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Research Article

Winter ambient temperature and daily activities of captive mugger *(Crocodylus palustris)* in Peshawar Zoo Pakistan

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Abstract

The Present study explored the effect of ambient temperature on the daily activities (behavior) of captive mugger (*Crocodylus palustris*) during winter season (December 2023 to February 2024) in Peshawar Zoo, Pakistan. Research data was collected through field observation of daily temperature and corresponding mugger behavior in predefined intervals, including morning (0600 to 1100 h), noon (1100 to 1700 h), evening (1700 to 2400 h) and night (00 to 600 h). Different behavioral parameters of mugger include aggression, eating, socialization, basking, submerge, and surface position and movement. Results showed that mean temperatures during study period were 8.85±0.39°C, 19.92±0.40°C, 14.50±0.36°C and 9.97±0.35°C for the morning, noon, evening and night time respectively. Mugger allocates 60%, 20% and 18% of their time in a surface position, submerged and basking during morning (0600 to 1100 h). As temperature increased at noon (1100 to 1700 h) and evening (1700 to 2400 h), crocodiles spent most of time in basking (55% and 40% respectively) and in surface position (40% and 58% respectively). However, during night (00 to 600 h), crocodiles allocated 98% of their time to being in a surface position in water ponds to regulate its body temperature. Linear regression analysis indicated that the mugger submerged activity has showed the highest negative correlation with daily temperature (R^2=-0.23), followed by socialization (R^2= -0.20), basking (R^2=0.10) and surface (R^2=0.10). Stepwise regression model indicated that basking, socialization, surface position, submerged position and animal movement have significant relationship with daily temperature (F= 27.68, df= 5, P-value<= .050) with overall R^2 and adjusted R^2 values of 0.364 and 0.351 respectively. The study concluded that basking, surface position and submerged behavior were the major activities of *Crocodylus palustris* in peak winter season and the effect of extreme temperatures may further be explored with respect to mugger thermoregulation at Peshawar Zoo.

Keywords: Peshawar Zoo, Mugger, Basking, Submerge, Extreme Temperature.

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Introduction

Reptiles often employ behavioral strategies to regulate their body temperature, specifically through the controlled adjustment of temperature, both elevating and reducing it [1 - 3]. Specifically, the thermoregulation of crocodilians is predominantly influenced by their behavior [3 - 4]. Certain behaviors, such as sunbathing and moving between land and water or sun-exposed and shaded areas, have long been acknowledged as having thermal importance in crocodiles [3]. Marsh crocodiles are relatively large reptiles, with adult males reaching lengths of 10 to 16 feet (3 to 5 meters), while females are generally smaller. They have an olive-green to grayish-brown coloration, providing effective cover-up in the murky waters they dwell in [5]. During the winter months exhibit several behavioral adaptations to cope with the colder temperatures. These adaptations are crucial for their survival in regions where temperatures drop significantly. Marsh crocodiles are ectothermic reptiles, meaning they rely on external sources of heat to regulate their body temperature. As ectotherms, crocodilians rely on environmental temperatures to maintain a "favorable" or "preferred" range of body temperatures (Tb), which influences health, appetite, and metabolic rates [6]. During winter, when ambient temperatures are lower, marsh crocodiles engage in basking behavior more frequently [3, 7]. They will often position themselves on riverbanks or along the edges of water bodies to absorb sunlight, which helps raise their body temperature [2 - 3]. During the winter, marsh crocodiles come out to take bask in the direct sunlight to maintain their body temperature [5]. In colder temperatures, marsh crocodiles tend to be less active compared to warmer months. They may reduce their movements and conserve energy to cope with the metabolic slowdown associated with lower temperatures. This decreased activity helps them preserve energy reserves during winter when food may be less abundant. Winter conditions can impact the feeding behavior of marsh crocodiles. Cold temperatures can reduce the activity of their prey species, making hunting less productive. As a result, marsh crocodiles may exhibit decreased feeding rates during winter months. They may rely on stored fat reserves to sustain them through periods of reduced food availability [6, 8 - 9]. Marsh crocodiles are typically solitary animals, but during the breeding season, they may exhibit increased social interactions. However, during winter, social interactions may decrease as individuals prioritize thermoregulation and energy conservation over social interactions. In regions where temperatures drop significantly, marsh crocodiles may seek out thermal refuges to avoid the coldest temperatures. These refuges could include deep water bodies with more stable temperatures or areas with geothermal activity that provides warmth even in colder conditions. Another behavioral strategy that crocodiles might employ in elevated temperatures involves lying with their mouths open, a practice that enhances evaporative cooling [10 - 11]. In crocodiles, a significant number of their behaviors occur in water, typically when their body temperature is lower than when they are outside the water [2 - 3]. They enable the crocodiles to evade prolonged exposure to extremely low (<5ºC) and high temperatures (>38ºC), conditions that could prove lethal [8, 10]. Understanding the behavioral adaptations of marsh crocodiles during winter is essential for conservation efforts and management strategies aimed at protecting these reptiles in their natural habitats. Marsh crocodile viable populations occurred only in protected areas and the species became locally extinct over large parts of its range. In 2013 total global population of *C. palustris* estimated at less than 8,700 [10] mugger crocodiles face threats such as habitat loss, pollution, and human-wildlife conflict. Conservation efforts are in place to protect their habitats

and raise awareness about the importance of coexisting with these reptiles. In case of these threats in the wild for various crocodile species, Pakistan various organization working on this to save these reptile from the extinction, they kept these species in captive environment. Estimated 600 *C. palustris* individuals are believed to inhabit four major wetland systems in Sindh, including a man-made lake [12]. Peshawar zoo also kept the Marsh crocodile in captive environment. In this study, the effect of winter ambient temperature on the behavior/ activities budget has been explored in order to evaluate thermoregulation of mugger crocodiles in captivity at Peshawar Zoo.

