित किया गया।

मॉडल दक्षता मूल्यांकन के लिए आंकलित की गई निर्धारण गुणांक (R^2), नैश स्ट्क्लिफ दक्षता (NSE), पियर्सन सहसंबंध गुणांक (r), मूल मध्य वर्ग त्रुटि प्रेक्षण मानक विचलन अनुपात (RSR), समझौता सूचकांक (d) के स्वीकार्य मानों और बायस प्रतिशत (PBAIS), मूल मध्य वर्ग त्रुटि (RMSE) और मुख्य शुद्ध त्रुटि (MAE) के निम्न मानों से पता चला कि भारतीय परिप्रेक्ष्य में APEX मॉडल ने क्षेत्र स्तर पर सतही अपवाह, मृदा हानि और फसल पैदावार मानों को बहुत अच्छे प्रकार से पूर्वानुमानित किया।

अंशांकित और सत्यापित APEX मॉडल जल अपवाह, मृदा तलछट उपज और फसल पैदावार पर विभिन्न प्रचलित भूमि और जल प्रबंधन तकनीकीयों के प्रभाव का आकलन करने में सहायक होगा और भारतीय परिप्रेक्ष्य में अध्ययन क्षेत्र के समरूप क्षेत्र में कृषि जल प्रबंधन के साथ- साथ विभिन्न मृदा एवं जल प्रबंधन तकनीकीयों में भी लाभदायक होगा।

कुंजीशब्द : APEX मॉडल, कृषि जलसंभरण, भूमि प्रबंधन, जल प्रबंधन, फसल प्रबंधन, मृदा हानि।

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ACRONYMS AND ABBREVIATIONS

Symbol	Definition
ACTMO	Agricultural Chemical Transport Model
ALMANAC	Agricultural Land Management Alternatives with Numerical Assessment Criteria
ANSWERS	Areal Non-point Source Watershed Environmental Response Simulation
APEX	Agricultural Policy/Environmental Extender
APEX-CUTE	Agricultural Policy Environmental eXtender Auto-Calibration and UncerTainty Estimator
ARM	Agricultural Runoff Management
AS	Aeration Stress
BD	Bulk Density
BGWS	Beginning Ground Water Surface
BMA	Bayesian Model Averaging
BMPs	Best Management Practices
BSW	Beginning Soil Water Content
Ca	Calcium
CEC	Cation Exchange Capacity
CHL	Distance from subarea outlet to most distant point of subarea
CI	Cumulative Infiltration
CN	Curve Number
COD	Chemical Oxygen Demand
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
Cu	Copper
d	Index of agreement
DAP	Di-Ammonium Phosphate

DDS-AU	Dynamically Dimensioned Search – Approximation of Uncertainty
DEM	Digital Elevation Model
DF	Difference in Error
DLAI	Fraction of growing season when leaf area declines
DMLA	Maximum potential leaf area index
DR	Dispersion Ratio
DTPA	Diethylene Triamine Penta Acetic Acid
EC	Electrical Conductivity
EI	Erosion Index
EPIC	Environmental Policy Impact Climate / Erosion Productivity Impact Calculator
ER	Erosion Ratio
ET	Evapo-Transpiration
EVRT	Evaporation from flow during routing
Fe	Iron
FGWS	Final Ground Water Surface
FSW	Final Soil Water Content
FYM	Farm Yard Manure
GIS	Geographical Information System
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
GLUE	Generalized Likelihood Uncertainty Estimation
GUI	Graphical User Interface
HI	Harvest Index
HRU	Hydrologic Response Unit
IBUNE	Integrated Bayesian Uncertainty Estimator

ICAR	Indian Council of Agricultural Research
IDSS	Integrated Decision Support System
IR	Infiltration Rate
IRG	Irrigation
IRGA	Irrigation Applied
IRLD	Irrigation Distribution Losses
ISSS	International Soil Science Society
K	Potassium / Erodibility Factor
KS	Potassium Stress
LAI	Leaf Area Index
MAE	Mean Absolute Error
MCMC	Markov Chain Monte Carlo
MCS	Monte Carlo Simulation
Mg	Magnesium
M ha	Million Hectare
mm	Millimetre
Mn	Manganese
MOP	Muriate of Potash
MUSLE	Modified Universal Soil Loss Equation
MWD	Mean Weight Diameter
MWHC	Maximum Water Holding Capacity
N	Nitrogen
Na	Sodium
NPP	National Pilot Project

NPS	Nonpoint Source Runoff
NRCS	Natural Resources Conservation Service
NS	Nitrogen Stress
NSE	Nash-Sutcliffe Efficiency
NTT	Nutrient Tracking Tool
OPV	Operation value
P	Phosphorus
PAWC	Plant Available Water Capacity
PBIAS	Percent BIAS
PCP	Precipitation
PD	Particle Density
PER	Percent error
PHU	Potential Heat Units
PRI	Physical health Rating Index
PRK	Percolation
PS	Phosphorus Stress
QDRN	Soluble nitrogen in drainage outflow
QGIS	Quantum Geographical Information System
QN	Nitrogen in runoff
QNW	Nitrogen in runoff from watershed
QRFN	Nitrogen in quick return flow
r	Pearson's Correlation Coefficient
R^2	Coefficient of Determination
RCHL	Distance of routing reach flowing through the subarea

RDF	Recommended Dose of Fertilizers
RMSD	Root Mean Square Deviation
RMSE	Root Mean Square Error
ROTO	Routing Outputs to Outlet
RS	Remote Sensing
RSFN	Soluble nitrogen yield in surface runoff
RSR	Root mean square error observations Standard deviation Ratio
RUSLE	Revised Universal Soil Loss
S	Sulphur
SCS	Soil Conservation Service
SHC	Saturated Hydraulic Conductivity
SMZ	Stream Management Zones
SOC	Soil Organic Carbon
SS	Salt Stress
SSI	Small Scale Irrigation
SSP	Single Super Phosphate
SUFI-2	Sequential Uncertainty Fitting -2
SW	Soil Water
SWAT	Soil and Water Assessment Tool
SWRRB	Simulator for Water Resources in Rural Basins
TBS	Minimum temperature for plant growth
TGA	Total Geographical Area
$t\ ha^{-1}\ yr^{-1}$	Tons per hectare per year
TN	Total Nitrogen

TOP	Optimal temperature for plant Growth
TP	Total Phosphorus
TS	Temperature Stress
TSS	Total Suspended Solids
USA	United States of America
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
VBA	Visual Basic for Applications
VFS	Vegetative Filter Strips
VSC	Variable Storage Coefficient
WA	Biomass energy ratio
WEEP	Water Erosion Prediction Project
WS	Water Stress
WSA	Watershed Area/ Water Stable Aggregates
WUE	Water Use Efficiency
WYLD	Water Yield
Zn	Zinc