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Developing of integrated model to evaluate the sustainability of climate smart and drought resilience agricultural adaptation technologies concerning water and food security in Australia

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Australia's climate change is apparent through increasing temperatures, unpredictable rainfall, and rising sea levels, reflecting worldwide patterns (Boulaire et al., 2025; Davamani et al., 2024; Gyanendra et al., 2022; IPCC, 2014). It greatly affects water resources, leading to water insecurity through a reduction in stream flow and a drop in groundwater levels by 1 m/year, as stream flow and groundwater recharge are largely dependent on yearly and seasonal rainfall (Mahdavi and Samani, 2024; BOM, 2023; Cook et al., 2022a; Maheshwari, 2021). Consequently, it increases drought and negatively impacts the agricultural system by diminishing crop yields, elevating pests and diseases, and lowering the average profits of farms (Paswan et al., 2024; Alexandra, 2022; CCA, 2023). It poses a considerable risk to land use alteration in the agricultural sector, including ongoing intensification of land use for farming, shifting agricultural areas, increasing desertification, and greater dependence on unsustainable farming practices (Jayaramu et al., 2024a, 2024b; Zhang et al., 2024; Mewett et al., 2013; Millar and Roots, 2012), which has become a primary factor in the rising agricultural water demand alongside the rapid growth of the population (Salim et al., 2024; Cook et al., 2022a; Maheshwari, 2021). Consequently, changes in climate and land use negatively affect the sustainability of water and food security in Australia (Sahoo et al., 2025; Mondal et al., 2025; Doble et al., 2024) due to a rising demand paired with diminishing water resource availability (both surface and groundwater) with increasing drought and desertification in cultivated area (CSIRO, 2024; Zhu et al., 2020; Zamanirad et al., 2018). This trend is evident in major iconic water resources and aquifers across Australia, including the Murray Darling River Basin, Lake Eyre Basin, Great Artesian Basin, Perth Groundwater, and Daly River Basin (Clark et al., 2025; BOM, 2023; Prasain, 2025; CSIRO, 2024; Smerdon et al., 2012) and land use changes on water quantity (stream flow, water yield, recharge rate, depth, and storage yield) as well as an assessment of agricultural sustainability in relation to water and food security remain unclear (Prasain, 2025; Mondal et al., 2024; Mewett et al., 2013; Millar and Roots, 2012). In addition to this, there is a shortage of developing and implementing effective methodologies and models for combining demand-supply analysis to enhance the sustainability of agricultural systems regarding water and food security in the context of climate change and land use in Australia and globally (Davamani et al., 2024; Dao et al., 2024; Cook et al., 2022b; Al Atawneh et al., 2021). On this context, this paper focuses on to develop the effective integrating model that can be used for measuring of possible climate smart and drought resilience agricultural practices with considering sustainable water and food security under changing climate and land use scenarios of Australia.