Materials and Methods

Study area

The study area of this research is situated in district Peshawar of Pakistan (Figure 1). District Peshawar lies between 33° 44’ and 34° 15’ north latitude and 71° 22’ and 71° 42’ east longitude and spread over 1257 square km. Peshawar Wildlife Range mainly located in the dry sub-tropical scrub forest. The flood plains/zones are the areas between Kabul River and Budni Nala where both the rivers start rising in February and reach the highest level of discharge in June and July.

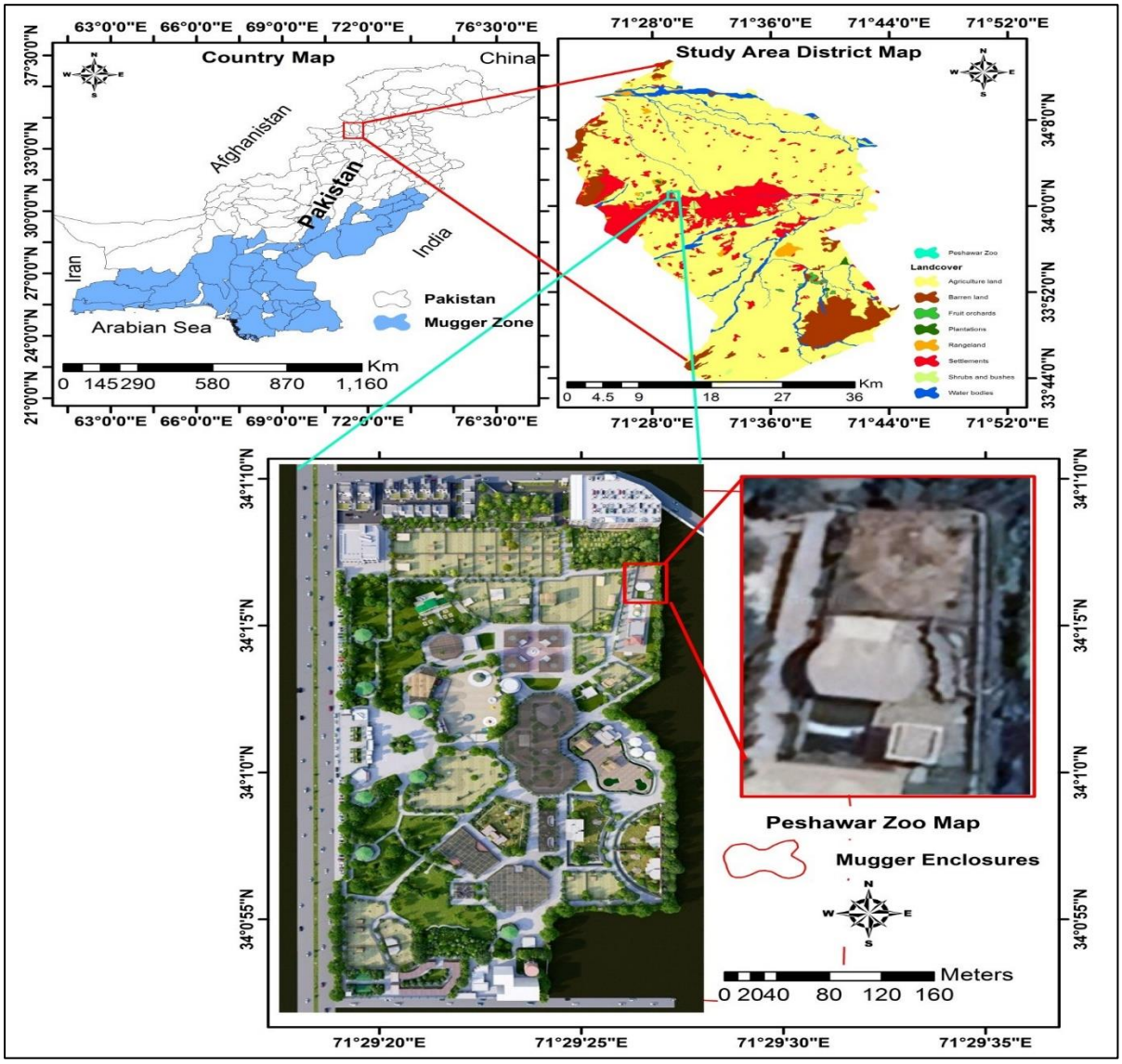

Figure 1: Study area map and mugger enclosure at Peshawar Zoo

However, naturally mugger crocodile do not exist over there. Winter in Peshawar starts from mid-November and lasts till the end of March. Summer months are May to September. The mean maximum temperature in summer is over 40 °C and the mean minimum temperature is 25 °C. Similarly, the mean minimum temperature during winter is 4 °C and maximum is 18.35 °C. Peshawar Zoo in located in district Peshawar which is the home of various species of carnivores, herbivores, omnivores, small mammals, birds, fishes and reptiles such as snakes and marsh crocodile. Peshawar Zoo is working under the wildlife department Khyber Pakhtunkhwa Pakistan. In February 2023, three mugger crocodiles (*Crocodylus palustris*) were put on display for visitors at Peshawar Zoo (Figure 1). A special enclosure was built to house them, adding to the variety of reptiles available for public viewing (Figure 2). These crocodiles, gifted by the Sindh Wildlife Department of Pakistan, are typically medium-sized, measuring around four to five meters in length, and are commonly found in their natural habitats in Sindh province of Pakistan.

Figure 2: Mugger crocodiles at Peshawar Zoo.

