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Utilization of artificial water holes by tiger (*Panthera tigris*) and its prey species in dry season in Bardia National Park of Nepal

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ABSTRACT

Waterholes play a crucial role in wildlife habitats, serving as a determining factor in maintaining a healthy ecosystem for wildlife. In the core area of the park, a total of 179 artificial waterholes were constructed to provide water to various wildlife species, with 24 of them selected for this study. The research utilized camera trapping, signs surveys, and direct observation methods. The camera trapping survey revealed that 17 different wildlife species frequented the artificial waterholes, and among them, 11 were identified as prey species for tigers. Interestingly, the study found that tigers primarily utilized artificial waterholes during the night or at dusk, while prey species used them both day and night. Tigers were recorded in seven different artificial waterholes, with pugmarks observed in an additional eight. In contrast, prey species were recorded in all selected artificial waterholes. Notably, the study identified a unique pattern of waterhole usage, with both tigers and their prey species sharing waterholes without temporal partitioning. Among the waterholes, those in grasslands were more frequently used by the prey base compared to others. Additionally, a greater diversity of wildlife species was recorded in the grassland waterholes. Based on these findings, it is recommended to conduct an in-depth study to explore the temporal and spatial aspects of the prey-predator waterhole usage relationship in Bardia National Park.

Keywords: Waterholes, Tiger, Prey species, Utilization, Bardia National Park, Camera Trapping, Biodiversity Index, Dry season

1. INTRODUCTION

The distribution and quality of water are elements that impact the carrying capacities of protected areas, as water availability significantly influences the distribution and abundance of animals in varied habitats (Kamando et al., 2008). Animals can obtain water from three different sources: preformed water (found in food), free water (streams, rivers, puddles, lakes, etc.), and oxidative or metabolic water (created as a byproduct of the oxidation of organic compounds

containing hydrogen). The levels of waterholes and rivers (i.e., the amount of free water) are directly influenced by highly seasonal patterns of rainfall, which also affect the seasonally available food. Animals can survive in water-scarce environments by congregating in locations with comparatively steady water supplies, developing water-resistant life forms through dormancy, seasonal resource tracking and movement, or developing high levels of tolerance for low water conditions through behavioral and physiological adaptations (Marion, 2003).

Many species rely solely on behavioral methods to prevent dehydration, even though physiological adaptations to high water deprivation have been observed in taxa restricted to dry environments (Oliver et al., 2005). The most frequently documented behavioral technique of medium to large-sized vertebrates for overcoming water scarcity during the dry season is seasonal migrations away from and toward locations with a high quantity of free water. Waterholes are one of the most important determining factors in maintaining a healthy ecosystem in habitat management (Ayeni, 2007). Artificial waterholes make a significant contribution to wildlife conservation and management (Sukumar et al., 2021). These waterholes are used to meet the needs of animals, particularly during dry spells, and to provide water to areas without natural waterholes.

Free water sources play a crucial role in determining wildlife species' presence or absence, movement, and carrying capacity in seasonally dry and semi-arid environments. Nevertheless, waterholes are regarded as prime places for competition and predation (Knight, 1995; Valeix et al., 2010). Both carnivores and their prey species act strategically when using waterholes. For instance, in savanna habitats of Africa, lions prey by taking advantage of vegetation surrounding waterholes (Makin et al., 2017). On the other side, prey species of lions opt for various anti-predation strategies at waterholes, including enhanced vigilance, minimized waterhole use at night, and increased numbers at high-risk waterholes (Valeix et al., 2009). Similarly, apex predators such as tigers are found preferring to stay near waterholes, while prey species are observed avoiding predators by modifying their activity patterns Beier and McCullough, (1990), either spatially Amoroso, (2020) or temporally partitioning to reduce the chance of overlapping with competitors or predators (Xue et al., 2018).

Bardia National Park (BNP) is the largest national park in the lowland Terai of Nepal. While the BNP is rich in biodiversity, dryness poses a serious challenge to wildlife management. Over 179 artificial waterholes have been constructed inside the park, but only some have water during the dry season. Despite the construction and periodic maintenance of waterholes in the BNP, there is no quantitative information available on the use of such waterholes by wildlife. Information on which species use these waterholes and how frequently would be important to evaluate the effectiveness of waterholes. This study aims to identify how artificial waterholes are being utilized by tigers and their prey species in the BNP. We expect that the findings from this study will help develop an artificial waterhole management strategy and program alongside its implementation for the habitat management of tigers and their prey species in the park.