A critical and comprehensive literature review has been conducted to evaluate and analyse modelling framework use in our topic by using the PRISMA-P framework and Double Diamond Approach for the selection of review and empirical research articles (1990-2025) which are sourced from Web of Science, Scopus, ScienceDirect, and Google Scholar. Finally, 875 (75 review and 800 empirical) articles have been selected for our review study. From this study, we classify this time period (1990-2025) such a that 1990s represented the era of foundational knowledge of the topic, the 2000s marked the introduction of climate and land use modelling and GIS tools to this research, the 2010s signified the emergence of integrated and coupled models, and the 2020s highlight the ascendancy of AI/ML/DL, use of big data for integrating of Crop models, MCDMs in to GSBMs for policy link, and use of hybrid models (SWBMS-HNMs, SWBMS/HNMs-WQBMs and hydro–crop-climate–land models) in sustainable use of water in agriculture by using climate smart and drought resilience agricultural practices. In this context, various Soil and Water Balance Models (SWBMs) combined with Hydrogeological and Numerical models (HNMs) like the SWAT-MODFLOW model (Tarkegn et al., 2025; Tezel et al., 2025; Feng et al., 2024; Ngo et al., 2024; Petpongpan et al., 2024), the WETSPASS-MF-OWHM model (Abdirahman et al., 2024; Abdissa and Chuko, 2024; Waiyasusri et al., 2024; Zarei et al., 2024), the SWAT-MODFLOW-WEAP model (Abbas et al., 2022; Dehghanipour et al., 2019; Moumane et al., 2021; Rhymee et al., 2024), and the SWAT-MODFLOW-GRACE-FO model (Sahoo et al., 2025; Dash et al., 2024; Hamdi and Goita, 2023) have been employed for assessing quantitative water supply metrics (stream flow, water yield, and groundwater storage). In a similar manner, the WEAP-MABIA model (Chapagain et al., 2025; Guan and Mascaro, 2023; Prasain, 2025; Rhymee et al., 2024), CROPWAT Model (Casella et al., 2019; Al-Najar, 2011), and ARIMA-ETS-NNAR model integrate with GIS (Rajballie et al., 2022) utilized for water demand analysis. Certain Crop Growth Simulation Models (CGSMs) such as DSSAT, APSIM, ABM, and AUACROP, integrated with SWBMs or HNM (Siad et al., 2019), including the Hydrus 1D-DSSAT model (Shelia et al., 2018), DSSAT-RZWQM model (Dokoohaki et al., 2016; Ma et al., 2006) , DSSAT-SWAP model (Dokoohaki et al., 2016), DSSAT-ABM model (Phetheet et al., 2021) and SWAT-MODFLOW-AQUACROP model (Mondal et al., 2025) were utilized to assess adaptive capacity, policy effectiveness, and agricultural system resilience through the simulation of crop growth, yield, and water needs. Techniques for Multi-Criteria Decision-Making (MCDM) like AHP, TOPSIS, EWM, and VIKOR (Paul and Roy, 2024; Mundetia et al., 2024; Yuan et al., 2024) are integrated with several groundwater vulnerability or sustainability assessment methods (Chandra and Sahoo, 2024, 2023; Bordbar et al., 2023) including the DRASTIC-AHP/TOPSIS/VIKOR model, GRACE-AHP/TOPSIS/EWM model, GLADI-AHP/TOPSIS/EWM model, AQUIVAL-AHP/TOPSIS model, and the SWAT-MODFLOW-WEAP-AHP/TOPSIS/VIKOR/EWM model (Paul and Roy, 2024; Mundetia et al., 2024; Hanifehlou et al., 2022) applied for evaluating water sustainability across various climatic and land use scenarios. These separate studies have shown the effectiveness of hydrological modelling (e.g., SWAT-MODFLOW), water demand simulation (e.g., WEAP-MABIA), crop modelling (e.g., DSSAT, APSIM), and decision-making tools (e.g., VIKOR). However, there is an absence of thorough and cohesive studies that merge these tools into one methodological framework. Additionally, prior studies inform us in developing a comprehensive integrated modelling framework that combines these tools (SWBMs, HNMs, CGSMs, and MCDMs) into a unified methodological structure by incorporating hydrological, agronomic, climate, land, and socio-economic elements to assess the long-term impacts of climate and land changes, trade-offs, and evaluate the effectiveness of climate-smart and drought-resilient agricultural adaptation technologies (Sahoo et al., 2019, 2020; Regmi and Paudel, 2024; Thottadi and Singh, 2024) regarding water and food security (Dzvene et al., 2025; Mondal et al., 2025; Salim et al., 2024; Ul Hasan et al., 2024; Zhang et al., 2024).

This research develops an innovative integrated models by the combination of **WETSPASS/SWAT-MODFLOW** (for water supply), **WEAP-MABIA** (for water demand), **DSSAT** (for agricultural productivity), and **VIKOR** (for sustainability ranking) to assess climate-smart and drought-resilient adaptation technologies in a comprehensive manner. It incorporates climate projections, land use dynamics, hydrological processes, and crop growth responses using the **Integrating Modelling Framework** in which the WETSPASS/SWAT-MODFLOW will use for quantifying groundwater and surface water availability, WEAP-MABIA will employ for assessing water demand for agriculture use, and WEAP-DSSAT-VIKOR will utilize for evaluating the sustainability of climate smart and drought adaptation technologies using MCDM tool. The Decision Support System for Agrotechnology Transfer (DSSAT) model is selected as the core crop simulation tool for this research due to its broad applicability, strong integration capabilities, and suitability for evaluating climate-smart and drought agricultural adaptation technologies (Sahoo et al., 2025; Chandra and Sahoo, 2023; Dokoohaki et al., 2016). DSSAT supports a wide range of crops commonly cultivated in Australia and is capable of simulating crop growth, yield, and water use under varying climate and land use scenarios. It has been widely used in conjunction with water management models like WEAP and decision-support tools like VIKOR, making it ideal for the integrated assessment framework adopted in this study. While APSIM, a model developed in Australia, offers robust capabilities for dryland and rotational cropping systems (Siad et al., 2019), DSSAT is preferred here for its interoperability, multi-crop flexibility, and established application in sustainability assessments involving both agronomic and hydrological parameters.

In conclusion, the integrating modelling framework has been developed to evaluate the sustainability of climate smart and drought resilience agricultural adaptation technologies concerning water and food security under changing climate and land use scenarios in Australia by achieving the following **Outputs:** creating GIS-based maps of 1. water availability, 2. water demand, and 3. crop yield potential; 4. developing sustainability zoning maps grounded in climate-smart and drought-resilient agricultural technology considering climate-land use change scenarios; and 5. formulating policy recommendations for climate-resilient agriculture.

Keywords: *Climate Change, Land Use Change, Climate Smart, Drought Resilience, Sustainability, Water Security, Food Security*

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