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Invited Review Article

Effectiveness of the adaptation strategies to climate change followed by the livestock rearers of the eastern coastal region, India

A. Veldandi[1], S. Zade[1], A. Panja[1], S. Garai[1] and S. Maiti[1*]

[1]Dairy Extension Division, ICAR-National Dairy Research Institute, Karnal- 132 001, Haryana, India

Abstract

Climate variability and extremities have been increasing and are projected to rise further with time, adversely impacting agriculture and livestock sectors in the country's coastal regions due to higher fluctuations in the temperature-humidity index. The livestock sector is affected by climatic fluctuations directly in terms of the performance and well-being of animals and indirectly in terms of water and fodder scarcity. The present study aims to review the adaptation strategies followed by livestock rearers residing in the eastern coastal region of the country and explain the concept of the effectiveness of adaptation strategies. Seventy-one adaptation strategies have been reviewed and categorised into 11 themes depending on the nature of adaptation strategies: Improved breeds, Herd management, Housing management, etc. While there is no universal metric for assessing adaptation effectiveness, it differs with the nature of the study. Cost-benefit analysis, Improved yield performance, Increased awareness about climate change and its impacts, etc., were a few metrics used to appraise the effectiveness of adaptation strategies to climate change. Very few studies have been conducted on the effectiveness of adaptation strategies, wherein in one of the studies, adaptation strategies like sustainable agriculture practices and water resource management were found to be effective. The study enlists the adaptation strategies followed by the livestock rearers to enhance their resilience, especially in vulnerable coastal regions, ensuring food security and livelihoods.

Keywords: Adaptation strategies, Climate change, Eastern coastal region, Effectiveness, Livestock rearers

Highlights

- Seventy-one climate adaptation strategies have been reviewed.
- Feeding management related practices were preferred over the other types of adaptation strategies.
- Significant adaptation strategies included housing, health, fodder, and heat stress management.
- The effectiveness of adaptation strategies was studied with cost-benefit analysis and yield performance.
- Participatory methods like QUIK (Quantification of Indigenous Knowledge) and fuzzy cognitive mapping methodologies were used in previous studies to assess adaptation strategies.

INTRODUCTION

Accelerated Climate Change has been impacting various sectors across the globe, especially agriculture and allied sectors including livestock. Livestock is one of the major components of agriculture, and particularly for the smallholder farming community, livestock and crop farming play an integral role. The sector contributes about 6.2 percent to the country's total Gross Value Added (GVA) (National Accounts Statistics, 2022). Climate change impacted livestock production regarding growth, milk production, reproduction, susceptibility to heat stress, and disease occurrence, leading to severe economic losses. Indirect impacts include reduced feed, fodder, and water scarcity (Sejian *et al*., 2015). An increase in the Temperature-Humidity Index (THI) is said to cause heat stress in animals which reduces their productivity (Koirala and Bhandari, 2019). It was found to reduce the productive and reproductive performance and increase the disease incidence among livestock. The productive performance of animals was found to be affected in terms of reduced feed intake, declined milk yield, poor quality of milk and reduced growth and feed efficiency, while the reproductive performance was found to be affected in terms of reduced length and intensity of oestrous cycle, increased incidence of anoestrous and silent heat, decreased fertility, reduced quality of semen and reduced pregnancy and conception rates. Increased incidence of mastitis, foot and mouth disease, zoonotic diseases, vector-borne, water-borne and tick-borne diseases was also observed (Baumgard *et al*., 2012; Kumar and Tuti, 2016).

Along with the animals' reduced productive and

*Corresponding Author, E-Mail: sanjit.ndri@gmail.com/Sanjit.Maiti@icar.gov.in

reproductive performance, considerable losses in milk production have been projected due to climate change-induced heat stress in animals. A loss of 15 million tonnes of milk production is projected by 2050 (Sreenivasiah, 2016). A 10-30 percent decline in milk production in the first lactation and 5-20 percent in the second and third lactations was observed (The Economic Times, 2017). It was also found that each unit increase in the Temperature-Humidity Index (THI) reduces the fortnightly milk productivity by 0.42-0.67 percent. This decline is more in crossbreds (0.61%), followed by buffaloes (0.5%) and indigenous cattle (0.4%) (Choudhary and Sirohi, 2022). The livestock sector is especially vulnerable in coastal regions with the Temperature-Humidity Index (THI) projected to exceed 80 during April-September during 2030's (Geetalakshmi *et al*., 2016). These adverse effects on livestock can be reduced by effective adaptation to the changing climate. As most of the studies have focused on documentation of adaptation strategies, it would be better to understand the dimension of effectiveness in adaptation for better and sustainable adaptation. Hence, the present review article discusses the climate change and livestock scenario in the eastern coastal region of India, the concept of adaptation effectiveness, adaptation strategies to climate change being followed by the livestock rearers, and the efficacy of these adaptation strategies in reducing the adverse impacts of climate change.

Climate change scenario of the coastal region of India

India has a coastline of 7516.6 km bordering the mainland and islands, with four states and one union territory along the east coast i.e., West Bengal, Odisha, Andhra Pradesh, Tamil Nadu and Puducherry. About 15.5 percent of the country's population resides in the coastal region (Census of India, 2011). Among them, approximately 63.9 million people (projected to increase to 216.4 million by 2060) reside in Low Elevation Coastal Zones (LCEZ)), which fall under 10 m of coastal elevation (Centre for Education and Documentation, 2010). They are on the frontline of a wide range of shifts in climate and natural disasters comprising sea-level rise, coastal erosion, cyclonic storms, severe cyclonic storms, storm surges, coastal flooding, etc (Panda, 2020).