2. METHODS

Study area

The BNP (Figure 1) is situated in the Bardia district of Lumbini Province in southwestern Nepal, covering an expansive area of 968 square kilometers. Established to protect representative ecosystems and conserve the habitats of tigers and their prey species, it is located in Nepal's Western Terai. Rivers, lakes, and waterholes serve as the primary sources of water for the diverse wildlife species within BNP. Globally endangered and charismatic species, including the one-horned rhino, elephant, tiger, Gangetic dolphin, and gharial, find their home in this rich habitat (Bashyal et al., 2021). The BNP is strategically positioned, benefiting from the presence of two major rivers, namely Karnali and Babai, along with their tributaries, which create prime habitats for wildlife (Bashyal et al., 2021).

The Babai, originating from the Churia Range in the Dang Valley, is a warm-water river system displaying seasonal changes in water temperature. In contrast, the Karnali is snow-fed and perennial, originating from the Tibetan Plateau (Bashyal et al., 2021). The park experiences a subtropical climate, broadly divided into three seasons: Summer (March–May), monsoon (June–September), and winter (October–February). Typically, from October through early April, the weather tends to be dry. The study was specifically conducted in the core area of BNP, encompassing the Karnali floodplain, Babai floodplain and valley, and the chure-bhabar region.

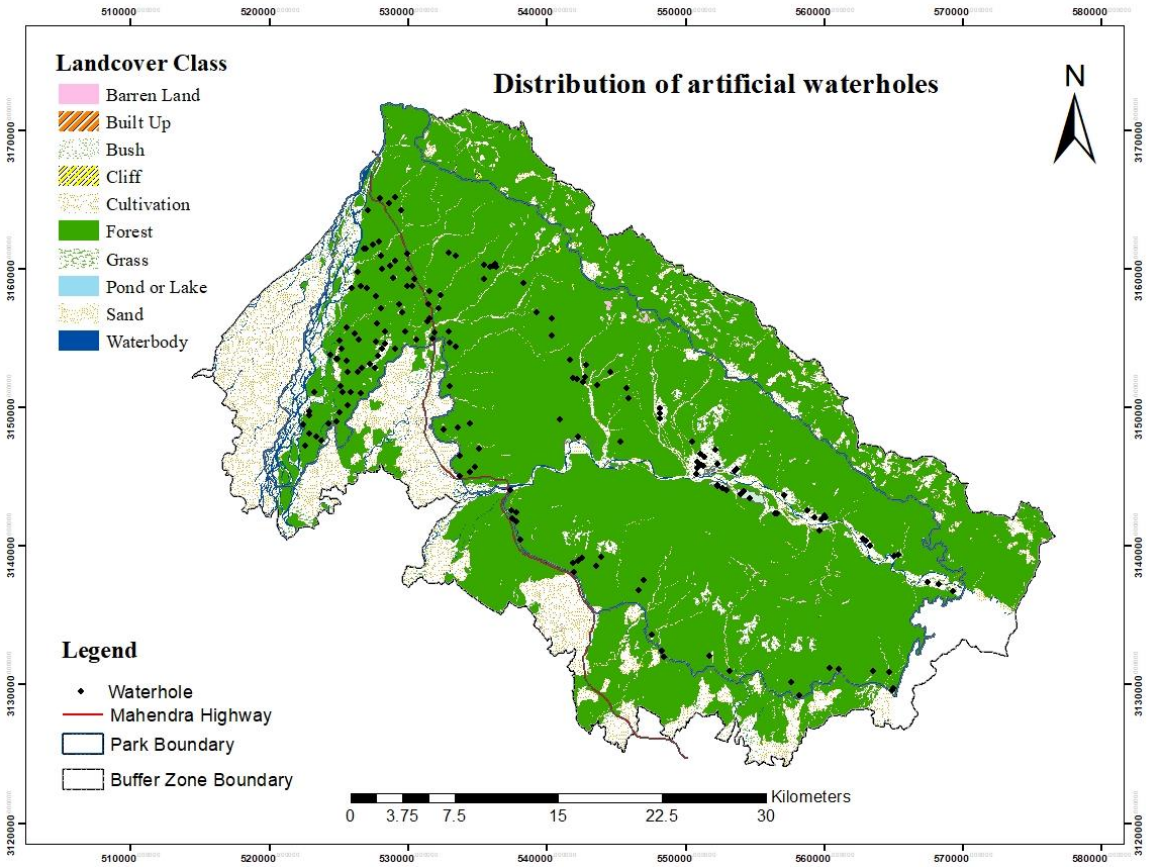

Figure 1 Map of Bardia National Park showing core area (in green shaded region) along with various water bodies and artificial waterholes distributed across the park.

