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RESEARCH ARTICLE

AGRICULTURAL SECTOR'S VULNERABILITY TO CLIMATE CHANGE AND VARIABILITY IN MACHAKOS COUNTY: A SYSTEMATIC REVIEW OF LITERATURE

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Abstract

Identifying the extent of exposure, agricultural systems' sensitivity, and adaptive capacity is essential in addressing agricultural vulnerability in an area and can lead to timely, appropriate, and effective adaptation strategies.Using the systematic literature review approach, this paper documented the vulnerability to climate change and variability of the agriculture sector in Machakos County, Kenya. The results revealed high exposure to climate change and variability, high sensitivity, and low adaptive capacity. With regard to exposure, a warming trend was observed in the County, while climate model outputs predicted enhanced warming and drying towards the end of the 21st century. Farming systemswerefound to be highly sensitive to impacts of climate change and variability, characterized by high incidences of drought, high rural population density, high percentage of smallholder farmers, and extremelyhigh susceptibility to land degradation. Adaptive capacity is generally low but depicted by substantial social capital and highly diversified agricultural production.

Introduction:-

It is now evident that climate change is real, and according to the Intergovernmental Panel on Climate Change (IPCC), 2018), the climate system will continue to warm. Climate change is generally predicted to have significant and extensive impacts, with differences in vulnerability and exposure to these impacts arising from non-climate stressors and multi-dimensional disparities (De Souza et al., 2015). The effects of climate change and variability will exceptionally be higher in developing countries that still rely heavily on agriculture and ecosystem services (Wunder et al., 2018; Myers et al., 2017). The agriculture sector, the primary source of livelihood for over 70% of the population in Africa, is considered one of the most sensitive sectors to climate change (Menike and Arachchi, 2016), contributing to the continent's high vulnerability to climate change and variability. The region's reliance on smallholder, rain-fed agriculture and its low adaptive capacity, especially the drought-prone arid and semi-arid areas, render the region particularly vulnerable to climate risks (Hallegatte et al., 2016; Hazell, 2019)

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Global warming will continue to altertemperatures, the intensity and duration of rainfall, and the frequency of droughts (World Bank, 2021). Increasing interseasonal variability and declining rainfall in the main rainy season have recently impacted agricultural production (World Bank, 2021; D'Alessandro et al., 2015). The agriculture sector in Kenya ispredominantly rain-fed and highly susceptible to climate variability and change and extreme weather events (D'Alessandro et al. 2015).Climate change risks,therefore,pose serious threats to Kenya’s sustainable agricultural production. Moreover, the vulnerability of agriculture to climate change is further associated with several factors, including farming activities in marginal areas, land degradation, inappropriate technology, low economic diversification, and poverty among smallholder farmers(GoK, 2019; Parry et al., 2012). These factors vary across the country; therefore, this variation suggests that vulnerability to climate change may vary substantially across different regions in Kenya.

A World Bank agricultural risk assessment in Kenya reported anincreasing vulnerability of the agriculture sector to risks, especially to extreme and growing weather variability (D'Alessandro et al., 2015).The country's arid and semi-arid counties, including Machakos County, are particularly vulnerable to the impacts of climate change and variability (GoK, 2018; Ringler et al., 2010).Similarly, a recent climate risk profile for Machakos County reported an increasing climate change risk to the agriculture sector in the County (MoALF, 2017). The available evidence, for instance, shows that climate change and variability impact about 60% of mixed smallholder farmers in Machakos County (Cleansens et al., 2012).

The sensitivity of the agriculture sector in Machakos Countyis worsened by higher population density due to its proximity to Nairobi, the country’s capital city, leading to a larger share of smallholder farmers, overreliance on rain-fed agriculture, and acute land degradation.The country’s adaptive capacity is impacted by the frequency of droughts, lower literacy rates, low incomes, and inadequate access to infrastructure. The County has yet to benefit from redressing the salient policy gaps for climate change but still relies on some national policies (MoALF, 2017). The national policy focuses on interventions at the national level, but there is a need for sufficient support at the local level (Souza et al., 2015).It is argued that macro-level vulnerability assessments may conceal extensive variability in lower-level exposure, sensitivities, and adaptive capacity (Coulibaly et al., 2015; IPCC, 2014).Local-level assessments of impacts and vulnerabilities are necessary for informing policy formulation to increase resilience and adaptive capacity among smallholder farmers.This study, thus,documented features of the climate-related vulnerability of the agriculture sectorto climate change and variability in Machakos County.

Methodology:-

Study area

Machakos County is located in the dry,arid, and semi-arid plains in lower eastern Kenya (Figure 1). The terrain in most of the County is relatively hilly, with some hills rising between 1800-2100m above sea level. Two permanent rivers, Tana and Athi, traverse the County (RoK, 2018; MoALF, 2017). The plains have well-drained, shallow, dark, and red clay soils. The plains receive less rainfall and are characterizedby open grasslands with scattered trees compared to the high altitudes, which receive high rainfall and are covered with dense vegetation (RoK, 2018).