The global mean sea-level rise was found to be 3.25 mm/year (1993-2018), and it was projected to increase further by the end of this century (IPCC, 2022), while in India, a sea-level rise of 3.3. mm/year has been observed (1993-2017) and was projected to increase to 300 mm by the end of 21st century. Almost 139 cyclonic storms formed over the North Indian Ocean during the past 55 years (1967-2021). The frequency of very severe cyclonic storms has increased in the past two decades (2000-2018), and the intensity is projected to increase further while the sea surface temperature (SST) has risen by 1^{o}C and during the past 65 years (1951-2015) and projected to rise further by the end of this century (Krishnan *et al*., 2020). Southern Peninsular Region of the country has recorded extreme weather events on 125 of 273 days (Jan 1 - Sept 30, 2022) that have claimed 350 lives, damaged 1.06 million ha crop area, 64,387 houses and killed 4382 animals (Pandey and Sengupta, 2022).

In the coastal region of the country, the eastern coastal region is said to be more vulnerable than the western coast in terms of frequency and occurrence of extreme climatic events (Anonymous, Climate Hazards and Vulnerability Atlas of India, Indian Meteorological Department, Pune, 1969-2019). Also, Bengal's coast is shallow compared to the western coast (Geetanath, 2022). It was found that about 58 percent of the cyclones formed in the Bay of Bengal hit the eastern coast. In comparison, only 25 percent of the cyclones formed in the Arabian Sea hit the western coast due to relatively higher rainfall, higher surface temperature, and lack of landmass in the Bay of Bengal due to which cyclones formed do not weaken and quickly move towards the eastern coastline (National Cyclone Risk Mitigation Project (NCRMP), 2020). Hence, it is evident that the east coast is more vulnerable than the western coast to cyclonic storms, severe cyclonic storms, and storm surges (Climate hazards and vulnerability atlas of India, Indian Meteorological Department (IMD), Pune). Fig. 1 and 2 show the tracks of cyclonic storms and severe cyclonic storms occurring over the various coastal belts of the eastern coastal region of India during the past 70 years (Indian Meteorological Department (IMD), 1951-2021).

Livestock scenario in the eastern coastal region of the country

The eastern Coastal Region of the country comprises four states viz. West Bengal, Odisha, Andhra Pradesh and Tamil Nadu. Good numbers of major dairy bovine breeds are found in these four states (Table 1 and Fig. 3). A snapshot of the livestock scenario in each of these states is as follows:

Andhra Pradesh has 3rd longest coastline in the country after Gujarat and Tamil Nadu, with a length of 974 km. The state has a coastal area spread over 92,906 sq.km. across nine coastal districts. The contribution of the agriculture and allied sectors of the state to the Gross State Domestic Product (GSDP) has shown a growth rate of 11.27 percent, with the livestock sector accounting for 6.86 percent of the growth rate (Socio-economic Survey, 2021-22). Andhra Pradesh is one of the major states rearing livestock (cattle, buffalo, sheep and goat) and stands 6th in the country with a total livestock

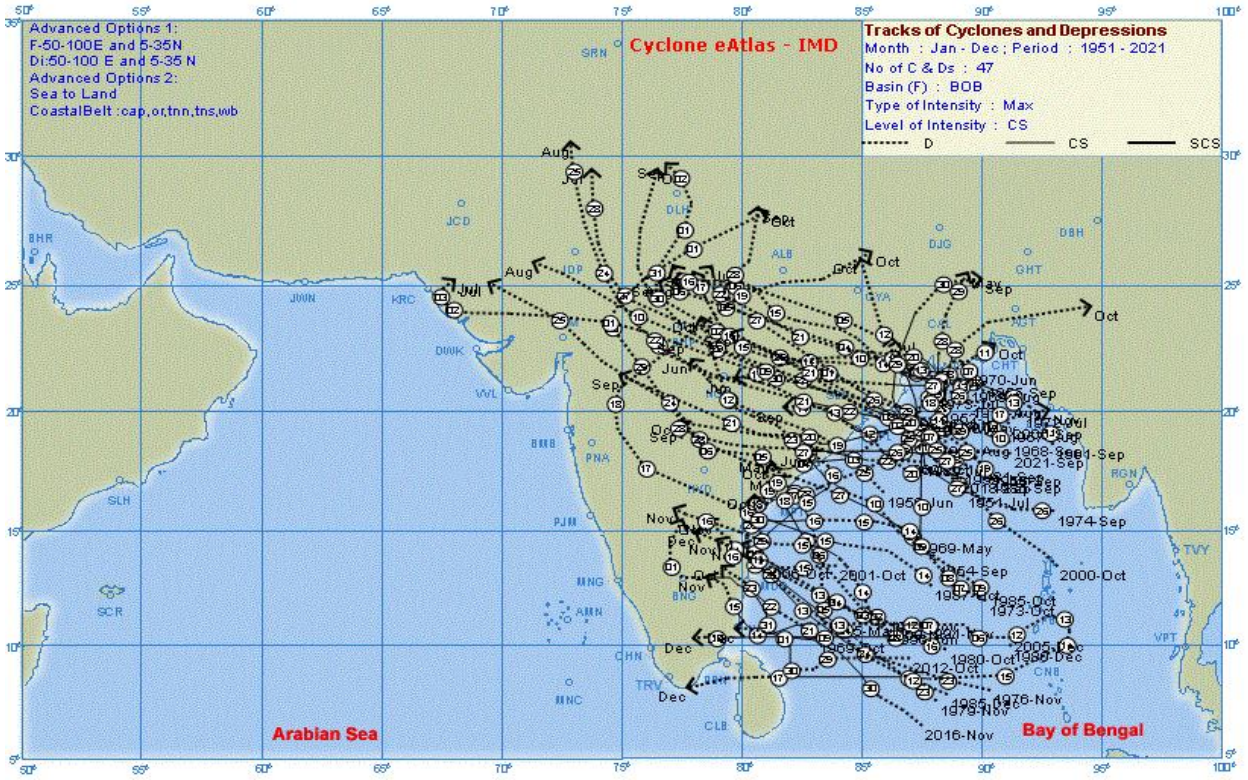

Fig. 1. Tracks of cyclonic storms occurring over the various coastal belts of the eastern coastal region of India [Indian Meteorological Department (IMD), 1951-2021]

