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Climate Change and the Rohu Conundrum: A Scientific Review of assessing the Vulnerability of *Labeo rohita* to Climate-Induced Stressors in Asian Freshwater Ecosystems

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Abstract

Climate change has emerged as a pressing global issue, driven by natural factors and human activities. Its far-reaching impacts on marine and freshwater ecosystems pose significant threats to fish populations, including Rohu (Labeo rohita). This review aims to synthesize existing knowledge on the effects of climate change on Rohu populations, focusing on changes in temperature, precipitation, and water quality. Rohu is a major carp species that plays a vital role in ensuring food security and supporting livelihoods. Climate change affects Rohu's physiology, behavior, and ecology, compromising its growth, reproduction, and survival. Understanding these impacts is crucial for developing effective conservation strategies and ensuring the long-term sustainability of Rohu populations. This review highlights the need for further research to inform sustainable management practices and mitigate the effects of climate change on Rohu populations. The findings of this review can contribute to the development of climate-resilient fisheries management practices, ultimately supporting food security and livelihoods. By exploring the impacts of climate change on Rohu populations, this review aims to provide insights into the complex relationships between climate change, fisheries, and food security.

INTRODUCTION

Climatic changing is the major problem of world since mid-nineteenth century. Anthropogenic and natural factors are major cause of these climatic changing's (M. J. Islam et al., 2020).These changes cause extreme alternations in weather events such as precipitation, temperature, ocean acidification, hypoxia and salinity level in aquatic ecosystems (Shahjahan et al., 2021; Yilmaz et al., 2021). As result of these changing's hydrological stressors creates on organisms live in water bodies (Armobin et al., 2023; Cox et al., 2018; Sabbir et al., 2010). In return these stressors have drastic impact on aquatic ecosystems (fresh water, marine, estuarine), flora and fauna and directly or indirectly human beings.

Aquaculture sector play significant role in economy of tropical and sub tropical countries (Siddika et al., 2025).Its fast growing sector in all over the world. It also play very important role in global fish production i.e. 46% (82.1 million tons) of total global fish production (179 million tons).It has been

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predicted that global fish production by aquaculture sector increases from 46-53% in 2030 (Action, 2020). Fish serve as source of food, animal protein, omega 3 fatty acid and fish oil (Ashaf-Ud-Doulah et al., 2021).Fish oil is mostly use by heart patient.

Industrial revolution increases amount of greenhouse gases especially carbon emissions. Protective use of ozone layer decreases due to CO_2 amount. Alternation of atmospheric chemistry leads to excessive temperature rise and irregular precipitation (Bağdatlı & Can, 2020).Water surfaces globally change due to global warming. Excessive rise and fall in temperature has adverse effect on living organisms (Albut et al., 2018).

Review of Literature

Fresh water species requires stable environmental condition such as optimal temperature and salinity level (0-5ppt) and high quality water for their survival (Ninawe et al., 2018; Rahman et al., 2022) Fluctuations in these conditions causes reduction in oxygen level rise in diseases susceptibility and mortality rate. It also cause change in metabolic pathways as well as reproductive performance(Georges & Holleley, 2018; Uppanunchai et al., 2018).Fishes are exothermic animal, not maintain its temperature. It depends solely on water temperature. Fluctuations in water temperature directly cause changing's in fish metabolism.1 °C fluctuations in water bodies cause 10% fluctuations in fish metabolism (Zhang et al., 2015).It cause genetic changing's (rise in expression of genes responding to stress which cause reduction in expression of other genes linked with candidates production) ,biochemical factors (hormonal imbalance, CBC biochemical composition, RBC death and glucose concentration imbalance), biological aspects (feeding behavior, reduction in body size reproduction, immunity, growth, body metabolism) and ecological (distribution patterns, regional genetic variability, relocation of population to other areas).Due to these changing's fish productivity decreases, mortality rate increases and aquaculture industries faces economic loss (Dawood et al., 2020; Shahjahan et al., 2018).Due to climate change 17% fresh water fishes are threatened and 25% are near to extinction. 90% of world aquaculture sector production is threatened by climate change (Cao et al., 2023).