Data collection

The marsh crocodile activities were noted in the month of December 2023, January, and February 2024. The marsh crocodile were directly observed by Zoo staff for whole day of 24 hours. The data were collected in four times of periods, (Morning, 06:00 to 11:00), (Noon, 11:00 to 17:00), (Evening 17:00 to 24:00), (Night 24:00 to 06:00), and cross checked with CCTV footage. Historic temperature data was downloaded from WorldClim website (https://www.worldclim.org/) in order to evaluate the favorable environment for mugger crocodile at Peshawar Zoo (Figure 3).

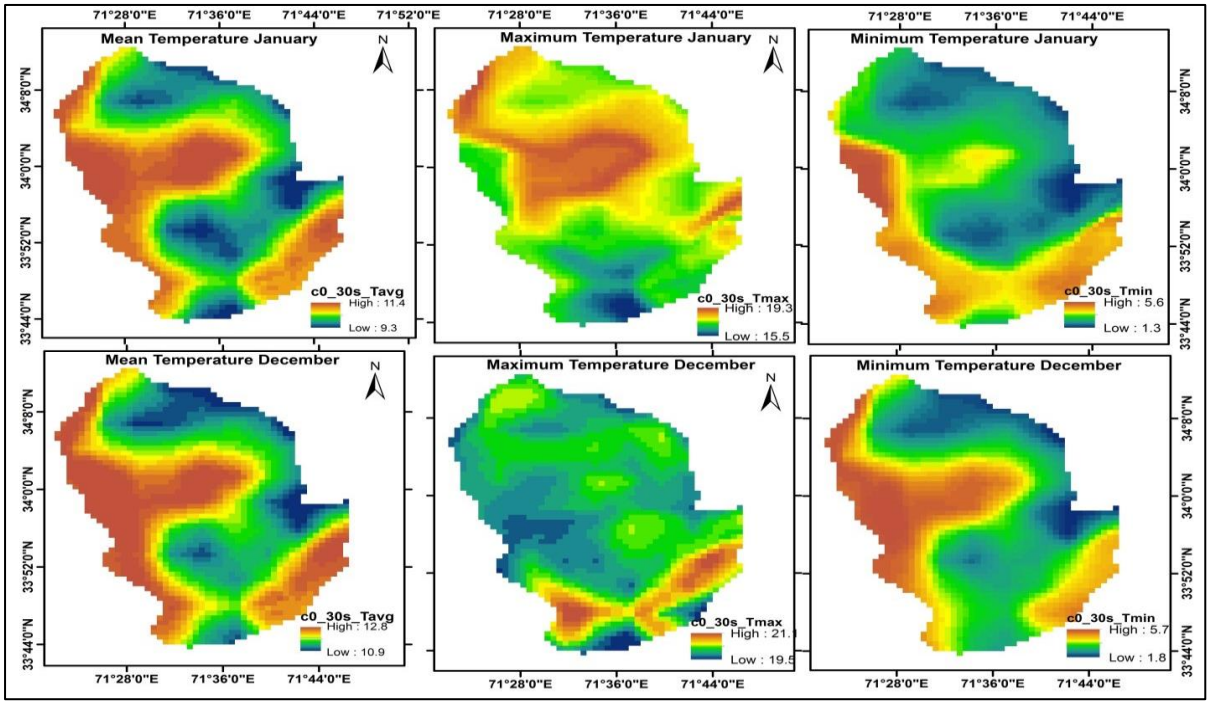

Figure 3.Historic mean, maximum and minimum temperature of the study area map.

Table 1: Description of mugger crocodile activities.

Activities	Description
Aggression	unenthusiastic activities (antagonism for non-food items), chase with violent intention Physical argument, Aggressive threat display, gaping
Socializing	Courtship (pairing, turning, rubbing of dorsal, coupling) attentiveness display, subservient pomposity
Basking	partly reserved out of water, whole body out of water, on land area; pestering victim
Submerge	whole body obscured below the surface of water
Surface	Whole body or head uncovered and floating at surface
Movement	Movement from one place to another.
Eating	Eating something for the sake of food item.

The enclosure where the marsh crocodile lives is concluded with rocks, water ponds, sand, grass, shelters and breeding coops. The size of the enclosure is 447 sqm. The enclosure is divided into 2 parts, part 1which is cover with shelter, (water pond = 1200 sqft, Breeding coup= 408 sqft (keeping in view the nesting and burrow behavior of crocodile 3 large chamber/Shelters have been constructed so that crocodile sought refuge from intense heat or cold temperature), grass substrate and rocks sloppy land near the pond, part 2 which is open area, (grass substrate, sands, plants). The temperature of the surrounding area of the crocodile enclosure was noted through the thermometer. The thermometer was installed inside the crocodile enclosure. The routine check of temperature was noted on daily basis. The feed was provided once a week is (Meat, Chicken, and Fish).

Statistical analysis

Temperature analysis of daily temperature measured and pre-defined interval has been represented through box plot and line paragraph. Furthermore single behavioral parameter was regressed against temperature using scatter plot. Lastly step wise linear regression model was developed using temperature as defendant variable and behavioral parameter as explanatory variable. Correlation matrix has also been developed between temperature and behavioral activities budget for all various times using (R) software.

Results

Variation in daily temperature in peak winter season

Daily observations of air temperature at different periods (morning, noon, evening and night) during peak winter season showed that highest temperature was observed during noon time (11 AM to 6:00 PM) followed by the evening time (6:00 PM to 12 AM) and night time (12:00 AM to 6:00 AM) whereas the lowest temperature was recorded during morning time (6:00 AM to 11:00 AM) due to fog dominated days. Overall, during peak winter months of daily temperature observation, minimum temperatures were 3°C, 11°C, 08°C and 5°C whereas the highest temperatures were 14°C, 25°C, 20°C and 14°C for morning, noon, evening and night timing respectively (Figure 4).