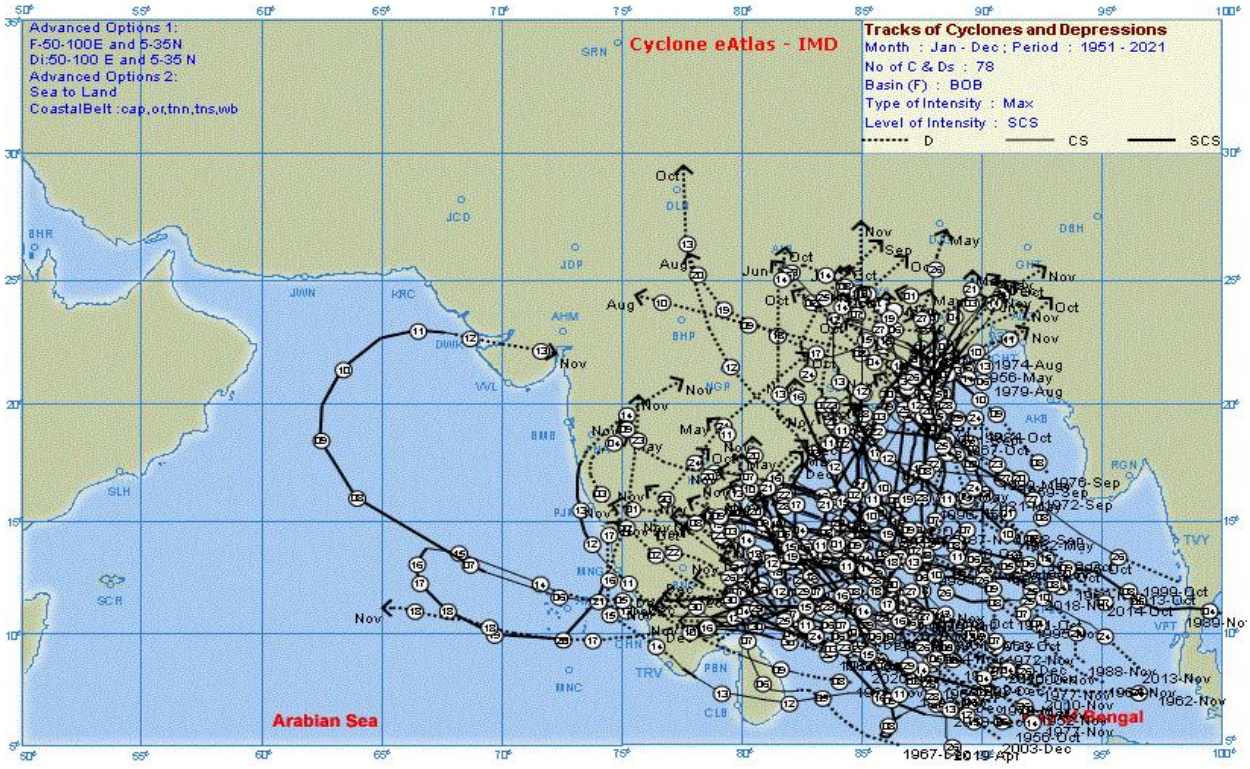

Fig. 2. Tracks of severe cyclonic storms occurring over the various coastal belts of the eastern coastal region of India [Indian Meteorological Department (IMD), 1951-2021]

Table 1. Distribution of cattle and buffalo breeds across the eastern coastal region of India

Sl. No.	State		Cattle/Buffalo breeds
1.	Andhra Pradesh	Cattle	Ongole, Punganur, Deoni, Hallikar, Jersey crossbred, Holstein Freisian Crossbred
		Buffalo	Murrah, Nagpuri
2.	Odisha	Cattle	Binjharpuri, Ghumusari, Khariar, Motu, Jersey crossbred
		Buffalo	Chilika, Kalahandi
3.	Tamil Nadu	Cattle	Kangayam, Bargur, Umblacherry, Jersey crossbred, Holstein Friesian crossbred
		Buffalo	Toda
4.	West Bengal	Cattle	Siri, Sahiwal, Gir, Jersey crossbred, Holstein Friesian crossbred
		Buffalo	Murrah

(Source: NDDB, 2018, Dairying in Andhra Pradesh, A Statistical Profile; NDDB, 2016, Dairying in Odisha, A Statistical Profile; NDDB, 2014, Dairying in Tamil Nadu, A Statistical Profile; NDDB, 2017, Dairying in West Bengal, A Statistical Profile)