Impact of climate change on Rohu

Rohu geographically present in both temperate and tropical areas including Bangladesh, India, Myanmar, Nepal, Pakistan and Vietnam as shown in Figure 1.Its obligate fresh water specie which need fresh water habitat to complete its cycle. It lives in middle layer of water column. 28 to 30 °C is optimal water temperature for Labeo rohita best performance (Rahi & Shah, 2012; Roychowdhury et al., 2020). In summer season water temperature in aquaculture pond increases up to 36 °C which is 6-8 °C higher than optimal range making it imperative to record the thermal stress compensatory mechanisms (M. J. Islam et al., 2020; Shahjahan et al., 2021). Rohu meat is very delicious, due to its taste its use as novel food source across Indian subcontinents particularly Bangladesh (Islam et al., 2015; Rahi et al., 2022; Sabbir et al., 2017).It contributes significantly in GDP of country (LEMA et al., 2024). For example aquaculture sector contribute 3.57% to total GDP in Bangladesh (LEMA et al., 2024).

Volume 3, Issue 2, 2025

Frontier in Medical & Health Research

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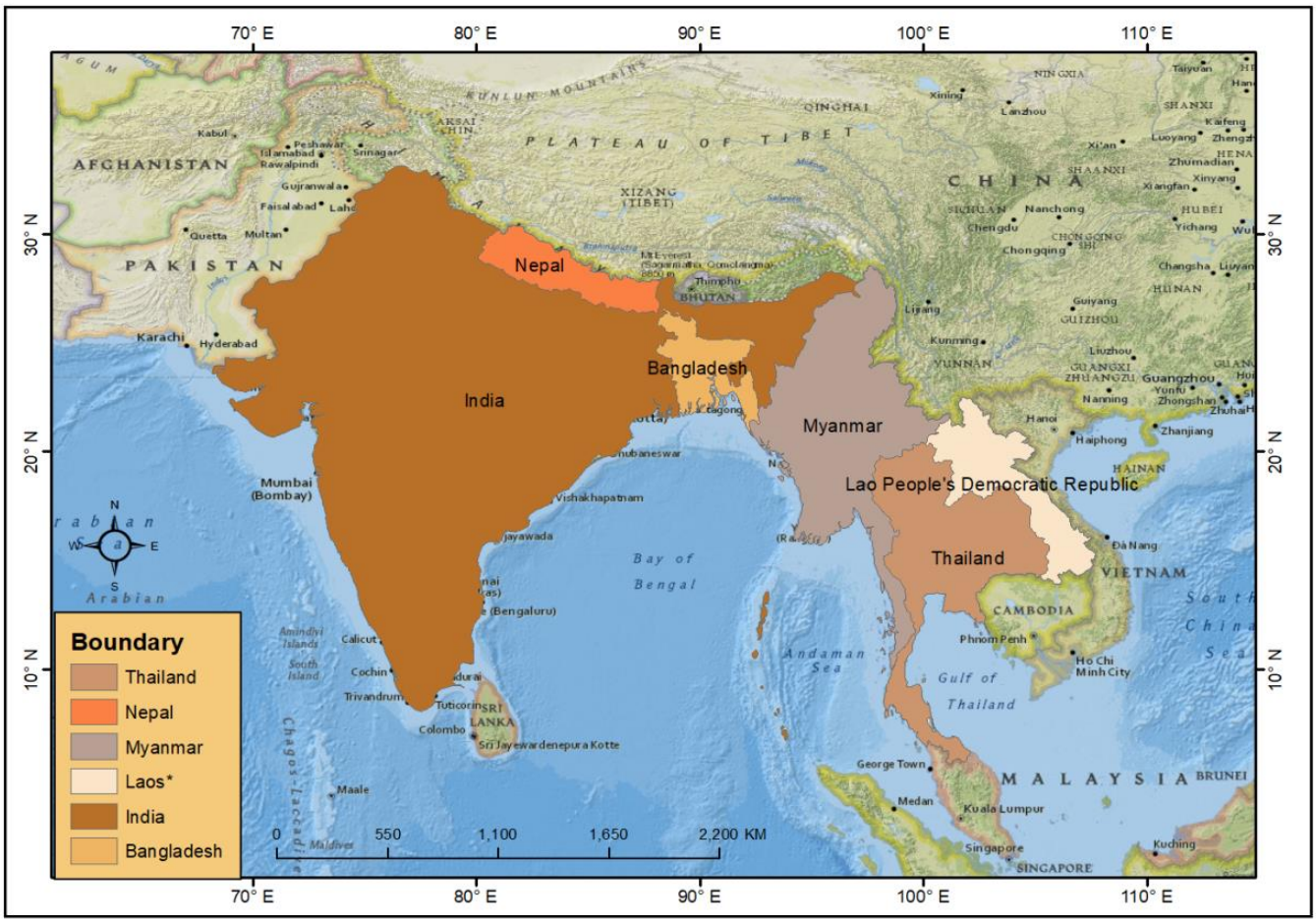