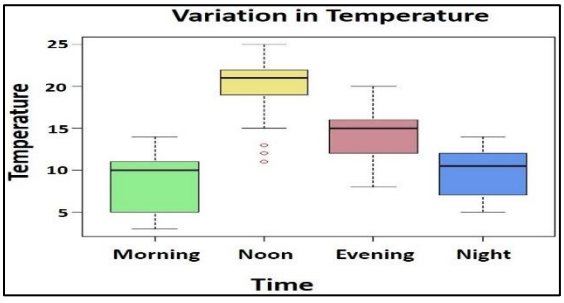

Figure 4: Overall daily temperature variation for marsh crocodile

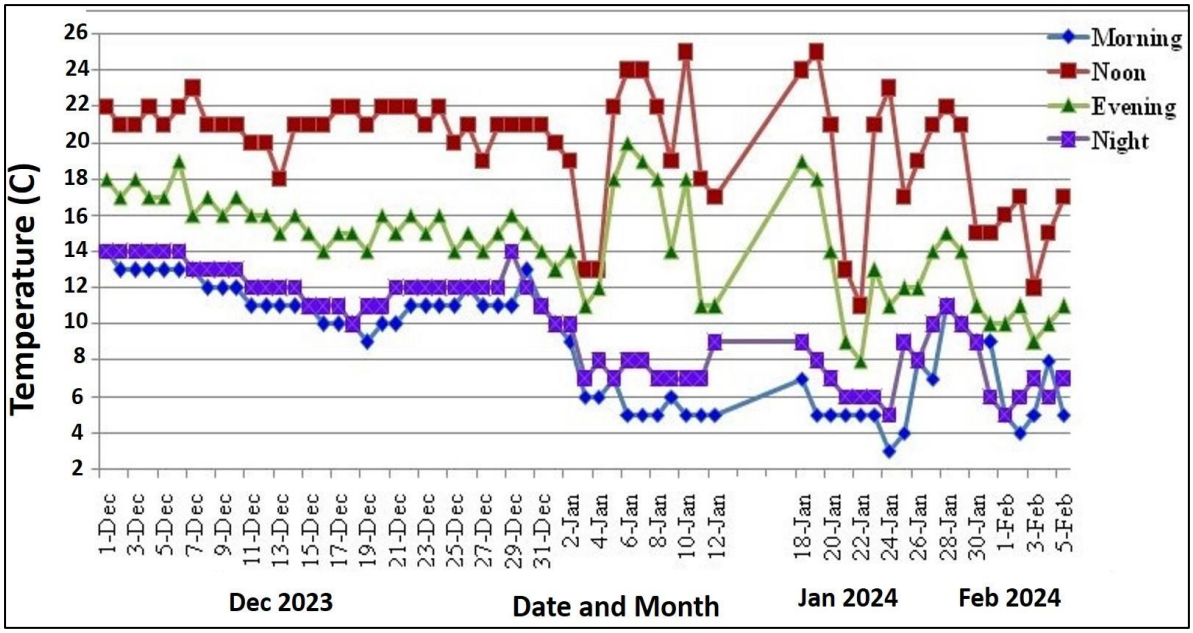

Figure 5: Variation in daily temperature during different intervals.

Mean temperatures were 8.85±0.39°C, 19.92±0.40°C, 14.50±0.36°C and 9.97±0.35°C for the morning, noon, evening and nighttime respectively. Furthermore, during December 2023, daily mean temperatures for morning time was 11.45±0.21°C, noon time 21.09±0.17°C, evening time 15.77±0.23°C and nighttime 12.23±0.20°C whereas on the other hand in January and February 2024, mean temperature trends, have been changed in all time intervals; such morning (6.26±0.37°C), noon (18.74±0.73°C), evening (13.23±0.61°C) and night (7.61±0.28°C). Overall, maximum daily temperatures have been increased, and minimum daily temperatures have decreased in January/February 2024 compared to December 2023, which has significant influence on the activities of marsh crocodile (Figure 5).

Activities budget of marsh crocodile

The findings indicated that the primary daily activities of marsh crocodiles during the peak winter season include basking, being in a submerged position, and lying at the water surface. Occasional movement and socialization were also observed (Figure 6), while activities such as aggression and eating were rare and negligible in overall observations. During the morning period (6:00 AM to 11:00 AM) with a mean temperature of 8.85±0.39°C, crocodiles spent 60% of their time in a surface position, 20% submerged, and 18% basking as temperatures rose, with only about 1% of their time dedicated to movement. As temperatures increased at noon (11:00 AM to 06:00 PM) with mean temperature 19.92±0.40°C, crocodiles allocated 55% of their time to basking in dry enclosures and 40% in a surface position during peak temperatures. Movement accounted for 2% of their time, while 3% was spent submerged during the noon period. In a similar pattern, during the evening hours (06:00 PM to 12:00 AM) with a mean temperature of 14.50±0.36°C, marsh crocodiles primarily spent 58% of their time in a surface position, followed by 40% of their time basking outside of the water, and 2% of their time engaged in movement (Figure 6). Night time.Similarly, during the night hours (12:00 AM to 6:00 AM) with a mean temperature of 9.97±0.35°C, crocodiles allocated 98% of their time to being in a surface position in water ponds, with about 1% of their time dedicated to movement and socialization activities.