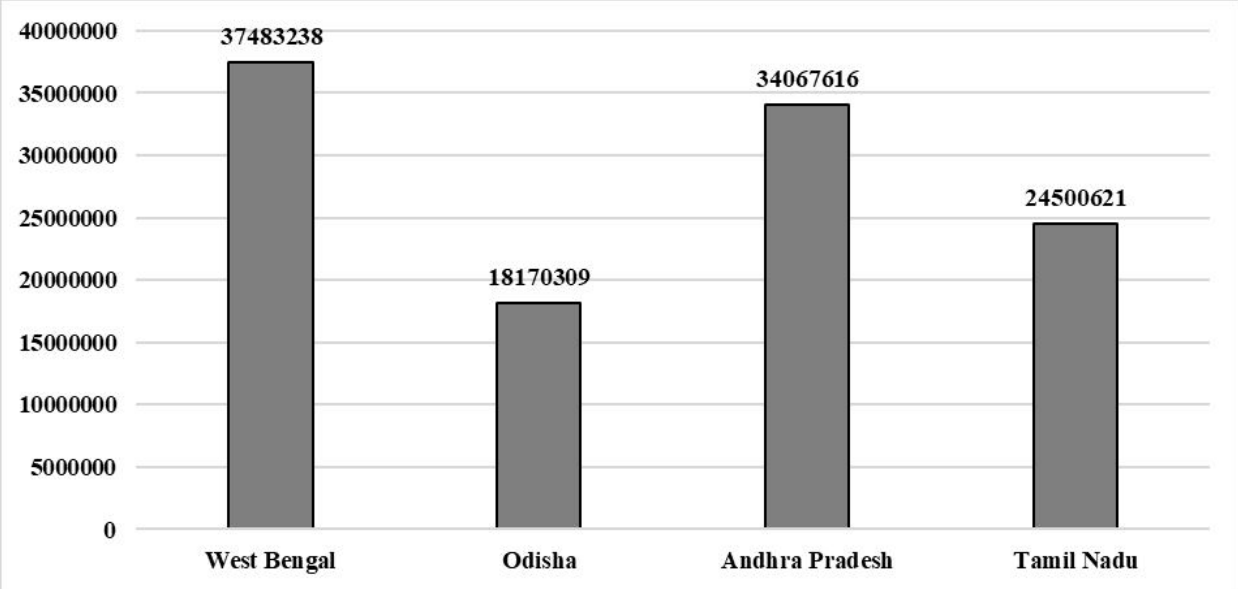

Fig. 3. Livestock population in the eastern coastal region of India (Source: Livestock Census, 2019)

population of 34.1 million. There is a 15.86 percent increase in the livestock population when compared to the last livestock census (19th). The state has 22,62,229 exotic and crossbred cattle and 46,00,087 indigenous/non-descript cattle population. Apart from cattle, the state has 6.2 million buffaloes, 17.6 million sheep and 55,22,133 goats (Livestock Census, 2019; Department of Animal Husbandry and Dairying, Annual Report 2021). The state's milch (adult female) bovine population is 51,41,000, as per the recent livestock census (20th). Milk production in the state is 147.17 lakh Mt which accounts for 7.69 percent of the nation's production with per capita availability of 799 g/ day (Socio-economic survey, 2021-22).

Odisha has a coastline of length 450 km with a coastal area spread over 1,55,707 sq.km. across six coastal districts. The state's contribution of agriculture, forestry and fishing to Gross State Domestic Product (GSDP) has shown a growth rate of 5.98 percent with the livestock sector accounting for a 3.6 percent growth rate (Directorate of Economics and Statistics, 2023). Odisha state has a total livestock population of 1,81,70,309 with 15,80,380 exotic/crossbred cattle and 99,03,970 indigenous/non-descript cattle population. Apart from cattle, there are 4,58,324 buffaloes, 12,79,149 sheep and 63,93,452 goats in the state (Livestock Census, 2019). The state's milch (adult female) bovine population is 1,03,62,294, as per the recent livestock census (20th). Milk production in the state is 2402 thousand tonnes during 2021-22 with per capita availability of 144 g/day (Basic Animal Husbandry Statistics, 2022).

Tamil Nadu has 2nd longest coastline in the country after Gujarat with a length of 1076 km spread across 13

coastal districts. Tamil Nadu state has a total livestock population of 2,45,00,621 with 77,24,719 exotic/ crossbred cattle and 95,18,660 indigenous/non-descript cattle population. Apart from cattle, there are 5,18,795 buffaloes, 45,00,491 sheep and 98,88,746 goats in the state. The state's milch (adult female) bovine population is 1,00,37,455, as per the recent livestock census (20th). Milk production in the state is 10.10 million tonnes during 2021-22, which accounts for 4.57 percent of the nation's production with per capita availability of 362 g/day (Dairy Development-Policy Note, 2023).

West Bengal has a coastline of length 157.5 km spread across three coastal districts. West Bengal is one of the major states rearing livestock and stands 4th in the country with a total livestock population of 37.5 million. There is a 23.51 percent increase in the livestock population when compared to the last livestock census (19th). There are 33,93,152 exotic/crossbred cattle and 1,90,77,916 indigenous/non-descript cattle. Apart from cattle, there are 6,30,921 buffaloes, 9,52,886 sheep and 1,62,79,340 goats in the state. The state's milch (adult female) bovine population is 1,97,08,898, as per the recent livestock census (20th). Milk production in the state was 6,414 thousand tonnes during 2021-22 with per capita availability of 179 g/day (Basic Animal Husbandry Statistics, 2022).

Concept of effectiveness of adaptation strategies to climate change

Adaptation in human systems is "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2022). Adaptation assessment is defined as "the practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility" (IPCC, 2001), while effectiveness refers to "the extent to which an action reduces vulnerability and climate-related risk, increases resilience, and avoids maladaptation" (IPCC, 2022). Effectiveness is the usefulness or efficiency of specific initiatives viewing specific objectives (Belal, 2021).