The County receives a bimodal rainfall with short rains from October to December and long rains from March to May. The rainfall ranges between 500mm and 1250mm and is highly influenced by altitude, with higher areas receiving an average of 1000mm while lowlands receive 500mm. Rainfall in the County is unevenly distributed and unreliable. Temperatures range from 18 to 29 °C (Machakos County, 2015). The County is categorized into five agro-ecological zones (AEZs) based on the potential crop production suitability (Jaetzoldet al., 2010; MoALF, 2017); Upper midland (UM-2-3), U.M. 5-6, Midland (LM3), L.M. 4 and L.M. 5. The U.M. zones covering 2,730.2 km^2 have a higher potential for agriculture than lower midland zones covering 3,478 km^2 and are mainly occupied by agro-pastoralists and pastoralists.

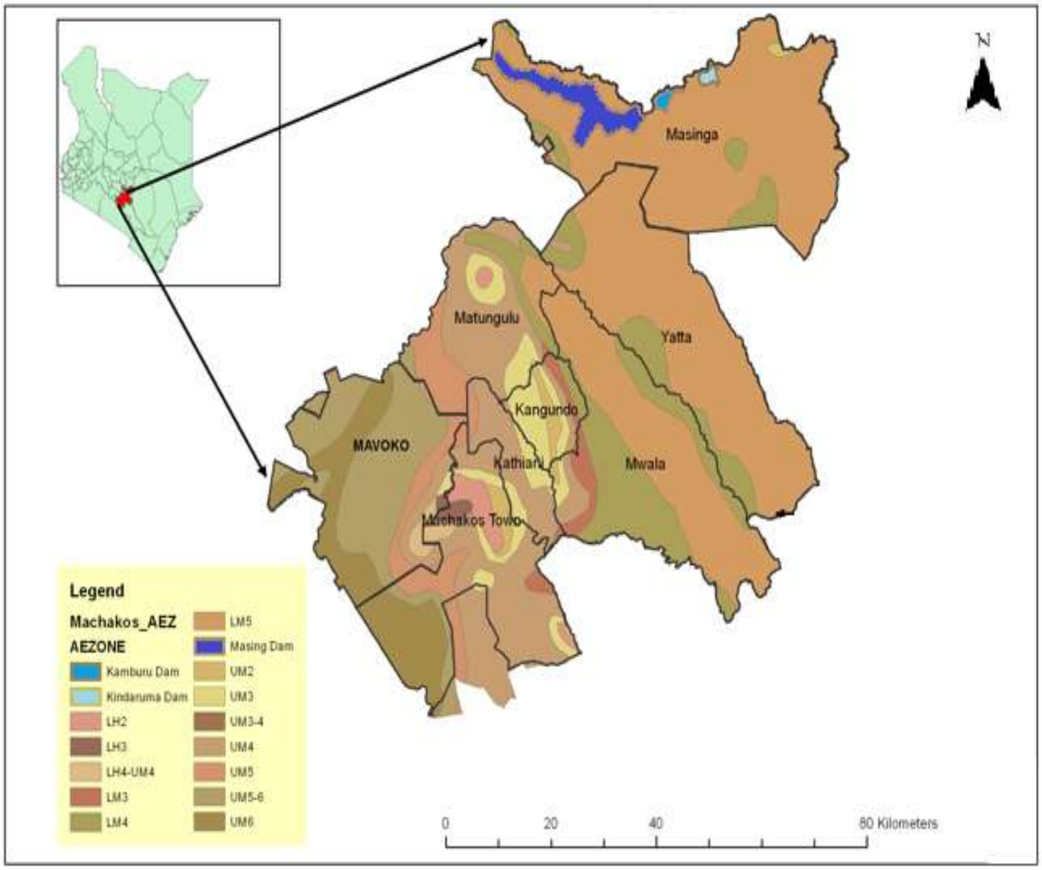

Figure 1:- Map of the study area (Source: Research generated from GIS).

Smallholder agriculture is integral to the County's livelihood and has recently been threatened by climate change and variability (RoK, 2018). Rain-fed mixed subsistence farming is the main economic activity. Cereals, such as maize,and drought-resistant crops, such as sorghum and millet, dominate the County's agriculture (RoK, 2018. The main livestock was cattle, beef, hair sheep, meat goats, and indigenous chicken (RoK, 2018). The County is generally dry, making rain-fed agriculture a challenge in most parts. The County also faces inadequate water for domestic use and crop and livestock production. Frequent droughts further aggravate the situation. Destruction of water catchment areas, persistent droughts, and destruction of existing earth dams and water pans are the primary causes of water insecurity. Similarly, unsustainable farming methods and pressure from the increasing population have led to the clearing of land initially reserved for the forest to create land for farming. According to NEMA (2009), the County has less than 2% forest cover.

Approaches to Vulnerability Assessment

The extent of agricultural vulnerability to physical climate risks in any given location is determined by a combination of factors (Ruane and Rosenzweig (2019). Measuring the agriculture sector's vulnerability to climate change impacts is necessary to increase the sector's resilience (Ezra, 2016). Vulnerability assessments identify the level of exposure, risks, and the risk management capacity of a specific region or group to climate change, help coordinate adaptation measures appropriately, and also help put in place supportive policy measures for smallholder farmers to respond to stressors and secure livelihoods under present conditions to reduce vulnerability to future climate change (Kumar, 2020; Carter et al., 2007; Smit and Wandel, 2006).