Figure 1. Major producer's countries of *Labeo rohita*

Climatic Parameters: Climatic parameters have profound impact on temperature, precipitation and humidity as shown in Figure 2.

Volume 3, Issue 2, 2025

Frontier in Medical & Health Research

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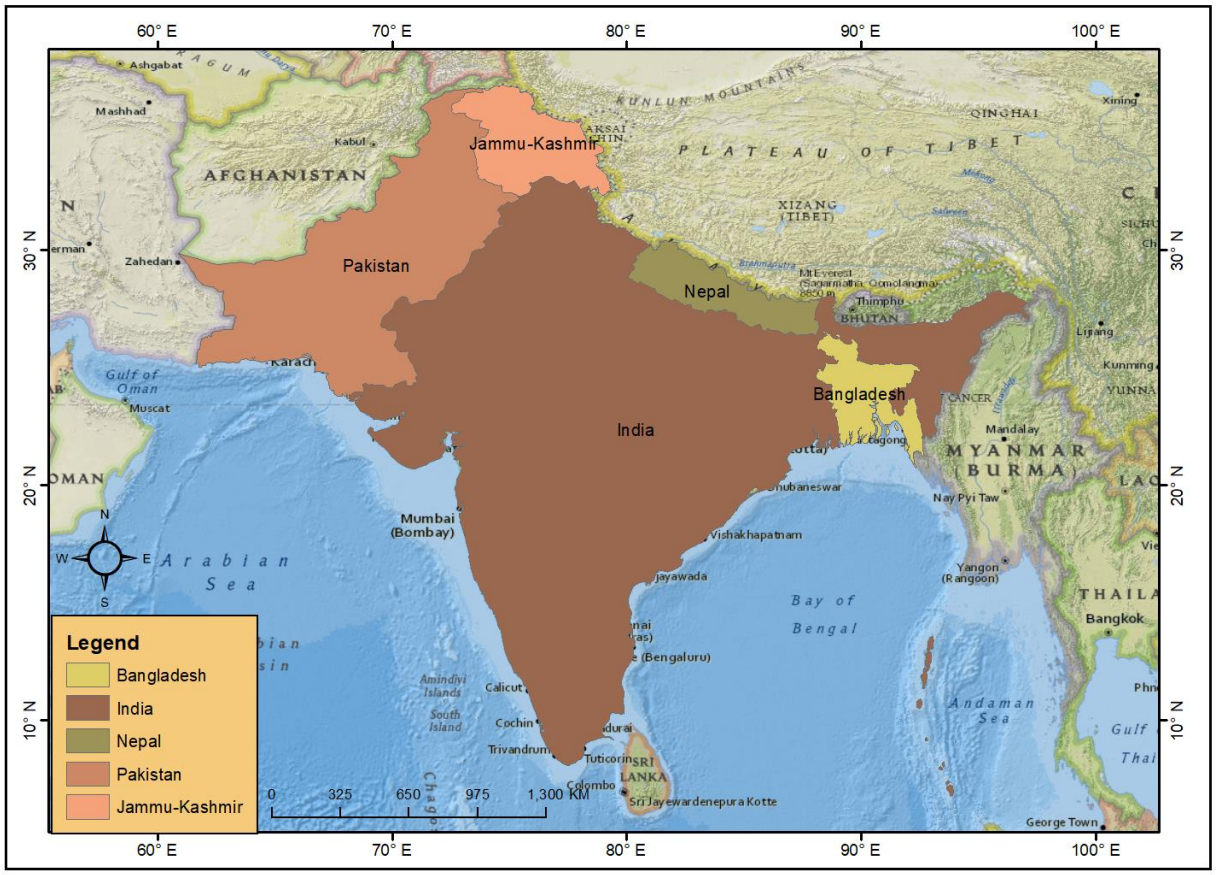