Adaptation effectiveness has been defined and evaluated differently depending on the nature of the study in the literature. Adaptation activities are expected to reduce the development deficit and address climate variability and future risks (Craft and Fisher, 2016). Adaptation is said to be effective only when it minimizes cost, maximizes benefit; facilitates achievement of material, subjective, and relational well-being goals; reduces vulnerability; increases adaptive capacity and resilience; maintains economic, ecological and social sustainability; avoids maladaptation; conserves, manage and restore ecosystem; community-based; socially just and equitable; oriented towards achieving transparency, accountability and representation through participatory processes and change thinking and practices to challenge vulnerability (Singh *et al*., 2022). The effectiveness of adaptation strategies can be further defined as their ability to cope with the adverse effects of changing climatic scenario and evaluated in terms of the effect on yield performance, associated cost, reducing climatic sensitivity and ease of availability and application (Yadav, 2019). It is the ability of climate-resilient agricultural technologies to increase adaptive capacity as well as to reduce the sensitivity of farming communities and evaluated in terms of awareness regarding climate change and its impact on agriculture, adaptive capacity and sensitivity (Abrar, 2019). Hence, the effectiveness of adaptation strategies can be defined as the potential of adaptation strategies in reducing risk and vulnerability and enhancing resilience and adaptive capacity to climate change. Stadelmann *et al.* (2011) stated that no universally accepted measure exists for measuring adaptation effectiveness, and only saved wealth and saved health could be generic adaptation effectiveness metrics. It can be evaluated in terms of reducing risk and vulnerability, developing resilient social systems, improving the environment, increasing economic resources and enhancing governance and institutions (Owen, 2020). Metric of adaptation effectiveness is given in Fig. 4.

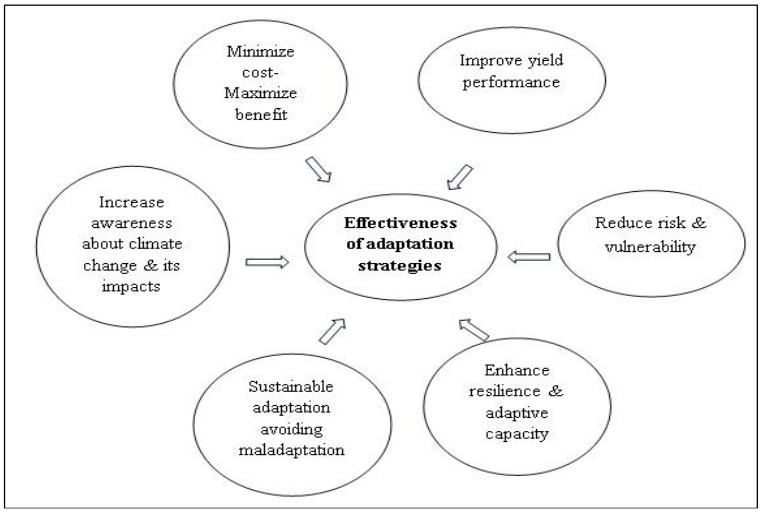

Fig. 4. Metrics of effectiveness of adaptation strategies to climate change [Conceptualized by the author based on literature review (Abrar, 2019; Yadav, 2019; Singh *et al.*, 2022)]

Adaptation strategies and their effectiveness

The adaptation strategies to climate change, followed by the livestock rearers residing in the eastern coastal region of India, were collected and categorized into 11 themes based on their nature, as given below:

Improved breeds: Adaptation strategies like rearing indigenous breeds, preferring/rearing Garole sheep, breeding animals by natural mating, rearing cross breeds, and shifting from buffalo to cattle were categorised under the theme, Improved breeds (Table 2). The livestock rearers used indigenous breeds as they were well adapted to fluctuations and extremities in the weather and performed better under heat stress (Nyong *et al*., 2007; Hoffmann, 2010; Maiti, 2013). Apart from indigenous breeds, farmers also prefer crossbreds as they can adapt well to changing climate, produce higher milk yield, are resistant to diseases, and are easy to manage (Paramesh *et al*., 2022). Garole sheep, an indigenous breed of Indian Sundarbans, is resistant to foot rot disease (*Dichelobacter nodosus*) that commonly occurs during seasonal fluctuations, is resilient to climate change and can adapt well to hot and humid weather (Dutta *et al*., 2021). Shifting from buffalo farming to cattle farming was predominantly observed as buffaloes are more susceptible to heat stress compared to cattle due to their higher absorption of solar radiation due to black skin and poor sweating capacity (Marai and Haeeb, 2010).

Herd management: Adaptation strategies like including of small ruminants in the herd, reducing herd size, selling of few animals from the herd and changing herd types and rearing different types of livestock were categorised under the theme, Herd management (Table 3). Shifting to small ruminants is because they can sustain more during climatic stresses and fodder scarcity and are effective converters of forage feeds compared to large ruminants (Dutta *et al*., 2021). Apart from this, other advantages include low cost, small size, suitability for smallholdings, etc. (Timan and Hanrahan, 1986). They also have adaptive capacities to survive and produce under challenging environments; they are disease resistant and less susceptible to heat stress (King *et al*., 2006). As livestock is an asset and insurance against shock, farmers sell it after extreme climatic events to meet their basic expenses (Maiti, 2013). This reduction in herd size is to cope with a shortage of feed and fodder in coastal regions (Knapp and Grummer, 1991).

Housing management: Adaptation strategies like

Table 2. Climate adaptation strategies related to improved breeds

Sl. No.	Adaptation strategies	Study area	References
1.	Rearing indigenous breeds	Indian Sundarban Region, West Bengal, Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013; Mohammad *et al*., 2022;
2.	Preferring/Rearing Garole Sheep	Indian Sundarban Region, West Bengal	Dutta *et al*., 2020a,b; Dutta *et al*., 2021
3.	Breeding of animals by natural mating	Indian Sundarban Region, West Bengal	Dutta *et al*., 2020a,b
4.	Rearing cross breeds	Odisha, Tamil Nadu, West Bengal, Andhra Pradesh	Paramesh *et al*., 2022
5.	Shifting from buffalo to cattle	Tamil Nadu	Uma *et al*., 2017