The existing literature indicates that vulnerability assessment has been performed at many levels, including regional, country, County, sub-county, community, household, or individual (IPCC, 2014; Deressa et al., 2009; Opiyo, 2016). Since impacts of climate change and variability are experienced at the local level, Thornton et al. (2006) advocate for local or sub-national level vulnerability assessment. With the possibility of substantial diversity in regional climate change impacts, farming systems, access to resources, and adaptive capacity, it is argued that macro-level assessments of vulnerability may conceal extensive variability in lower-level exposure, sensitivities, and adaptive capacity (Coulibalyet al., 2015; IPCC, 2014)

There are three major conceptual approaches to analysingvulnerability to climate change: the biophysical, socio-economic, and integrated assessment approaches. The biophysical or impact assessment approach mainly focuses on the biophysical effects of climate change that can easily be quantified or the physical impact of climate change on different attributes, such as yield and income (Fussel and Klein, 2006). Though helpful in assessing the level of damage that a given environmental stress may cause to social and biological systems, its major limitation is its inability to capture the complex dynamics of vulnerability. The socio-economic approach mainly concerns society's social, economic, and political aspects. It analyses what causes people to be vulnerable to natural hazards such as climate change and identifies the adaptive capacity of individuals or communities based on their internal characteristics. Finally, the integrated assessment approach combines biophysical and socio-economic attributes in vulnerability analysis (Fussel, 2007).

The econometric and indicator methods are the most commonly used methodological approaches in climate change research. The econometric method uses household-level survey data to analysethe level of vulnerability of different populations (Gbetibouo et al., 2010). The indicator method of quantifying vulnerability is based on selecting and combining some proxy indicators from a whole set of potential indicators to indicate the level of vulnerability (Fellman, 2012; Gbetibouo et al., 2010). This study adopted the integrated vulnerability assessment and the indicator method to document features of the climate-related vulnerability of the agriculture sector in Machakos County.

According to Fellman (2012), a common method to quantify vulnerability to climate change is using a set or composite of proxy indicators. Fellman points out that indicators can be used to 'measure' and characterisethe vulnerability of a system. Vulnerability assessment attempts to quantify the three components of vulnerability (exposure, sensitivity, and adaptive capacity) by identifying appropriate indicators, which include both biophysical for exposure and sensitivity, and socio-economic, mainly for adaptive capacity (Adger et al., 2004; Gbetibouo et al., 2010). Following an intensive review of previous literature (Hitayezuet al., 2014; Gbetibouet al., 2010; Deressa et al., 2008; Thornton et al., 2006), the indicators selected for the review and classified into three components either as exposure, sensitivity, or adaptive capacity following IPCC, (2007) definition as summarisedin the table below.

Table 1:- Selected indicators for assessing agricultural vulnerability to climate change.

Determinant/component of vulnerability	Indicators	Description of indicator
Exposure	Detected climate change; Temperature and Rainfall	Changes in current temperature and rainfall
	Global Circulation Model (GCM) projections	Long-term projection of future climate
Sensitivity	Frequency of droughts and floods	Frequency of droughts and floods
	Rural population density	The population density or people affected.
	Dependency of smallholders' on-farm income from crop and animal production	% of smallholder farmers whose primary source of livelihood is farming
	Share of smallholder farmers involved in farming	% of smallholder farmers engaged in farming
	Share of smallholder farmers with rain-fed farming	% of smallholder farmers practicingirrigation farming
	Land degradation	Degradation due to wind, water, or human-induced erosion
Adaptive capacity	Access to physical capital; Infrastructure	All-weather roads, telephone services, energy, and markets
	Access to physical assets	A mechanism that represents wealth, such as money/Income, savings, and credit
	Access to technical	Modern farming technology, including

	assistance/technology	ICT
	Human capital and social capital	Relationships, institutions that shape societal interactions
	Irrigation	Irrigation potential
	Enterprise diversification	Level of enterprise diversification

Source: Based on Gbetibouo et al. (2010)

Exposure refers to the changes in temperature and rainfall between the current conditions and the future projections and exposure to natural hazards, including droughts and floods. Current and projected climate trends denote the extent of exposure to climate change and variabilityof temperature, rainfall, droughts, and floods. Increasing temperature and declining rainfall adversely affect agriculture; therefore, an increase in temperature and decline in rainfall for the county point to exposure to climate change and variability.

The sensitivity of agricultural systems to climate change and variability is indicated by population density, which denotes the number of people who could be at climate risk, whereas the share of smallholder farmers generally signifies the associated socio-economic vulnerability to the form of small farm sizes, low capitalization, and technology adoption rates, and multiplicity of livelihood stressors, land degradation designates the quality of land, i.e., it's productivity and sustainability under climate change conditions and frequency of extreme climate events such as droughts and floods. According to Deressa et al. (2008), agriculture in areas prone to droughts and floods is more sensitive to climate change and variability in terms of yield reduction.

Physical capital indicates adaptive capacity, signifying relative access to services in times of climate crisis. Better access to physical capital implies better service provision. According to Thornton et al. (2008), access to the market means a more diversified income and high resilience to shocks, even with small-sized farms. Financial assets represent the economic diversification that reduces the susceptibility to climate change. Access to human capital signifies the relative availability and quality of labour to mitigate the effects of climate change, while social capital illustrates the relative access to social networks, such as membership in groupsto overcome the challenges associated with remoteness and isolation, such as access to information credit, and collective action, and availability of water for irrigation.