Figure 2. Profound climatic impact on Asia regions

TEMPERATURE

Temperature also help in determine the diversity of species in particular habitat because species perform best at optimal temperature and as a result their survival rate increase which ultimately increase diversity and abundance of species in particular environment (Schulte et al., 2011).Fishes cannot regulate body temperature they depend on water temperature , so water temperature is key factor in determine fish biological system functioning. Optimal range of temperature is necessary for proper growth and development. Growth of embryo and organ formation is effected by increase or decrease in temperature (Ashaf-Ud-Doulah et al., 2021) Fishes are more sensitive to temperature at larval and juvenile stage as compare to adult (Ashaf-Ud-Doulah et al., 2021).

Labeo rohita perform best at 28-30°C, when temperature fluctuates above and below this limit, its survival rate decreases and mortality rate increases (Mridul et al., 2024).At 28-30°C Labeo rohita daily weight gain, protein efficiency ratio, thermal growth coefficients and survival rate increases. At 32-36 °C daily weight gain, protein efficiency ratio, thermal growth coefficients and survival rate decreases (Mridul et al., 2024). 34°C temperature cause yolk and zygote damage also slow down incubation time and hatching success rate. At 36 °C hatching success rate is zero (Matolia et al., 2024).

Effect on embryonic development

Rise in temperature also effect the embryonic development by increasing incubation duration, decreasing hatching intensity or rate and increasing mortality rate of embryo. 80% hatching success rate observe at optimal temperature, when temperature rises upto 34 °C it decreases hatching success rate(from 80%-26%) and increase embryo mortality (Ashaf-Ud-Doulah et al., 2021).Yolk sac provide nutrients to embryo for growth and survival. Elevated temperature such as 36°C disrupt embryo by darkening yolk sac which is key component for its proper development ,ultimately leads to embryo deformities (Ashaf-Ud-Doulah et al., 2021).

Frontier in Medical & Health Research

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Effect on erythrocytes physiology

Erythrocytes or RBC carry oxygen from gills and transport it various part of body for efficient working of fish. During cell division when chromosomes fails to incorporate to nucleus then as result micronucleus form. Micronucleus act as bioindicators use to access genetic damage cause by temperature stressors.Elevated temperature effect formation of micronucleus in fingerlings of Labeo rohita. At 30 ^{0}C,33^{0}C and 36 $^\circ$C micronucleus formation rate was 0.5% followed by 0.8% followed by 1.4%.At 36^{0}C micronucleus formation in fingerlings erythrocytes relatively higher which disrupt which health by decreasing RBC oxygen delivering to different parts of body efficiency. As a result rohu overall metabolism decreases and susceptibility to disease increases.

Effect on gill morphology

Gill play very important role in maintaining water and salt balance in body (osmoregulation), excretion (removal of waste product like ammonia) and respiration. Rise in water temperature(36 $^\circ$C) increases oxygen demand which increases pressure on oxygen carrying system and as result alters the morphology of rohu fingerlings gills (Chen et al., 2019).Abnormal cell growth (hyperplasia), separation of the outer cell layer (epithelial lifting), swelling of blood vessels (telangiectasis), tissue damage (epithelial necrosis) and enlargement of chloride cells are changing which appear in gill lamellae and filaments due to temperature rise (S. M. Islam et al., 2020).

Erythrocytes are also called as RBC. They contain hemoglobin. Anemia and physiological status of rohu is known by blood hemoglobin content. Size and quantity of erythrocytes are effected by temperature fluctuations which ultimately effect hemoglobin quantity (Ashaf-Ud-Doulah et al., 2019).Fluctuations in temperature decreases oxygen content from water and as a result rohu metabolism increases. Low oxygen exposure for long time can lead to poor development and growth rate, weak immune system, nuclear and cellular level anomalies of RBC increases and ultimately mortality rate rises (Ashaf-Ud-Doulah et al., 2019).

Effect on hemoglobin concentration

Extreme rise in temperature denature hemoglobin such as at 33-36°C temperature Hb contents of blood quantity reduces in rohu. Reduction in hb content decreases transportation to different tissues which causes sluggish behavior and weaken immune system and hypoxia (Ashaf-Ud-Doulah et al., 2019).At 36°C temperature WBC level increases in blood .Blood glucose level increases in rohu at 36°C. Elevated temperature activate hormones such as adrenaline and cortisol which triggers gluconeogenesis and glycogen break in glucose to provide energy to rohu to cope with thermal stress.Prolonged exposure to thermal stress causes metabolic imbalance in rohu (Ashaf-Ud-Doulah et al., 2019).