Table 3. Climate adaptation strategies related to herd management

Sl. No.	Adaptation strategies	Study area	References
1.	Inclusion of small ruminants in the herd	Indian Sundarban Region, West Bengal	Mohammad *et al*., 2022
2.	Reduction in herd size	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh, Andhra Pradesh	Maiti, 2013; Vijayabhinandana *et al*., 2022
3.	Selling of few animals from the herd	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013
4.	Changing herd types and rearing different types of livestock	Andhra Pradesh	Vijayabhinandana *et al*., 2022

modifying housing, housing with cross ventilation for keeping livestock, improved shelter for animals, making a pucca shed for livestock, making animal sheds slightly above ground level to avoid damage from the flood, change in micro-climate in cattle-shed/grazing area/ stall, covering the roof of shed by paddy straw to get relief from extreme heat, shed with concrete flooring and at the high elevated area and protection from extreme weather events through proper shelter were categorised under the theme, Housing management (Table 4). Modifying housing design according to needs by using concrete/brick flooring, raising the floor height by 1.5 m, ensuring proper ventilation, and installing concrete manger would be a practical approach to reduce the impact of climate change on livestock (Ambazamkandi *et al*., 2015; Kumar *et al*., 2021). Cross ventilation facilitates the removal of excess heat, micro-organisms, dust, gases, moisture, and odours, replacement with fresh air, maintenance of proper Temperature-Humidity Index (THI), and cooling of the shed (King *et al*., 2006). Pucca shed, slightly above the ground level, ensures sanitation and protection from extreme climatic events (Behera *et al*., 2021). Electric fans, heat insulating roof material, coconut leaves/straw on the roof, mist cooling system, planting forestry saplings in grazing lands to provide shade for animals, sprinklers/soakers are used to modify micro-climate in cattle shed/stall/grazing area to alleviate heat stress in animals (Knapp and Grummer, 1991).

Health management: Adaptation strategies like vaccination against diseases, providing more health practices to livestock, using mosquito nets to protect from mosquitoes, prophylactic measures taken against disease infestation, measures towards disease resistance in animals, disease surveillance and timely immunization against endemic diseases and use of indigenous knowledge to combat with livestock diseases were categorised under the theme, Health management (Table 5). Climatic stresses cause various diseases like

Table 4. Climate adaptation strategies related to housing management

Sl. No.	Adaptation strategies	Study area	References
1.	Modifying housing	Indian Sundarban Region, West Bengal	Mohammad *et al*., 2022
2.	Housing with cross ventilation for keeping livestock	Indian Sundarban Region, West Bengal	Dutta *et al*., 2020a,b; Dutta *et al*., 2021
3.	Improved shelter for animals	Andhra Pradesh	Balanarayana, 2016
4.	Making a pucca shed for livestock	Odisha	Behera *et al*., 2021
5.	Making animal sheds slightly above ground level to avoid damage from flood	Odisha	Behera *et al*., 2021
6.	Change in micro-climate in cattle shed/grazing area/stall	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013
7.	Covering the roof of the shed with paddy straw to get relief from extreme heat	Odisha	Das *et al*., 2019
8.	Shed with concrete flooring and at a high elevated area	Odisha	Das *et al*., 2019
9.	Protection from extreme weather events through proper shelter	Dryland Region of India	Ramana, 2022

Table 5. Climate adaptation strategies related to health management

Sl. No.	Adaptation strategies	Study area	References
1.	Vaccination against diseases	Indian Sundarban Region, West Bengal; Odisha	Das *et al*., 2019; Mohammad *et al*., 2022
2.	Providing more health practices to livestock	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh; Indian Sundarban Region, West Bengal	Maiti, 2013; Sarkar and Chakraborty, 2021
3.	Using mosquito nets to protect from mosquitoes	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013

Cont. Table 5.

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Sl. No.	Adaptation strategies	Study area	References
4.	Prophylactic measures taken against disease infestation	Odisha, Tamil Nadu, West Bengal, Andhra Pradesh	Paramesh *et al*., 2022
5.	Measures towards disease resistance in animals	Andhra Pradesh	Gopal *et al*., 2014
6.	Disease surveillance and timely immunization against endemic diseases	Dryland Region of India	Ramana, 2022
7.	Use of indigenous kno wledge to combat livestock diseases	Indian Sundarban Region, West Bengal	Dutta *et al*., 2020a,b

Hemorrhagic septicemia (HS), Foot and mouth disease (FMD), Black Quarter (BQ), etc. causing considerable losses to livestock rearers. So, they adopt a proper schedule of vaccination to minimize losses (Maiti, 2013; Moenga *et al*., 2016; Wetende *et al*., 2018; Thomas *et al*., 2022; Yadav *et al*., 2022). Indigenous knowledge is mainly used to cure livestock diseases. Feeding of neem and babul leaves paste to cattle for deworming, jackfruit and bamboo leaves for diarrhoea, feeding eucalyptus leaves and smelling lemon grass for cold are some of the Indigenous Technical Knowledge (ITK) techniques used by the livestock rearers which increase the adaptation capacity of livestock to the changing climate scenario (King *et al*., 2006). The changing climate has increased the mosquito population and the usage of mosquito nets is increasing in cattle sheds and on animals for protection (Maiti, 2013).

Fodder management: Adaptation strategies like cultivating green fodder, better fodder and feed storage methods, cultivation of fodder crops on raised land, raising green fodder during the off-season, use of community lands for fodder production during drought/floods, borrowing fodder from relatives/large farmers from the same village, bringing fodder from the government fodder department/cattle camps, high yielding and drought resistant forage crops/varieties, enhancing fodder production, developing common property resources and fodder banks and fodder preservation techniques were categorised under the theme, Fodder management (Table 6). Climatic stresses often lead to feed and fodder scarcity. Hence, green fodder is produced during the offseason to ensure a year-round animal feed supply (Paramesh *et al*., 2022).