Camera trap survey

A total of 179 artificial waterholes (Table S3: Supplementary materials) have been constructed across Bardia National Park (BNP) since 1994. For the camera-trap survey, waterholes were not selected based on specific criteria; instead, we chose those that consistently contained water even during the dry season. Our goal was to have representation from the Karnali and Babai floodplains, the Chure-Bhabar region, and various habitat types including forests and grasslands. The camera trap survey aimed to assess the distribution and utilization patterns of artificial waterholes by tigers and their prey species during the dry season (April to May 2020 A.D). Each selected waterhole was equipped with one camera trap (Cuddeback camera), except for two larger waterholes (Lower Lamkauli and Reinforced Cement Concrete (RCC) Lamkauli), where two camera traps were installed.

Cameras were set to operate 24 hours a day with a 5-second delay between photographs, and date and time were recorded automatically on all images. To maximize species encounters, camera traps were strategically placed 2–3 meters from the water's edge in areas with higher concentrations of wildlife signs, such as footprints. Depending on the topography and location, camera traps were positioned on trees or poles at a height of 60–70 cm above the ground to increase the chance of capturing large ungulates. We ensured a maximum trigger distance of approximately 20 meters to detect animals, and all cameras were set to medium sensitivity to minimize false captures caused by moving vegetation. Waterholes were visited every six days to check batteries and storage. After completing the survey, we collected all camera traps, transferred data (images) from memory cards to a computer, and identified the species captured by the camera traps.

Biodiversity index

The diversity of wildlife species using waterholes was calculated by using Shannon-Wiener diversity index (*H*) after animal's identification in photographs provided by camera trapping multiplied by -1:

$$H=-\sum_{i=1}^{S} Pi \ln Pi$$

If the value of H, is <1.5=Low diverse

1.5-2.5=Medium diverse

>2.5=High diverse

3. RESULTS

Spatial distribution of artificial waterholes

Out of the total artificial waterholes constructed across the park, only 24 were selected for the study. Among them, 13 had a solar boring system for water supply, while 11 did not. The distribution of artificial waterholes was more concentrated in the Karnali floodplain area compared to the Babai floodplain and the eastern part of the park (i.e., 54 in Babai valley, 27 in the eastern parts, and the remaining 98 in the Karnali floodplain and north of the Karnali floodplain). Similarly, among the selected artificial waterholes for the study, four were in the grassland habitat, 16 were in mixed Sal (Shores Robusta) Forest, and four were located in between grassland and Sal Forest (boundary line). All the artificial waterholes inside the park are situated in Sal Forest, grassland, or in the boundary line (i.e., between grassland and Sal Forest). Therefore, three habitats were considered for the study.

Utilizations of artificial waterholes by wildlife

The utilization of artificial waterholes by wildlife was determined through the analysis of images captured by the camera traps placed in each of the selected waterholes. Additionally, indirect animal surveys conducted in the study area, such as observing pug marks, fecal pellets, scat, scratches, and footprints, were used to analyze data and examine the use of artificial waterholes by wildlife. Frequent utilization of specific waterholes by animals was determined based on the number of images captured by the camera traps at each location. Similarly, a high frequency of indirect signs recorded in and around the waterholes indicated more substantial use of these water sources. The species recorded in the study area, specifically in the selected artificial waterholes, are detailed in (Table 1).