Effect on FCR

FCR is measure of feed efficiency of fish. It is calculated as feed intake/ total body weight consumed. Temperature and feed quality have significant effects on FCR.24-26°C is optimal temperature range at which rohu show best FCR value (Kausar & Sultan, 2006).Temperature above this range increases increase feed intake but reduces growth.

Effect on oxygen consumption

Environmental factors such as temperature alter the oxygen consumption in fingerlings (Burton et al., 2011).Oxygen transport system weakens by warmer atmospheric condition (Norin et al., 2014).Rise in temperature increases oxygen demand of rohu fingerlings. At 36°C oxygen consumption rate of rohu is 81mgO_2/kg/h while at 30 °C consumption rate is 57 mgO_2/kg/h.Increases in oxygen uptakes volume in gills and weakening of oxygen transport system exert extra stress on rohu body which leads to lowering swimming ability, decreasing energy level and impaired growth and survival (S. M. Islam et al., 2020).

Effect on GH and IGH

Hypothalamus -pituitary – liver (somatotropic axis) is primary initiator of growth and development. Somatotropic-axis influence by endogenous and exogenous factors which regulate GH and IGFs (Reinecke, 2010).Growth hormone (GH) and insulin

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like growth factor (IGF) play significant role in growth of rohu.GH activate liver cells to produce IGF-1 which increase proliferation of cell, muscle growth, enhance development and leading to better growth. Steroidogenesis, sexual maturation and gematogenesis regulation GH play important role (Rahman et al., 2019).28-33°C is optimal temperature for rohu.Rise in temperature i.e. 36°C leads to reduction in weight gain, specific growth rate and increases FCR. Higher temperature effect growth by suppressing expression of insulin like growth factors (IGF-1 & IGF-2) in liver and expression of growth hormone (GH) in juvenile pituitary (Shahjahan et al., 2021).

SALINITY

Salinity is one of the a-biotic factors of aquatic ecosystems. It adversely affects the growth, immunity (either general or specific), metabolism and cognitive behavior (Siddika et al., 2025). Due to climate change sea water level increases which cause intrusion of saline water into inland especially in coastal areas (Shirangi et al., 2016) Aquaculture industry faces challenges especially in Bangladesh due to these climatic changing's (Islam, 2021; LEMA et al., 2024). 2%, 4% and 6% increase in salinity level decreases survival rate of rahu from 98-83% followed by 98-72% followed by 98-64% respectively. Every 2% increase in salinity level causes approximately 2% decrease in body weight (Siddika et al., 2025).

Effect on gill ultra structure

Salinity alters the lamellae and filaments of tissues. Slightly increase in salinity cause damage in form of mucus mass aggregation while gills filaments start rupturing and tearing at 6% increase in salinity level(Siddika et al., 2025).

Effect on growth performance and survival

Climate change is long term change in weather pattern in region over period of 30 years. Rohu is fresh water specie. Salinity is one of the limiting factors in growth and survival of rohu fingerlings. Sea level rise and coastal storm surges increases salinity intrusion in ponds or flowing water bodies near coastal regions. Growth and salinity both are inversely proportional to each other. When salinity level increases it decreases specific growth rate. Increase in salinity level lower amount of ascorbic acid (Vitamin C) in tissue levels. Vitamin C reduction causes lowering of growth and weakening of immune system. The optimal salinity range for rohu was 2% but it show normal growth at 0-4% salinity range. Up to 6% salinity level rohu show erratic behavior or mortality. Reduction in appetite behavior of rohu also observes at up to 6% salinity level. High salinity make difficult for rohu to cope with water and salt balance in body. Due to this osmotic stress, digestibility decreases ultimately lower feed intake and growth retard (Islam et al., 2014).4.5ppt salinity leads to rohu fingerlings death (Sharma et al., 2015).

PRECIPITATION PATTERN

Climate change shift precipitation patterns of Asia regions which have profound effect on Labeo rohita as shown in Figure 3.