Table 6. Climate adaptation strategies related to fodder management

Sl. No.	Adaptation strategies	Study area	References
1.	Cultivating green fodder	Indian Sundarban Region, West Bengal	Mohammad *et al*., 2022
2.	Better fodder and feed storage methods	Andhra Pradesh	Balanarayana, 2016
3.	Cultivation of fodder crops on raised land	Indian Sundarban Region, West Bengal	Dutta *et al*., 2020a,b
4.	Raising green fodder during off-season	Odisha, Tamil Nadu, West Bengal, Andhra Pradesh	Paramesh *et al*., 2022
5.	Use of community lands for fodder production during droughts/floods	Odisha	Das *et al*., 2019
6.	Borrowing fodder from relatives/ large farmers from the same village	Andhra Pradesh	Vijayabhinandana *et al*., 2022
7.	Bringing fodder from the government fodder department/cattle camps	Andhra Pradesh	Vijayabhinandana *et al*., 2022

Cont. Table 6.

Table 6., Cont. ...

Sl. No.	Adaptation strategies	Study area	References
8.	High yielding and drought resistant forage crops/varieties	Andhra Pradesh	Gopal *et al*., 2014
9.	Enhancing fodder production	Dryland Region of India	Ramana, 2022
10.	Developing common property resources	Tamil Nadu	Uma *et al*., 2019
11.	Fodder banks and fodder preservation techniques	Tamil Nadu	Uma *et al*., 2019

Feed management: Adaptation strategies like providing clean and fresh drinking water frequently, providing extra concentrates and mineral supplements to livestock, feed additives, use of more amount of crop residue and hay, change in feeding schedule, change in grazing time, cattle feed with mineral mixture, urea and molasses, scientific feeding of livestock, soaking concentrate feed in the water, feeding mineral mixture during summer, storing animal feed to use during climatic stresses and cultivating azolla in backyards for feeding livestock were categorised under the theme, Feed management (Table 7). Clean and fresh drinking water is provided to livestock along with cross ventilation in their housing to reduce their heat load due to unpredictable increases in the temperature-humidity index, which might cause decreased fertility, fitness and longevity in livestock (King *et al*., 2006; Dutta *et al*., 2021). Apart from this, a balanced diet composition (Upadhyay *et al*., 2009; Prasad, 2010; Sirohi and Sirohi, 2010) with more green grasses, hay, concentrates and mineral supplements like common salt and mineral mixture are essential to enhance the productivity of livestock (Dutta *et al*., 2020a,b). Animals are fed in the early morning or late evening to prevent increased body temperature during summer. Few livestock rearers feed livestock throughout the day in small quantities, which increases their feed intake during heat stress conditions (Upadhyay *et al*., 2009; Sirohi and Sirohi, 2010). Grazing animals is generally avoided between 11.00 am and 3.00 pm during the summer season (Knapp and Grummer, 1991).

Table 7. Climate adaptation strategies related to feed management

Sl. No.	Adaptation strategies	Study area	References
1.	Providing clean and fresh drinking water frequently	Indian Sundarban Region, West Bengal; Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Dutta *et al*., 2021; Dutta *et al*., 2020a,b; Maiti, 2013
2.	Providing extra concentrates and mineral supplements to livestock	Indian Sundarban Region, West Bengal; Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh; Andhra Pradesh	Maiti, 2013; Dutta *et al*., 2020a,b; Vijayabhinandana *et al*., 2022
3.	Feed additives	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013
4.	Use of more amount of crop residue and hay	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013
5.	Change in feeding schedule	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh, Andhra Pradesh	Maiti, 2013; Vijayabhinandana *et al*., 2022
6.	Change in grazing time	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013; Uma *et al*., 2017
7.	Cattle feed with mineral mixture, urea and molasses	Odisha	Das *et al*., 2019
8.	Scientific feeding of livestock	Dryland Region of India	Ramana, 2022

Cont. Table 7.

Table7., Cont. ...

Sl. No.	Adaptation strategies	Study area	References
9.	Soaking concentrate feed in water	Tamil Nadu	Uma *et al*., 2017
10.	Feeding mineral mixture during summer	Tamil Nadu	Uma *et al*., 2017
12.	Storing animal feed to use during climatic stresses	Indian Sundarban Region, West Bengal	Mohammad *et al*., 2022
13.	Cultivating azolla in backyards for feeding livestock	Indian Sundarban Region, West Bengal	Mohammad *et al*., 2022

Income generation: Adaptation strategies like integrating crops with livestock, integrating livestock production systems with agriculture and allied sectors and searching for alternate sources of income were categorised under the theme, Income generation (Table 8). Integrating crops with livestock is one of the major adaptation strategies followed by farmers in the southern states of India (Andhra Pradesh and Tamil Nadu), which requires considerable farming experience, sufficient farm income, livestock possession, large farm size, access to market and extension contacts (Kumar *et al*., 2023). Also, farmers tend to search for alternate sources of income to protect themselves from unforeseen circumstances which might lead to considerable losses in the livestock sector.

Government initiatives: Adaptation strategies like livestock insurance, construction of cyclone shelters, environmental awareness programmes and providing early warning were categorized under the theme of Government initiatives (Table 9). Farmers take livestock insurance to get monetary benefits from accidental death of livestock during extreme climatic events (Maiti, 2013). The government conducts environmental awareness programmes and provides early warnings to minimize losses that may occur due to extreme climatic events. Further, cyclone shelters are constructed to provide shelter to animals during climatic extremities.