Table 1 Different wildlife species recorded in the artificial waterholes

Name of waterholes	Species Recorded
Chisapani range post waterhole	Jackal, Wild boar, Rhesus monkey, Spotted deer, Porcupine, Civet cat, Mongoose, Birds
Guthi machan waterhole	Jackal, Spotted deer, Wild boar, Elephants, birds
Bhurigau chital waterhole	Spotted deer, Civet cat, Mongoose, Porcupine, Rhesus monkey, Grey langur, Barking deer, Birds
Kharivatti 1	Sambar, Spotted deer, Grey langur, Rhesus monkey, Wild boar, Birds
Khairvatti 2	Sambar, Spotted deer, Rhesus monkey, Wild boar, Grey langur, Birds
Rammpur Boring Pokhari	Spotted deer, Grey langur, Wild boar, Rhesus monkey, Hog deer, Birds
Guthi Kathkuwa waterhole	Jackal, Spotted deer, Civet cat, Wild boar, birds
Thuloshree waterhole	Jackal, Spotted deer, Wild boar, Porcupine, Birds
Sano Baghaura Phanta waterhole	Elephant, Spotted deer, Mongoose, Sambar, Rhesus monkey, Grey langur, Birds
Chandramukhi waterhole	Tiger, Spotted deer, Mongoose, Porcupine, Elephants, Swamp deer, Rhesus monkey, Grey langur, Birds
Jarayo waterhole	Tiger, Elephant, Spotted deer, Mongoose, Birds
Hatti/Ganesh waterhole	Tiger, Elephant, Sambar, Gray langur, Mongoose, Spotted deer, Rhesus monkey, Wild boar, Birds
Balkuni waterhole	Elephant, Spotted deer, Rhesus monkey, Civet cat, Birds
Dhanesh waterhole	Elephants, Spotted deer, Wild boar, Mongoose, Sambar, Bird
Kuwabhar Highway waterhole	Spotted deer, Grey langur, Rhesus monkey, Barking deer
Baghaura North waterhole	Elephant, Spotted deer, Sambar, Rhesus monkey, Grey langur, Mongoose, Civet cat

Tirbhuj waterhole	Jackal, Rhesus monkey, Grey langur, Mongoose, Spotted deer, Birds
Sarju waterhole	Tiger, Elephant, Spotted deer, Rhesus monkey, Grey langur, Porcupine, Mongoose, Birds
Lower Lamkauliphanta pokhari	Tiger, Jackal, Hog deer, Spotted deer, Swamp deer, Rabbit, Wild boar, Rhesus monkey, Porcupine, Birds
Chitkaiya waterhole	Tiger, Civet cat, Sambar, Grey langur, Spotted deer, Wild boar, Rhesus monkey, Barking deer, Mongoose, Birds
Google waterhole	Elephant, Spotted deer, Sambar, Wild boar, Porcupine, Grey langur
Khayervatii 3	Elephant, Sambar, Spotted deer, Porcupine, Wild boar, Rhesus monkey, Mongoose, Birds
Amreni north waterhole	Jackal, Spotted deer, Sambar, Rhesus monkey, Wild boar, Porcupine, Mongoose, Birds
RCC Lamkauli waterhole	Tiger, Civet cat, Swamp deer, Sambar, Hog deer, Porcupine, Spotted deer, Wild boar, Grey langur, Mongoose, Birds

A total of 17 different wildlife species were recorded in the camera traps. Major species include Tiger (*Panthera tigris*), Jackal (canis aureus), Indian Civet cat, Elephant (*Elephas maximus*), Spotted deer (*Axis axis*), Samber (*Rusa unicolor*), Barking deer (*Muntiacus muntijak*), Hog deer (*Axis porcinus*), swamp deer (Rucervus duvaucelii) Wild boar (*Sus scrofa*), Mugger crocodile (*Crocodylus palustris*), Terai Grey Langur (*Semnopithecus hector*), Rhesus monkey (*Rhesus macaque*), Mongoose (Herpestes javanicus), Porcupine (hystrix indica), Rabbit (Lepus nigricollis) and birds. Predator species include tiger, Jackal, Indian Civet cat while prey species inlcude spotted deer, Samber, Swamp deer, hog deer, barking deer, wild boar, grey monkey, Rhesus monkey, Rabbit and remaining species were elephant, crocodile, Mongoose, Porcupine and Birds.

Biodiversity index in artificial waterholes

Three artificial waterholes from different habitat were taken to find the biodiversity index which is shown in (Figure 2). These were selected as the representative of each habitat like Chitkaiya waterhole represent the Sal Forest, RCC Lamkauli waterhole represents grassland and Sarju waterhole represents boundary line. And they were selected based on maximum number of species captured on cameras. It was observed Lamkauli waterhole has the maximum species diversity with a diversity index of 2.26 which was located on grassland habitat and Sarju waterhole has the least species diversity with a diversity index of 1.6.