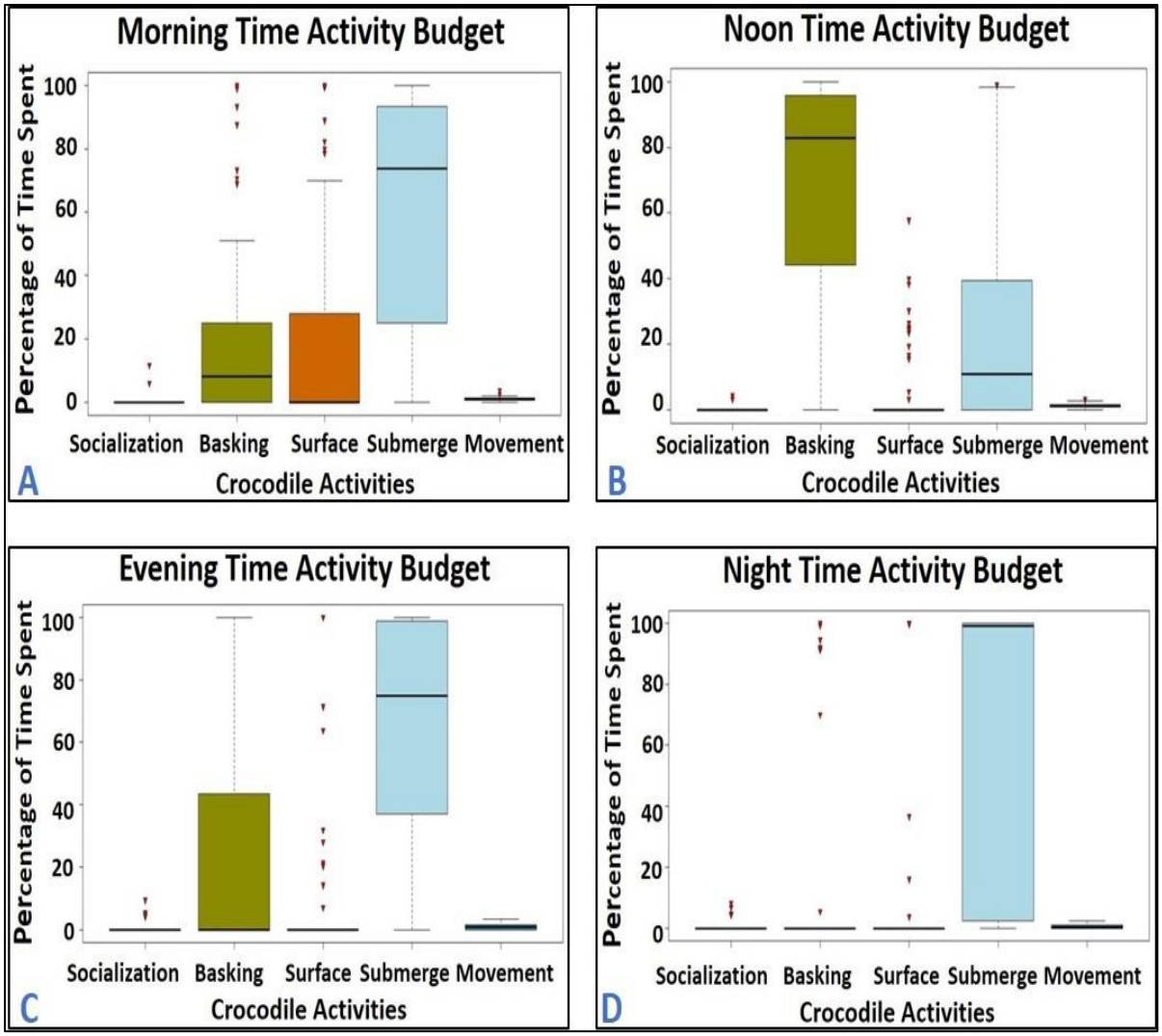

Figure 6: Mugger activities A. Morning time; B. Noon time; C. Evening time; D. Night time.

Correlation of temperature with activities of marsh crocodile

The correlation matrix analysis revealed that during the morning hours with a mean temperature of 8.85±0.39°C, there was a weak positive correlation for submerge position (R=0.05) and surface position (R=0.08), while socialization, basking, and movement showed negative correlations with R values of -0.16, -0.15, and -0.15, respectively (Figure 7). Similarly, at noon with a mean temperature of 19.92±0.40°C, a weak positive correlation was observed for submerge position (R=0.18) and movement (R=0.02), while negative correlations were noted for socialization (R=-0.26), surface position (R=-0.05), and basking (R=-0.02). During the evening hours with a mean temperature of 14.50±0.36°C, the submerge position and surface position of marsh crocodiles showed weak positive correlations with R values of 0.05 and 0.07, respectively (Figure 7). However, socialization, movement, and basking exhibited negative correlations with R values of -0.32, -0.29, and -0.09, respectively. Conversely, during the night hours with a mean temperature of 14.50±0.36°C, only the surface position of marsh crocodiles demonstrated a good positive correlation (R=0.17). The other activities, including socialization, movement, and submerge position, displayed negative correlations with R values of -0.22, -0.29, and -0.01, respectively.