Migration: Adaptation strategies like shifting livestock to highland/temporary sheds for their safety, using government buildings as temporary places for the livestock, sharing animal sheds with friends/relatives residing in the upland during the flood period, social migration, and sending some of the livestock to goshala

Table 8. Climate adaptation strategies related to income generation

Sl. No.	Adaptation strategies	Study area	References
1.	Integrating crops with livestock	Andhra Pradesh, Tamil Nadu	Kumar *et al*., 2023
2.	Integration of livestock production systems with agriculture and allied sectors	Dryland Region of India	Ramana, 2022
3.	Search for alternate sources of income	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013

Table 9. Climate adaptation strategies related to government initiative

Sl. No.	Adaptation strategies	Study area	References
1.	Livestock insurance	Andhra Pradesh; Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013; Balanarayana, 2016
2.	Construction of cyclone shelter	Indian Sundarban Region, West Bengal	Sarkar and Chakraborty, 2021
3.	Environmental awareness programme	Indian Sundarban Region, West Bengal	Sarkar and Chakraborty, 2021
4.	Providing early warning	Indian Sundarban Region, West Bengal	Sarkar and Chakraborty, 2021

during drought/flood year were categorised under the theme, Migration (Table 10). Migration of family members of livestock rearers to cities for employment or their enrolment in the MGNREGA programme was observed after extreme climatic events (Maiti, 2013). Shifting livestock to highlands/relative's sheds is done temporarily to cope with extreme climatic events.

Improved reproductive performance: Adaptation strategies like cooling and not allowing for grazing after insemination, deworming animals 2-3 days before insemination, feeding lemon after insemination, feeding mineral mixture during summer, feeding aloe vera and neem oil for 15 days before insemination and modifying the time of reproduction were categorised under the theme, Improved reproductive performance (Table 11). Heat stress was found to hamper the reproductive performance of animals in terms of reduced length and intensity of the oestrus cycle, the prevalence of anoestrus and silent heat, reduced pregnancy and conception rates, etc. Hence, the reproduction period is modified to avoid the period of heat stress.

Alleviation of heat stress: Adaptation strategies like extra bathing of cattle and buffaloes, providing shade during the day time, cooling animals by washing and using electric fans/coolers during summer were categorised under the theme, of alleviating heat stress (Table 12). Bathing animals at 10 am and 5 pm is done to reduce heat stress. The wallowing tank is also used by a few livestock rearers of coastal Odisha (Knapp and Grummer, 1991). Electric fans/coolers are used during summer to reduce heat stress among animals and enhance milk production (Paramesh *et al*., 2022).

A study conducted in the Sundarban region of India evaluated the effectiveness of adaptation strategies followed by the farming community residing in the Indian Sundarban Region using Fuzzy Cognitive Mapping. Based on the FCM-based simulations wherein the baseline (fluctuation in weather parameters and extreme climatic events) and the adaptation strategies like Dykes and embankments, Water resource

Table 10. Climate adaptation strategies related to migration

Sl. No.	Adaptation strategies	Study area	References
1.	Shifting of livestock to highland/ temporary sheds for their safety	Odisha	Das *et al*., 2019; Behera *et al*., 2021
2.	Using government buildings as temporary places for livestock	Odisha	Behera *et al*., 2021
3.	Sharing of the animal shed with friends/ relatives residing in the upland during the flood period	Odisha	Behera *et al*., 2021
4.	Social migration	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013
5.	Sending some of the livestock to Goshala during drought/ flood year	Andhra Pradesh	Vijayabhinandana *et al*., 2022

Table 11. Climate adaptation strategies related to improving reproductive performance

Sl. No.	Adaptation strategies	Study area	References
1.	Cooling and not allowing for grazing after insemination	Tamil Nadu	Uma *et al*., 2017
2.	Deworming animals 2-3 days prior to insemination	Tamil Nadu	Uma *et al*., 2017
3.	Feeding lemon after insemination	Tamil Nadu	Uma *et al*., 2017
4.	Feeding mineral mixture during summer	Tamil Nadu	Uma *et al*., 2017
5.	Feeding alo vera and neem oil for 15 days before insemination	Tamil Nadu	Uma *et al*., 2017
6.	Modifying the time of reproduction	Andhra Pradesh	Vijayabhinandana *et al*., 2022

Table 12. Climate adaptation strategies related to alleviation of heat stress

Sl. No.	Adaptation Strategies	Study Area	References
1.	Extra bathing of cattle and buffaloes	Indian Coastal and Alpine Region, Odisha, West Bengal, Arunachal Pradesh	Maiti, 2013
2.	Providing shade during daytime	Tamil Nadu	Uma *et al*., 2017
3.	Cooling animals by washing	Tamil Nadu	Uma *et al*., 2017
4.	Use of electric fans/coolers during summer	Odisha, Tamil Nadu, West Bengal, Andhra Pradesh	Paramesh *et al*., 2022

management, sustainable agriculture and aquaculture practices and strengthening local institutions were clamped together, it was found that the adaptation strategies were effective as they led to increase in the agricultural and livestock productivity in the Sundarban region of India which led to a decrease in the economic poverty of farming community (Singh *et al*., 2019).

Conclusion

Climatic stresses were found to have a profound impact on agriculture and livestock sectors and, thereby, the farming community, which demands effective adaptation from the farming community. Many studies were conducted in this line to document and prioritize the adaptation strategies to climate change followed by farming community in general and livestock rearers in particular. Very few studies have focused on the effectiveness dimension of adaptation strategies to climate change followed by livestock rearers residing in coastal regions of the country. In these studies, the effectiveness dimension was primarily measured through perception, cost-benefit analysis, participatory approaches like QUIK (Quantification of Indigenous Knowledge) methodology and, fuzzy cognitive mapping, etc. To understand adaptation better, the effectiveness dimension has to be further explored in adaptation studies, especially in the country's coastal regions, which might help in better and more sustainable adaptation planning for the eastern coastal region of the country.

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