Volume 3, Issue 2, 2025

Frontier in Medical & Health Research

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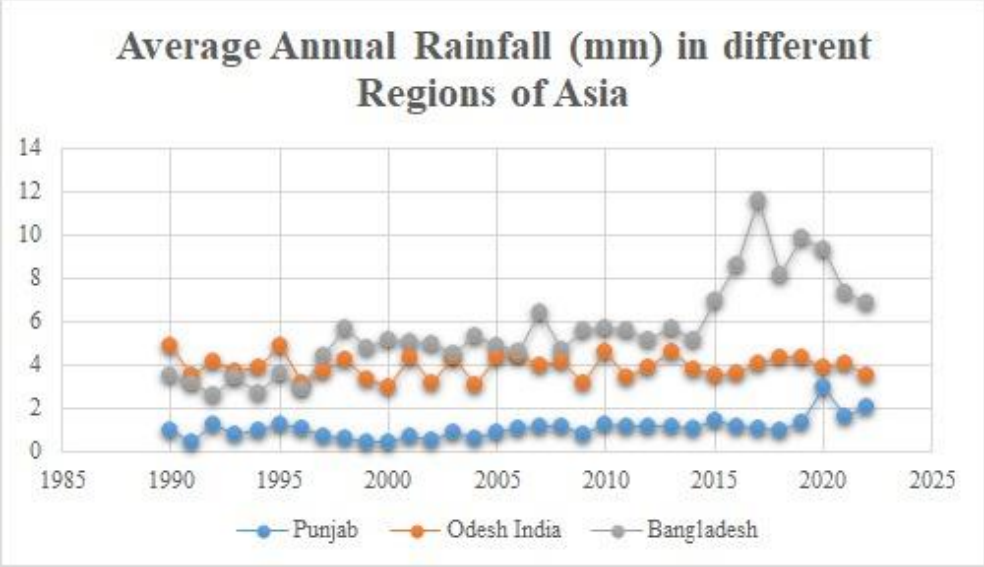

Figure 3. Average rainfall in different regions of Asia

Effect on gonadotrophin secretion

Environmental clues such as seasonal variation help in determine pre and post spawning behavior of fish. Monsoon is favorable for gonads maturation and promoting spawning while in dry or cold season fish gonads development slow downs. Seasonal variation effect GSI which indicates spawning time and duration of fish.Labeo rohita spawning season has very short duration ranges from May to July. Rohu breed in flowing water, monsoon rains increases water flow which promotes their gonads development ultimately increase gonadotrophin hormone secretions. Ova development inside ovary starts. Female release egg and male spray millet (sperm). Alternations in monsoon patterns alter water flow which effect egg and millet quantity ,delay in egg production and millet release overall effect reproductive cycles of rohu which ultimately reduces diversity and abundance of Labeo rohita (VERMA, 2024).

Effect on population

Climate change causes reduction in natural breeders by reducing egg and sperm quantity, decreases egg viability, reduces sperm motility, lowering ovulation of eggs which ultimately cause reduction in fertilization rate (Degani, 2020).Every living organisms perform reproduction to ensure their survival over time. Favorable environmental conditions such as optimal temperature, water PH and photoperiods align best with reproductive behavior of rohu. Sensory organs receive message from cues and send it to brain for further processing (Froehlich et al., 2022). Gonadotropin releasing hormone secretion starts by hypothalamus which stimulates pituitary (Muhala et al., 2021).Pituitary gland secrete FSH and LH which stimulates gonads. Testosterone, progesterone and estradiol produce by gonads which stimulate spawning behavior.It increases fertilization rate and hatchling production ultimately increase rohu diversity and abundance. In sexual differentiation thyroid hormone play important role (Deal & Volkoff, 2020).Climatic changing causes increase or decrease in optimal temperature which influence hormonal secretion and sexual maturity of rohu male.Reduction in pitutary and thyroxin hormone secretion leads to poor sperm production, decreases fertility rate ,reduction in number of offspring's which ultimately decrease rohu population (Ehsan Eslamizadeh, 2024).