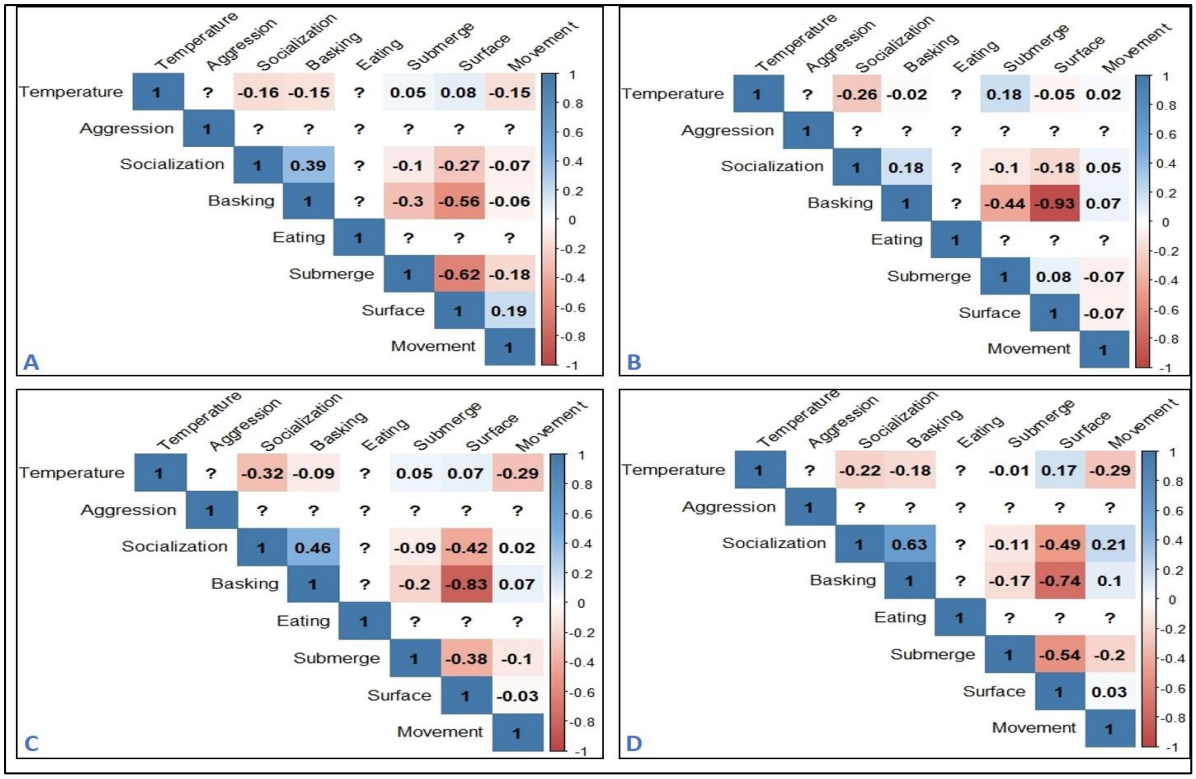

Figure 7: Correlation matrix A. Morning time; B. Noon time; C. Evening time; D. Night time.

Linear regression between daily temperature and crocodile activities

The scatterplot illustrating the relationship between daily temperature and marsh crocodile activities has been presented in Figure 8. The linear regression analysis indicated that the submerge activity of marsh crocodiles achieved the highest negative correlation with daily temperature, with an R^2 value of 0.23. This suggests that during the December 2023 to January 2024 winter season, as temperatures decreased, the marsh crocodiles exhibited a preference for being in a submerged position within the ponds of their enclosure to regulate their body temperature. Furthermore, the analysis revealed that socialization activity, although constituting a small proportion of the daily activity budget, exhibited a correlation with temperature (R^2= -0.20) and specifically, at lower temperatures, marsh crocodiles were observed to engage more in socialization activities. The scatterplot depicting the relationship between basking and daily temperature (R^2=0.10) indicated that marsh crocodiles tended to engage in basking behavior outside water ponds as temperatures increased. However, at peak highest temperatures, the crocodiles avoided basking and returned to the ponds to regulate their body temperature. Similarly, the scatterplot for the surface position of marsh crocodiles (R^2= -0.10) demonstrated that during optimal temperatures in late morning, early noon, and early evening, the crocodiles were observed lying on the surface of the water with their head or dorsal position outside the water (Figure 8). As temperatures increased, the crocodiles progressively avoided the surface position regarding the movement of marsh crocodiles, the analysis revealed a weak relationship with daily temperature (R^2=0.05). However, fluctuations in temperature, whether high or low, prompted the crocodiles to adjust their positions relative to their body temperature, moving towards or away from the water ponds accordingly. Other activities, such as aggression and feeding do not exhibited no relationship with daily temperature.