Irrigation signifies the resilience of smallholder farming systems. Enterprise diversification designates the advantages of variance in the effects of rainfall and temperature on diversified cropping patterns (Bradshaw et al., 2004). Diversification, particularly of cropping systems, increases agricultural productivity, yield stability, nutrition, and food security, reducing livelihood vulnerability to weather shocks (FAO, 2018; Mango et al., 2018). According to O'Brien et al. (2004), areas with better-developed infrastructure and availability of water for irrigation are projected to have a higher capacity to adapt to climate change and variability-related risks.

Systematic Literature Review Approach

In applying the indicator approach to vulnerability assessment, this study employed a systematic literature review to examine and document the extent of agricultural vulnerability in Machakos County. Systematic review literature is a methodology for analysingexisting knowledge related to a topic of interest in a rigorous, structured, and robust manner (Pearce et al., 2011; Ford et al., 2011). It is also viewed as a focused literature review that seeks to answer specific research questions using standardisedtechniques and explicitly outlined methods' (Kilroy 2015). Systematic reviews are increasingly used to address environmental-related research questions (Berrang-Ford et al., 2015; Ford et al., 2014; Pearce et al., 2011).

This review involves the identification and synthesis of peer-reviewed research work relevant to the target research problem. The study systematically reviewed and examined documents found in selected literature databases. Databases or search engines used included Google Scholar and peer-reviewed journals. Initially, over 120 studies were identified from the databases. This included peer-reviewed journals, reports, and grey literature (published and unpublished thesis, conference proceedings, working papers, policy documents, and project reports). The literature was reviewed to determine the relevant documents for data extraction based on the three components of interest: exposure, sensitivity, and adaptive capacity. The review yielded a total of 36 documents from which data were extracted.

Observations and Discussions:-

Exposure to the Agriculture Sector in Machakos

Detected Climate Change: Temperature and Rainfall

Based on the temperature and rainfall analysis, significant information and scientific evidence indicate that the climate in Machakos County has been warming and drying over the last two decades. Existing literature in the County has revealed wide variability in seasonal and annual maximum and minimum temperatures. Analysis of temperature data from 1991 -2010 by Omoyo et al. (2015) shows warming of temperatures at a rate of 0.017℃ with potential evapotranspiration increasing at a rate of 0.02 mm per annum.

The analysis of rainfall in Machakos County shows that rainfall is not constant. Instead, the area experiences fluctuating rainfall characterisedby El Nino and La Nina and has become insufficient to support significant crop harvest or livestock rearing. Studies conducted on rainfall variability in the Machakos District by Michael and Tiffen (1992) from 1930 to 1990 showed no evidence of a long-term trend in rainfall but only clear evidence of inter-annual and within-season variability. Similarly, analysis by Indiatsy (2018) on monthly, seasonal, and annual rainfall variability from 1990 to 2014 established that monthly rainfall distribution in the County is highly variable, erratic, and unreliable, making it challenging to plan farming activities. Using coefficient of variability (CV), Rainfall anomalies (R.A.), and precipitation concentration index (PCI) on monthly seasonal and annual scales from 1990-2014, the study established highly erratic, unreliable characteristics and variable declining trends of rainfall. The author concludes that the variability affects the production of maize, coffee, and cattle in Machakos County.

Huho (2017) and Indiatsy (2018) also analysedrainfall variability in the County from1990 to 2014, with resultsrevealing negative annual and seasonal rainfall trendscharacterized by very high variability, especially in Machakos County and ASALs, an indicator that rainfall is gradually declining and becoming less dependable. In addition, the studies identified variations in rainfall amounts during wet and normal climatic conditions as the vital rainfall parameters influencing rain-fed agriculture activities in Machakos County.

A report by NEMA (2021) notes that data analysedfor 37 years between 1978 and 2015 shows an increased temperature of approximately 0.0292 ℃ per year, translating to 0.292 per decade. Similarly, analyses from Machakos Meteorological Station show an increase in both minimum and maximum temperature.

Analysis of rainfall in the County indicates a decreasing trend in annual and seasonal rainfall, according to NEMA (2021), and the annual rainfall decreased by 1.5 mm per year between 1857 and 2015. In the long rains, March, April, and May (MAM) rainfall seasons, the area recorded an annual decrease of 0.008 mm per year. A similar decrease was recorded in the analysis of short rains, October, November, and December (OND) rainfall season data at the rate of 0.64 mm per year.Rainfall data for long-term monthly mean rainfall and monthly mean rainfall from 1980 -2018 show that monthly mean rainfall was lower compared to long-term monthly mean rainfall.

Climate Change Model Projections

Projections from downscaled GCM outputs suggest that climate variability will increase over the County of Machakos in the future. Therefore, the County is expected to experience more severe and persistent extreme weather events. Future trends based on the Representative Concentration Pathway (RCP) 2.6 and 8.5 climate projections show that the County will continue to experience increases in temperature while rainfall declines. Under the two climate scenarios, a substantial temperature increase is expected in 2021 -2065 (MoALF, 2017). A study by Said et al. (2017) projected an increase in temperature and a decline in rainfall. Based on RCP 2.6 and 8.5 projections, the study shows that the maximum temperature increase will range between 1.12℃ to 1.10℃ and 1.35℃ to 3.08℃ respectively, over Machakos County for the period 2030-2070. Bosireet al. (2018) used two climatic scenarios-RCP 4.5 and 8.5 from 3 GCMs (GFDL-ESM2M, CanESM2, NorESM1-M), and the ensemble from the Coordinated Regional Downscaling Experiment (CORDEX) for 2010-2039, 2040-2069 and 2070-2099 periods to simulate future climatic changes for Machakos County using data from KALRO Katumani met station. The GCMs projected increased temperature for the three future periods under the two RCPs, with a mean temperature increase between 0.8℃ and 3.8℃.