Effect of water hardness on survival and growth of fry

Water is necessary for survival of living beings. For fish water is elixir of life. Protoplasm of every cell contains 80% water. Almost all biochemical reaction requires water to happen. Water quality play significant role in growth and survival of living organisms. Physical, biological and chemical character of water tells about water quality (Raosaheb et al., 2018).Pakistan is water stressed country. Out

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of 17 extremely water risk country Pakistan come on 14 rank (Maqbool, 2023).Due to climate change rate of evaporation of water from fresh water bodies increases. As a result concentration of calcium ,magnesium etc increases in water which ultimately increase water hardness. Water hardness had positive impact on growth and survival of Labeo rohita.In optimal range water hardness provide calcium and magnesium which is essential for overall health and bone development. Growth rate of rohu (fry stage) increases upto 150 mg/l and further rise in water hardness above this limits does not favor growth and weight gain.PH range (6-9) is effective for rohu growth and survival (Parra & Baldisserotto, 2019). Water hardness less than 20mg/l and above 300mg/l causes stress and mortality of rohu respectively (Bhatnagar et al., 2004).

Effect of seasonal variation on haemato-biochemical parameters

Climate change disrupts natural timing of season

RBCs (red blood cell), HCT (haematocrit), Hb (hemoglobin) and WBCs (white blood cell) concentration were higher in summer season, followed by spring and winter respectively. While MCHC (mean corpuscular hemoglobin concentration), MCHV (mean corpuscular hemoglobin volume) and MCH (mean corpuscular hemoglobin) concentration were higher in winter followed by spring and summer respectively. Moisture content help in maintaining shelf life of fish. Due to seasonal variation, moisture content also varies. Variation in moisture content is directly linked with biochemical variable i.e. lipid concentration. In rohu body 70.81-74.76% moisture contents present. Fat and moisture content both have inverse relationship. When moisture content increases in winter then fat concentration decreases in rohu (Habib et al., 2021).

Kotri Downstream to Indus River Delta-PAKISTAN

The kotri downstream area stretch almost 155km along Indus river delta. This delicate ecosystem is adversely affected by climatic changes (Gleeson et al., 2012).Fluctuations in precipitation and temperature patterns, rise in sea level effect salinity and water flow ultimately leads to adverse effect for fish population (Khaliq et al., 2024).In winter and summer season water temperature range from 9°C to 34 °C while optimal temperature for rohu survival and spawning range from 25 °C to 28 °C. Cooler (9 °C) and hotter (34 °C) water temperature effect spawning and survival of rohu. Rohu diversity and habitats health supported by salinity PH ranging from 7.4-8.6 (Mashori et al., 2024).

Climate change disrupt water chemistry-USA

Climatic change disrupts water chemistry. Warmer water increases growth of algal blooms. CyanoHAB grow faster in warmer temperature as compare to other algal blooms. Fluctuations' in rainfall patterns such as increase in rainfall intensity bring nutrients from land into water bodies which favor HAB production (Gobler, 2020).

CHITWAN-NEPAL-SOUTH ASIA

Elevated temperature favor red algal blooms growth in shallow ponds. It has adverse effects on Labeo rohita farming such as it decreases in yield of rohu, increases nitrates and decreases oxygen quantity in shallow ponds. It decreases almost 10% overall yield from rohu and 20% survival rate. Dissolve oxygen concentration decreases 2 times while nitrates concentration 3 times decreases in pond due to red algal bloom. Low DO causes stress and reduces growth rate. Optimal concentration of nitrates necessary for proper growth. Lower concentration reduces immunity, ultimately cause rohu death (Mandal et al., 2018).

Due to climatic changing i.e. global warming aquatic animal diversity and abundance decreases worldwide(Fey & Greszkiewicz, 2021).Water temperature is most primary key to environmental factors which regulates growth, reproduction and diversity of species in aquatic ecosystems (Yoon et al., 2022).Water bodies temperature has great influence on physiological mechanisms such as reproduction, feeding, swimming and nutritional adaptability(Enders & Boisclair, 2016; Lindmark et al., 2022).Water temperature below or above thermal limits weakens immune systems and aquatic species easily become susceptible to infectious disease (Azhar et al., 2022; Cascarano et al., 2021).