It was revealed that more predator species were observed in mixed Sal Forest followed by grassland and boundary line artificial waterholes while prey species were recorded more in grassland artificial waterholes followed by mixed Sal Forest and boundary line. Maximum usage of the artificial waterholes by spotted deer while barking deer used minimally. Even tigers were repeatedly observed using the artificial waterholes of mixed Sal Forest waterholes followed by grassland and boundary line habitat (Figure 3).

Temporal activity pattern

The temporal activity pattern in the use of artificial waterholes by predator including tiger and its prey species was recorded through the details obtained from camera traps (Figure 4). Artificial waterholes were mostly used by prey species during evening from 17:00-18:00 hrs while predators were found using the artificial waterholes mostly in night. Tiger was recorded in mid-night at 12 pm, evening at 8 pm and even in early morning at 2 am. During the day, very few number of prey species were utilizing the artificial waterholes while tiger was found active in day time, evening and early in the morning.

They were found utilizing the waterholes for different purposes like drinking, wallowing, etc. Examining the waterholes use pattern of tiger, the presence of it in artificial waterholes can be clearly observed. Tiger was found using the artificial waterholes of grassland more at night and in early morning while that of mixed Sal Forest were utilized during the day and night time. Tiger was found actively utilizing the artificial waterhole during the dusk & evening period (19:00-20:00 hrs) and comparatively low in dawn and day time (Figure 5).