This study also projected an increase in rainfall for the three future periods across all GCMs under the two RCPs relative to the baseline period of 1976-2005. The projected mean rainfall change was 8.2%, though varying across GCMs. The mean projected rainfall changes were 6.6 % and 9.7 %under RCP4.5 and RCP8.5, respectively. Previous studies have indicated a future rainfall decline for ASALs in the County (Huho, 2017; Said et al., 2017).

Because of the uncertainties in processes supporting the changing climate, especially on rainfall projections, and in a county with several AEZs exhibiting varying rainfall characteristics, there is a need to use climatic data from meteorological stations across the various AEZs.

Sensitivity of Smallholder Farming Systems in Machakos County

Frequency of Droughts and Floods

Droughts are common in Machakos County (Indiatsy, 2018; GoK, 2013). Records from historical data analysis indicate that there has been a significant drought in 4 out of ten years (Huho, 2017; GoK, 2013). An earlier analysis of data covering 1897-1987 by Tiffen et al. (1994) indicates that the then Machakos district, part of which is Machakos County today, experienced about 90 droughts of varying magnitudes. D'Alessandro et al. (2015) revealed that the recent frequency and severity of droughts in Machakos County have also increased. The report notes that the County experienced a drought every five years three decades ago, and the frequency has increased to drought once every two years. For example, between 2000 and 2015, the County experienced droughts in 2001, 2003, 2005, 2008, 2011, and 2014. The report notes that the increases in severities of the droughts resulted in yield losses estimated to have increased from 20-50% to 100 in the past. Similarly, data from Machakos Meteorological Station indicate that the area experienced three droughts every ten years, with extreme droughts in 1987 and 2016.

Future projections for the County also indicate an increase in the number of days with drought stress. Both GHG emission scenarios (RCP 2.6 and RCP 8.5) indicate the possibility of increasingly variable rainfall shifts in season onset and duration with a continued rise in temperature, resulting in higher risks of drought, dry spells, and floods (MoALF, 2017). Droughts cause heavy loss of livelihoods and may paralyseeconomic activities in the agriculture sector (Guha-Sapir, 2013). A study by Huho (2017) notes that the County experiences droughts every three to four years, negatively impacting food security.

Rural Population Density

The current population of Machakos County is 1,421932 people (KNBS, 2019). This translates to a population density of 235 persons per km^2, higher than the national population density of 82 persons per km^2. Approximately 60% of the total land area in Machakos County is arable, and agriculture is the main activity carried out in most of the County. Climate change-related vulnerability is higher in highly populated areas.Therefore, increasing rural population density signifies an increased number of people at risk from hunger and food insecurity. This is important for the County's climate change response planning.

Dependency of Smallholders on Farm Income and Share of Smallholder Farmers Involved in Rain-Fed Farming

A review of existing literature on Machakos County indicates that agriculture is the major source of livelihood in the County, employing about 74 %of the population and contributing approximately 70 %of household income (MoALF, 2017; Machakos County, 2015). Most households in the county practice rain-fed mixed crop-livestock farming, with an analysis of data from the 2019 Kenya population and housing census showing that about 94%are involved in crop production, mainly maize, and beans, while 76 %are livestock keepers (KNBS, 2019). Population growth is driving a steady fall in the average farm sizes in the County. These smaller farm sizes may undermine the capacity of smallholder households to produce enough for the family and generate a surplus, which they can use to finance investment in climate resilience production and inputs for increased productivity. The County is, therefore, at risk of food insecurity.

Climate change and variability will likely result in low crop yields and livestock productivity in Machakos County. A projected maximum temperature increase that exceeds 1.5°C over Machakos County by 2050 (Said et al., 2017) will damage crops, notably the dominant maize crop. It has been demonstrated that temperatures exceeding 35°C will damage maize crops. Similarly, increasing warming to 2°C by 2040 would result in yield losses and damage to other crops, including sorghum, millet, and cassava (IPCC, 2018). Similarly, projections also indicate that by 2030, most livestock keepers will have their livestock affected by temperatures above 30^{o}C (Said et al., 2017). With rising temperatures, cattle production will be physiologically affected by feed intake and reproduction (Mortola&Frappell, 2000; Collier and Gebremedhin, 2015; De Rensiset al., 2015), and feed quality, water stress, and pests as well as diseases (IPCC, 2018)

Land Degradation

The total arable land in Machakos County is approximately 3720.20 km^2 (372,020 Ha) out of the total county cover of 6,028km^2 (RoK, 2018; Boitt&Odima, 2017; RoK, 2009). There are, however, concerns that land degradation has become severe under the pressure of population increase, aggravated by frequent and prolonged droughts and rising poverty levels. The causes of land degradation in the County are natural and anthropogenic (RoK, 2018; WARMA, 2009; RoK, 2009). These include natural conditions related to climate and weather events such as floods, droughts, steep slopes, highly erodible soils, and human activities such as inappropriate land management practices, including overgrazing, over-cultivation, poor land husbandry, and excessive forest conversion (RoK, 2009). The fragile ecosystem, characterisedby an unfavourable climate, poor soils, and a history of soil erosion, makes Machakos County one of the most degraded lands (RoK, 2018; Ngugi, 2002). In addition, the County's proximity to Nairobi, the capital city of Kenya, has contributed to a rapid increase in the County's population (Atela et al., 2018). This has resulted in the opening of new, hitherto grazing lands for farming and settlement.