Frontier in Medical & Health Research

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PAKISTAN-SOUTHREN PUNJAB-LARVAE

In Pakistan environmental factors i.e. light, air, temperature, precipitation pattern drastically change throughout the year (Dastagir et al., 2016; Hussain et al., 2023).In sindh and Baluchistan during summer temperature reaches upto 50 °C(Ashraf et al., 2022) while it drops below -2°C in skardu,baltistan(Raza et al., 2015).Flactuations in water temperature increase energy demand also increase glucose for balancing carbohydrates metabolism(Forgati et al., 2017; Jia et al., 2020).Drastic fluctuations in water effect food intake rate because below 25°C digestive enzyme efficiency decreases(Ahmad et al., 2014).Labeo rohita is belonging to family cyprinidae whose dominance is about 53.7%, inhabitants of Ganga river channels in Pakistan, bangaldesh, Nepal and north india (Sheikh et al., 2017).They are eurythermal species which flourish at about 25-32°C water temperature (Azhar et al., 2022).

Labeo rohita is commonly cultured fish in indian subcontinent. Due to climatic changes fresh water fish face environmental challenges in Pakistan. Temperature changes are most common and distressing environmental factor for major carps. When water temperature dropped or rise from 28 °C it increases mortality rate (Azhar et al., 2022).Warmer temperature has great impact thermodynamics rate on biochemical reactions rate (Little et al., 2020).Lower temperature has negative impact on hormonal and cellular response as shown in Table 1 (Lindmark et al., 2022).

Table 1 Mortality rate of Labeo rohita at different temperature

Temperature	Mortality Rate	References
28°C	0%	(Azhar et al., 2022)
25°C	16%	(Azhar et al., 2022)
20°C	22%	(Azhar et al., 2022)
15°C	43%	(Azhar et al., 2022)
10°C	85%	(Azhar et al., 2022)
30°C	1%	(Azhar et al., 2022)
33°C	2%	(Azhar et al., 2022)
35°C	3%	(Azhar et al., 2022)

In outdoor farming water temperature vary significantly with changing season's pattern due to climate change, hence maintenance of optimal temperature is not possible in outdoor culturing (Cascarano et al., 2021; Tahir et al., 2024).Temperature fluctuation effects protein metabolism, higher temperature rise protein consumptions which leads to excessive ammonia production and excretion in water bodies ultimately leads to eutrophication ,deteriorate water quality and cause death of many aquatic species (Huang et al., 2016; McCarthy et al., 1999; Volkoff & Rønnestad, 2020).Inadequate dietary protein can weaken immune system, stunt growth and increases susceptibility to disease (Cai et al., 2018; Wu et al., 2021; Yadata et al., 2020).Dietary protein requirements for Labeo rohita is about 30% of total diet (Renukaradhya & Varghese, 1986; Singh et al., 2006) and for optimal performance culture temperature about 28-33 °C (Das et al., 2005; Shahjahan et al., 2021). At 30 °C Labeo rohita show best growth performance, increase cost efficiency and reduce feed waste as compare to 25°C and 35°C.At lowest temperature it does not show good performance because feed not efficiently utilize (Tahir et al., 2024).

In Pakistan both native and exotic fresh water species exist (Haseeb & Yousafzai, 2023).193 native species present in freshwater ecosystem (Iqbal et al., 2023; Rafique & Khan, 2012). Pond based aquaculture produces 31 edible freshwater species (Inayat et al., 2024). Monsoon season acts as environmental clue which trigger spawning season (Bais, 2018). Labeo rohita is major carp optimal temperature for its spawning is 22-32 °C (Azhar et al., 2022), beyond this thermal limit spawning behavior decreases as shown in Table 2. It produces about 1.5-2kg eggs of their body weight (Tripathi et al., 2017). Indian major carps are the backbone of freshwater fish farming because these grow faster as compare to

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other (Paul et al., 2016). Their growth rate is optimum when dietary protein level is about 28-35 °C (Mishra, 2021).

Table 2 Labeo rohita reproductive performance affected by water temperature

Area	Temp	Ovulation-%	Spawning time-hour	Fertility %	Hatching -hours	References
Islamabad (Punjab)	26.3	100	9	85	29	(Azhar et al., 2022)
Bangladesh	32	100	8	88	13	(Ashaf-Ud-Doulah et al., 2021)
India	28	100	6	85	24	(Iqbal et al., 2023)
Barisal (Bangladesh)	29	100	7	86	24	(Minar et al., 2012)
Punjab(India)	28	100	7	77	24	(Tiwana & Raman, 2012)
New Delhi (India)	29	100	7	82	22	(Sridhar et al., 2014)

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