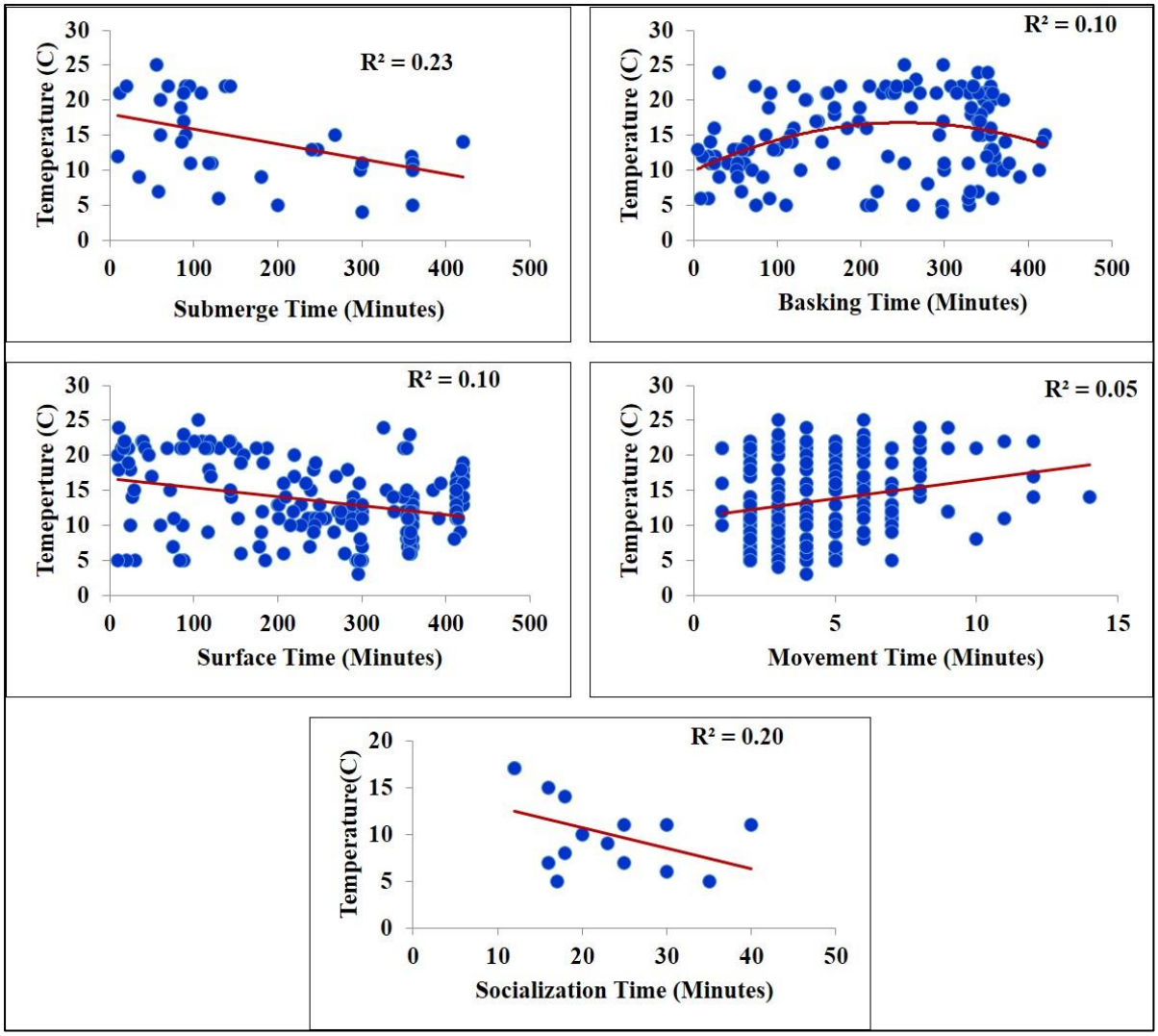

Figure 8: Scatterplot of mugger activities versus daily temperature.

Additionally, observations indicated that marsh crocodiles consumed a negligible amount of food, approximately 1-2 kg of meat per month and the food provided remained unconsumed even after several days within enclosures.

Stepwise linear regression (SLR) between daily temperature and crocodile activities

SLR model showed that daily activities of marsh crocodile including basking, socialization, surface position, submerged position and animal movement have significant relationship with daily temperature (F= 27.68, df= 5, P-value<= .050). Model summary showed that overall R^2 and adjusted R^2were 0.364 and 0.351 respectively with standard error of 4.25 (Table 2). Stepwise selection in SLR has been completed in five different models where predictors have progressively been added and the corresponding R^2 has been increased from 0.13 in the first model to 0.36 in the last model. SLR model indicated almost 36% of the variance of the daily temperature could be accounted for daily activities budget observations.

Discussion

This study identified the impact of ambient temperature on the daily activities of mugger (*Crocodylus palustris*) during winter season at four prominent intervals (morning, noon, evening and night) in Peshawar Zoo.

Table 2: SLR model daily temperature and crocodile activities.

Variables Entered/Removed		Model Summary				
Variables Entered	Variables Removed	R	R Square	Adjusted R Square	Std. Error of the Estimate	
Basking	Aggression Eating	0.603	0.364	0.351	4.25	
Socialization		**ANOVA**				
Surface			SS	df	MS	F
Submerge		Regression	2500.21	5	500.042	27.686
Movement		Residual	4370.88	242	18.061	
		Total	6871.09	247		

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error			
(Constant)	-4.055	2.33		-1.74	0.083
Basking	0.058	0.007	1.593	8.731	0
Socialization	-0.267	0.051	-0.289	-5.251	0
Surface	0.042	0.006	1.240	6.546	0
Submerge	0.045	0.007	0.762	6.134	0
Movement	0.209	0.097	0.114	2.149	0.033

a. Dependent Variable: Daily Temperature
Predictors in the Model: (Constant), Basking, Socialization, Surface, Submerge, Movement.
Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

Overall, variations in daily hourly temperature (3°C to 25°C) in January and February 2024 were more prominent as compared to the temperature (8°C to 23°C) December 2023. It is because that remarkable dense fog continued for weeks with up to 100% humidity in the month of January 2024 during the cold wave in the study area. Moreover, the temperature variations was also consistent with the monthly official reports of country meteorological department, that throughout the month of January 2024, an abnormal occurrence of prolonged and dense fog persisted in Khyber Pakhtunkhwa (province of study area) Pakistan [13]. Further, mean temperature in January 2024 was 14.2°C with maximum 23°C and minimum 4.1°C [13]. According to the monthly climate data acquired from Climate Data Processing Center (Figure 9), Pakistan Meteorological Department (https://cdpc.pmd.gov.pk/), temporal variations in temperature in the past four years showed that mean and maximum temperature has been increased from December 2020 to December 2023 whereas on the other hand, maximum and minimum temperature has been decreased from January 2021 to January 2024.

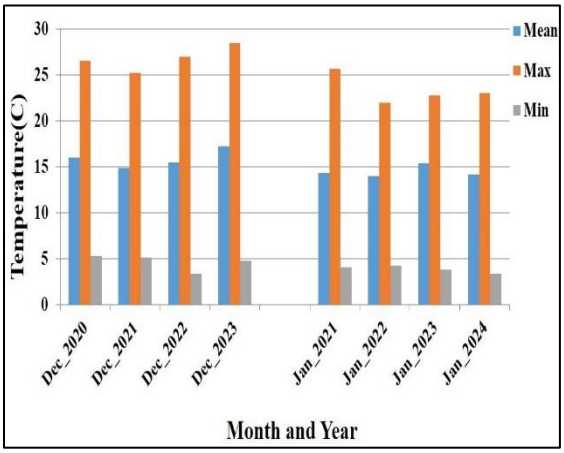

Figure 9: Temperature temporal data acquired from climate data processing center, Pakistan.