Additionally, converting range/grazing land into farms and settlements has squeezed livestock into small pieces, resulting in overgrazing and bare land. Land degradation may manifest as soil erosion and gullying. This washes away the top fertile soils or applied fertilizer, making it challenging to work in the field.Consequently, land use constitutes an important aspect of resilience in small-scale farming systems in Machakos County. According to a climate risk profile report in the County, An interplay of climate vagaries and soil degradation due to poor agricultural practices has resulted in the characteristic low productivity in the County (MoALF, 2017).

Adaptive Capacity

Access to Physical Capital

The availability of physical capital boosts productivity and enhances household incomes by enabling faster accomplishments of tasks as well as allowing diversification. According to Herrero et al. (2010), investment in infrastructure and market development in the ASALs, supported by adopting risk management practices, could significantly increase crop and livestock production. Machakos County Integrated Plan report notes that roads and energy are recognized as the central enablers of social and economic development. However, Machakos County is ranked among the counties with the poorest road transport networks in the country (RoK, 2018; 2013). A recent climate risk profile in the County (MoALF, 2017) showed that poor infrastructure, including markets, road networks, and produce handling and transportation systems, increases farmers' vulnerability. KNBS survey reports KNBS (2019, 2009) notes that paved roads in the County accounted for only 6.9 % of the total roads, while access to electricity stands at 48.3%, while an assessment by KIPPRA (2013) notes that access to the paved road network in the County is very low as most roads are earth roads which according to RoK (2018) are inaccessible during the rainy season.

A study by Chamberlin and Jayne (2013) showed that although most farmers in the Machakos County region live near motorable roads, the average distance to all-weather roads is about 12 kilometres, while produce markets and production-oriented services are 2-4 kilometresaway from most households. According to this study, farmers in the region travel more than 5 kilometresto reach the nearest telephone service. In their study in Yatta, one of the sub-counties in Machakos County, Muthamaet al. (2014) found that, although roads were not sufficient to serve the inhabitants, most of them smallholder farmers, for access to goods and services, including markets, there was a positive relationship between good roads investment in the farms and standards of living.As a result, the ability of the farmers in Machakos County to absorb and recover from climate-related shocks and stresses remains constrained.

Access to Financial Assets

The availability of capital allows the growth of livelihood sources through innovation, diversification, and skill enhancement (Mphande, 2016). The poor infrastructure in markets, road networks, and cold chain facilities hinder connectivity to more lucrative markets and confines smallholder farmers to local markets or subsistence farming, predisposing them to low economic returns (Mwakuboet al., 2005). Poor infrastructure leads to spoilage of perishable commodities and increased prices of goods from the farms and vice versa, eating into smallholder farmers' profits. Low production and wastage contribute to low incomes among smallholder farmers. Empirical evidence shows that smallholder farmers have inadequate financial resources, owing to competing budgetary demands, to counteract the effects of climate change and variability (MoALF, 2017; Mburu et al., 2013)

Despite many financial institutions in Machakos County, ranging from banks, microfinance, and SACCOs (RoK, 2018), most smallholder farmers do not have access to credit facilities due to various factors (Mutukuet al., 2017; GoK, 2014). Studies by Nyangena and Sterner (2009) and Ngugi (2002) pointed out that limited access to credit is attributed to a lack of collateral, such as land title deeds for a majority of smallholder farmers, and the unwillingness of lending institutions to finance farming activities due to higher chances of loss; as a result, crop failures and livestock deaths. The most common source of credit is merry-go-round or rotational savings and credit associations in which members make periodic contributions to one another on a rotational basis (Gathaara, 2011; Nyangena and Sterner, 2009). Lack of credit and low incomes from farming activities increases the County's agriculture sector's vulnerability.

Human Capital and Social Capital

While human capital is necessary for enabling the full use of physical capital, social capital enhances productivity in individuals by reducing the cost of doing business and easing coordination and cooperation between them (Bhandari&Yasunobu, 2009; Ellis, 2000). With relatively low incomes from agriculture, Kenya's education system largely orients young people for white-collar jobs, and negative attitudes to agriculture among the youth have contributed to the high rate of rural-urban migrations (Herrero et al. 2010). Due to the proximity of Machakos to Nairobi, many able-bodied and economically active youths are turning away from agriculture into employment, leaving behind the old, tooyoung, and women to till the land. Moreover, extension services are inadequate, with Chamberlin and Jayne (2013) revealing that farmers in the region travel more than 7 and 6 kilometresto get an extension and veterinary services, respectively. Extension service is crucial in improving knowledge and skills about climate change (Gbetibouo, 2009). A study by Mburu et al. (2013) showed that lack of extension and inadequate information are significant constraints to climate change and variability adaptation strategy adoption in the County.

A review of past literature indicates that Machakos County has community-based solid organizations (CBOs), such as farmer groups, cooperatives, and self-help groups (SHG), which foster support and information-sharing networks among farmers. A study by Nyagena and Sterner (2009) found membership in agricultural and other associations in Machakos County to be high; however, the County's social capital is declining. Group membership provides opportunities for interactions and support, particularly for sharing labour and information (Musyokaet al., 2020; Mphande, 2016).

According to Machakos County (2015), there are 315 registered cooperatives in the County categorized into production, financial, and investment-based cooperatives, with a total membership of 205,000. In addition, the County has 4,976 registered women's groups, 2,044 youth groups, 13,791 self-help groups, and 478 CBOs. A study by Atela et al. (2018) reports that strong CBOs and farmers' organizations in Machakos County enable advocacy for and support the adoption of new agricultural technologies. The study revealed that most CBOs and farmer groups mobilize farmers, link them with extension officers, manage group savings, and coordinate farming activities.Well-organized self-help groups are one of the major reasons for the success of soil and water conservation activities in Machakos County (Gathaara et al., 2011; Obareet al., 2004). According to Mphande (2016), these associations are crucial in accessing credits and funding for individual and community projects among rural populations.

A study on the socio-economic effects of Women's self-help groups on household livelihoods by Mulavaet al. (2018) in Kalama, Machakos, established that most members in Self-Help Groups (SHG) were the young and the middle-aged in 18-30 and 31-43 age group brackets. This is generally the most productive age that actively participates in socio-economic activities, including farming in the County. The study also revealed that women and low and middle-income groups mainly participate in SHGs. These are the most vulnerable groups in society (D'Alessandro et al., 2015) and are intent on improving their incomes by creating income-generating activities from resources or credit from group savings. According to the findings of this study, members in SHG groups generally benefited from improved incomes through contributions, savings, initiation and expansion of income-generating activities, and improved education and health status. The SHG members are, therefore, more prepared to better manage climate risks and opportunities in response to changing climatic conditions.

In an assessment of the impacts of participation in Self-Help Groups (SHG) on the livelihoods of group members, Kyalo and Matayo (2020) the benefits group members get from participation in SHG, including saving, access to credit, creation of employment, and reduction in dependency rate. The study noted that involvement in SHG was crucial in mobilizing group members' resources for saving and credit access. Members take loans for various purposes, including purchasing livestock, agricultural inputs, food, and household goods and setting up petty businesses. In addition, investment in income-generating activities such as fish, poultry farming, and brick farming by participants in the study helped create employment for members. The study also noted that participation in SHG helped reduce the dependency rate among members, especially women who can meet their daily needs instead of relying on their husbands for support. The authors conclude that participation in SHG is crucial in improving the livelihoods of vulnerable groups, especially women in Machakos County.

The existence of strong CBOs, such as farmer groups and cooperatives, and SHG, which foster networks of support and information sharing among farmers, help farmers, link them with extension officers, manage group savings, and coordinate farming activities, had a significant impact on agricultural commercialization and hence farm income generation. This constitutes an important aspect of resilience in small-scale farming systems in Machakos County.

Access to Technical Assistance/Technology

Using modern technology in agriculture can lead to higher farm productivity and help the sector better absorb the perennial climate-related shocks it faces (Mellor, 2019). According to a study by Atela et al. (2018), proximity to KALRO—Katumani, from which several improved maize and grain legume varieties have been released over time, among them varieties resistant to biotic and abiotic stresses, has benefited Machakos County. In addition, several new technologies and techniques have been promoted in the area, including rainwater harvesting, micro-irrigation, conservation agriculture, agro-forestry, crop production in greenhouses, and goat-rearing for dairy and meat production. However, the use of agricultural inputs such as certified seeds, fertilizers, and pesticides in Machakos County is reported to be low (MoALF, 2017). The reports put planting fertilizer at 37%, top dressing fertilizer at 32%, storage pesticides at 43%, field pesticides at 0.9%, and herbicides at 0.3%. The report further notes that only 1(one) percent of farmers in the County irrigate their crops due to inadequate and inappropriate infrastructure and water scarcity.

A recent study by Velesi (2018) indicates that up to 56% of farmers in Machakos County use improved crop varieties; 36% use manure and fertilizer, while only 11% use fertilizer. Indeed, a study by Wambua et al. (2018) revealed low farm input use in Machakos County and that female-headed households did not use fertilizers and storage pesticides on beans. The authors explained that this could be because the area is semi-arid and has limited sources of income. Limited technical information has been reported as one of the major constraints in theadoptionof agricultural technologies in Kenya. According to Gathaara et al. (2011), most county farmers lack access to technical information and depend on farmer-to-farmer sources. Despite the good mobile network coverage of about 85% with good internet connectivity (Machakos County, 2018) and availability of ICTs in extension, that provides agronomic, market- and climate-related information services to farmers using mobile phones (Atela et al. 2018), a report by KNBS (2020) reveals that only 59.3% of farming households used mobile phones while 17.6% used internet services. Availability of technology is assumed to indicate better information dissemination and economic well-being. Low incomes, the inflexibility of the farmers to change their production systems, and inefficient markets are the major obstacles to adopting new agricultural technology (MoALF, 2017).