Moreover, this study indicated that major activities of *Crocodylus palustris* during peak winter season were basking, remain

on surface of water (head and dorsal body outside water) and submerged position during morning, noon and evening time (from 06:00 to 1800 hours) whereas during night time mugger remained in surface position. The findings of winter activities of mugger demonstrated in this study were consistent with several other studies [14 - 17]. During the winter, basking is a seasonal phenomenon that was observed to occur for longer periods of time on land compared to the summer [15]. Moreover, Mugger utilize burrows in extreme temperatures as refuges for thermoregulation [18 - 19]. Specifically, *C. palustris* were seen basking from 9 AM to 4 PM during the winter season [15, 17]. Scientists highlighted that basking sites play a crucial role in thermoregulation for all types of crocodiles. During winter, *C. palustris* preferred to bask outside the water when the temperature ranged between 27.4ºC and 19.9ºC with a preference for basking on rocky soil or substrate outside the water [16]. Crocodiles engage in a behavior "mouth-gaping" where they face the sun and open their mouths to facilitate evaporative heat loss. By keeping their mouths open while basking, crocodiles are able to regulate their body temperature effectively [14].When not basking, they typically prefer to remain in the water. The basking behavior is deemed crucial for raising the body temperature of crocodiles, as this elevated temperature may enhance their performance when they re-enter the water [3]. According to researchers, the main typical daily activities of crocodiles include basking for extended periods under the sun, swimming on the water surface, and surface/ stagnant position in the water [15, 17]. The observations of this study are consistent with the results that mugger exposed themselves to the sun during the day and remained in the water during the night, particularly during the winter season [2].

In a study it was found that the mean body temperature of crocodiles ranged from minimum of 18.8–19.6°C to maximum of 26.9–29.2 °C. Additionally, the body temperature of crocodiles tended to increase during the day, typically rising after 10:00 in the morning. This increase in temperature often prompted the crocodiles to leave the water and engage in basking during the morning and noon hours [3]. Crocodiles typically begin basking at 09:00 hours when temperatures range from 14 to 20°C followed by the peak winter basking period occurs at 13:00 hours when temperatures reach 24°C or higher during December and January. Moreover, adult crocodiles are observed to bask predominantly on land from 10:00 to 14:00 hours, especially when the air temperature ranges from 19 to 24°C [20]. However, as temperatures rise to 30 to 35°C in the afternoon, the proportion of crocodiles basking fully on land decreases, with more crocodiles opting to bask partially in the water [20]. Moreover, the research on the basking/ sunning behavior of a wild mugger population (from 0900 to 1600 hrs) during winter in Rajasthan, India, conducted aligns with the findings of this study [21].

Crocodiles regulate their body temperature through behavioral mechanisms, such as they move to deeper water to decrease body temperature and do basking to warm up. The researchers also suggested that a temperature of 33°C might be associated with basking behavior, while temperatures around 26°C could be linked to crocodiles being on the water surface or in shallow water [22 - 23]. Captive mugger in the Zoo of Bangladesh regulate their body temperature by alternating between sunning themselves and seeking shade or cooler water. Moreover, adult mugger were observed to maintain stable temperature of their bodies within the preferred range of 30 to 32°C for extended periods, including overnight [24]. Scientists also reported a similar body temperature range of 30-33°C for crocodiles. The study further explained that when crocodiles are sunning or basking, they orient themselves to

maximize their surface area to regulate their body temperature. To prevent further overheating, crocodiles may return to the water in a surface position [25]. During a habitat survey conducted in Nepal between February and March, which are considered the post-winter months, it was observed that the majority (76%) of the muggers engaged in basking behavior whereas the rest of the muggers (26%) were observed to be submerged in the river [26]. Likewise, muggers showed a preference for basking on elevated platforms and sloping riverbanks in their in-situ home range [27]. The highest numbers of mugger crocodiles were seen basking during the winter season in the late morning time 1100 hrs compared to the summer season. Such sunning or basking behavior involves moving between the sun, shade, and water, is primarily influenced by the ambient temperature [28].

Throughout most of the year, freshwater crocodiles typically do not engage in social interactions with each other. However, during the breeding season, males and females are observed to spend a significant amount of time with one another. It is important to highlight that the social behavior of freshwater crocodiles remains relatively understudied in comparison to their saltwater species [29]. In addition, the eating behavior of muggers was deemed negligible in this study, as observations showed that crocodiles could go for weeks without eating during the winter season. Similarly, larger crocodiles have the ability to go for extended periods without consuming a meal [30]. In extreme situations, these crocodiles may even enter a state where they shut down and survive by utilizing their own body tissues for sustenance over a prolonged period of time. Breeding of freshwater crocodiles in captivity can be challenging unless the facility is located in a tropical area with constant ambient and water temperatures [31]. Further, maintaining the optimal environmental conditions for mugger breeding in captivity is difficult and expensive, as it requires a large exhibit for accommodation [29].

Conclusion

This research concluded that the ambient temperature plays a significant role in influencing the daily activities of mugger crocodiles (*Crocodylus palustris*) during the winter season at four specific times of the day (morning, noon, evening, and night) at Peshawar Zoo. Overall, the main activities of *Crocodylus palustris* during the peak winter season include basking, staying on the water's surface with their head and dorsal body exposed, and adopting a submerged position during the morning, noon, and evening hours (from 06:00 to 18:00). The study proposes that additional research could investigate how extreme temperatures impact the thermoregulation of mugger crocodiles at Peshawar Zoo.

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