Agricultural production in Machakos County is handicapped to a large extent by limited access to productivity-enhancing technology, including affordable, appropriate, and timely inputs, weak extension services, low technology adoption, and poor smallholder use of ICT for market access- and climate-related information services among others. These constraints reduce income growth and amplify the impacts of adverse shocks such as drought, disease, and disease outbreaks by weakening farmers' ability to manage risk events and recover from their aftershocks.

Irrigation

Machakos County's integrated development plan indicates that the County has enormous potential for Irrigation, with 1725 acres of land identified as suitable for Irrigation. Despite the enormous potential, according to a recent study by Mwangi&Mundia (2022), the County has predominantly non-mechanized rain-fed agriculture as opposed to irrigated agriculture, which poses challenges to crop production and food security. A survey by KNBS (2019) found that only 7 % of farming households in the county practice irrigation. Reports indicate that Irrigation in Machakos County is constrained by declining water availability, the level of infrastructure development, and high levels of contamination and pollution of water sources (Machakos County government, 2018; Aywa et al., 2017). Cleansens et al. (2012) similarly point to an acute shortage of irrigation infrastructure and scarcity of water as the main reasons for low Irrigation among smallholder farmers in Machakos County.

Although the low level of Irrigation is associated with declining water levels due to the destruction of water towers through encroachment, deforestation, and poor management of the existing water resource, such as evaporation and uncontrolled surface run-off, climate change and variability have contributed significantly to water scarcity in the County (Machakos County, 2018). Most of the rivers in the County are seasonal and yield water only during the rainy season, remaining dry during the dry period. With rising temperatures and declining rainfall, river water flows will continue to shrink. Some water sources have also been polluted by industrial effluent, commercial wastewater, agrochemicals, and domestic waste (Machakos County, 2018; Muiruriet al., 2013; Musyokiet al., 2013).

The lack of Irrigation and overreliance on rain-fed agricultural production predisposes smallholder farmers to climate change and variability risks. Coupled with high crop sensitivities to the maximum temperature, high dependence on rain-fed agriculture indicates significant vulnerability to the sector from climate change and variability. Therefore, Mwangiand Mundia (2022) propose an integration of rain-fed and irrigated agriculture to increase crop yields and ensure food security by allowing farmers to farm throughout the year.

Enterprise Diversification

Enterprise diversification is one of the major adaptation strategies to climate change and variability in Machakos County (Thiongo&Ngaira, 2019; Baaru&Gachene, 2016; Mwenda et al., 2019; GoK, 2014). Claensenset al. (2012) report that agricultural production in the County mainly consists of cropand livestock farming systems. According to the study, many crops are grown and livestock kept; however, maize is the dominant crop. In a study by David (2018), households engaged in maize production are diversifying into other crops. Velesi (2018) found that farmers diversified into livestock keeping and kept various livestock, including cattle, goats, sheep, and poultry, to take advantage of the synergy between crop and livestock to increase productivity and income. According to the study, farmers set aside almost half of their total land for maize crops; however, yields from the crop have been fluctuating and declining from 2000 to 2014, leading to increased farmers' vulnerability to food security. The study findings further indicate that 76% of farmers intercrop maize with other crops to maximisesmall land use. Common crops intercropped with maize included beans, cowpeas, pigeon peas, and green grams.

Therefore, enterprise diversification constitutes an important aspect of resilience in small-scale farming systems in Machakos County. According to a recent study by Kimoni et al. (2022), the ability to cope with climate change mainly influenced the type of crops the households grew. Enterprise diversification broadens the options to increase weather-related risks and plays a vital role in creating resilience against climate-related risks in farm production and enhancing resilience in food systems (Macqueen, 2021).

Conclusion:-

The objective of the present study was to provide information about the climate change and variability-related vulnerability of farming systems in Machakos County. Using the indicator approach, the study adopted a research synthesis method to gather and analyze the existing research evidence on the extent to which the agricultural sector in the County is vulnerable to climate change and variability. This review unveiled some key features of exposure, sensitivity, and adaptive capacity of farming systems in the County.

Based on the analysis of rainfall and temperature trends and the Global Circulation Models, a warming trend was observed in the County, while climate model outputs projected enhanced warming and drying towards the end of the 21st century. The farming system was found to be highly sensitive to climate change and variability impacts, indicated/ attributed by high incidences of droughts, high rural population density, a high percentage of smallholder farmers, and severe high susceptibility to land degradation. Adaptive capacity is, however, enhanced by substantial social capital and highly diversified agricultural production. While enterprise diversification is an essential element and a major source of resilience, social capital is one of the essential resources in managing overpopulation and land degradation in the County.

Interventions such as providing basic infrastructure such as electricity, markets, good roads, access to credit facilities, and access to extension agents will increase resilience to climate change and variability in the agriculture sector of Machakos County.

Recommendations:-

The high exposure to climate change and variability indicates the importance of formulating a county-specific response policy, focusing on the more pronounced vulnerability aspects, and leveraging the existing resilient farming systems and opportunities to develop more effective interventions.

The county should develop climate change communication strategies and dissemination methods to facilitate farmers' access to weather and climate information.

The County should promote crop and livestock diversification and investments in irrigation to reduce sensitivity and enhance the resilience of farming systems.

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