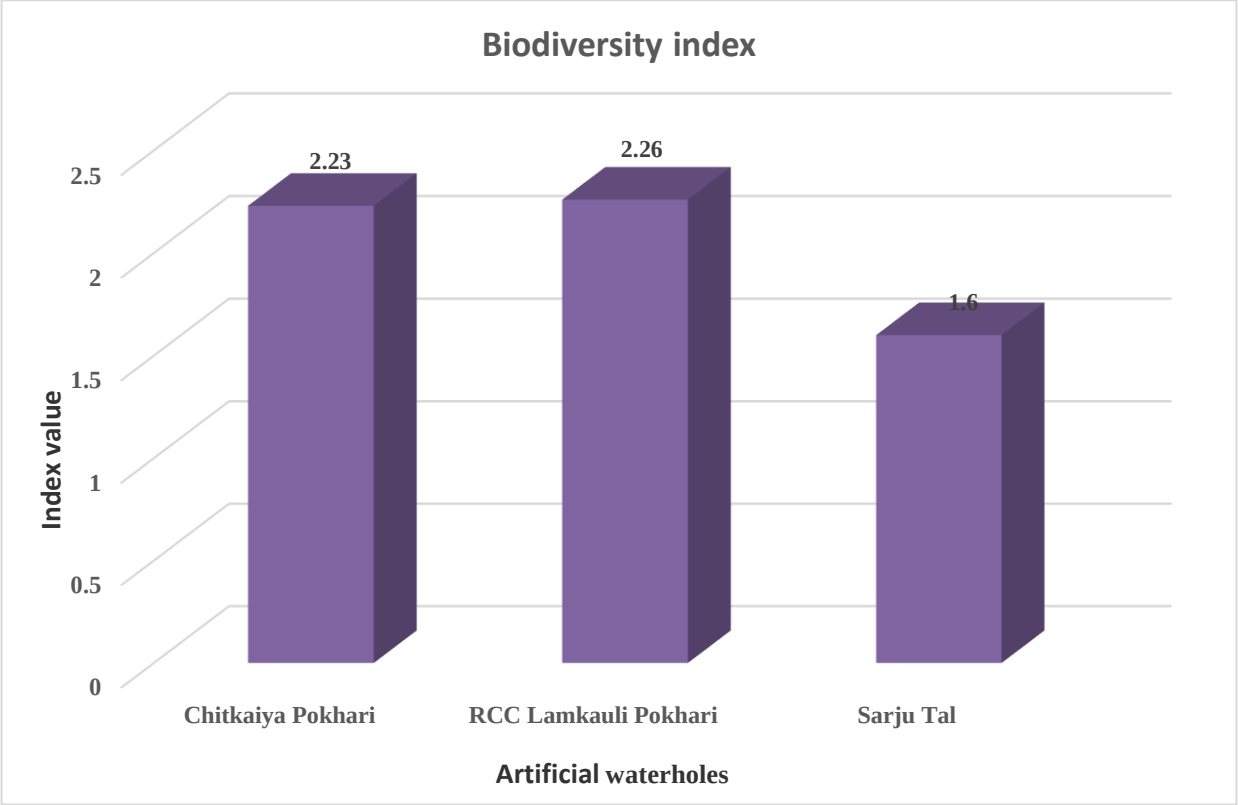

Figure 2 Bar graph of biodiversity index in artificial waterholes

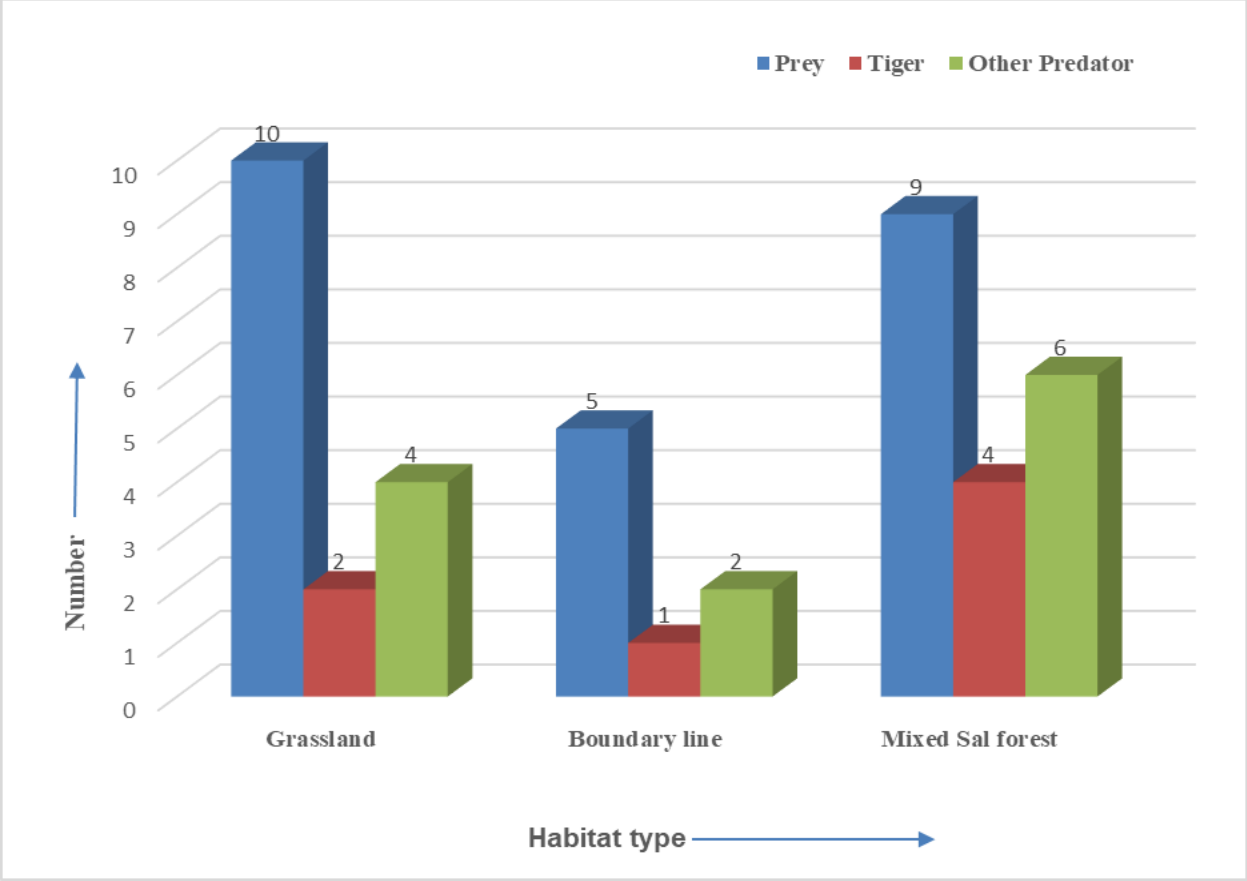

Figure 3 Prey species and predator in artificial waterhole of different habitat

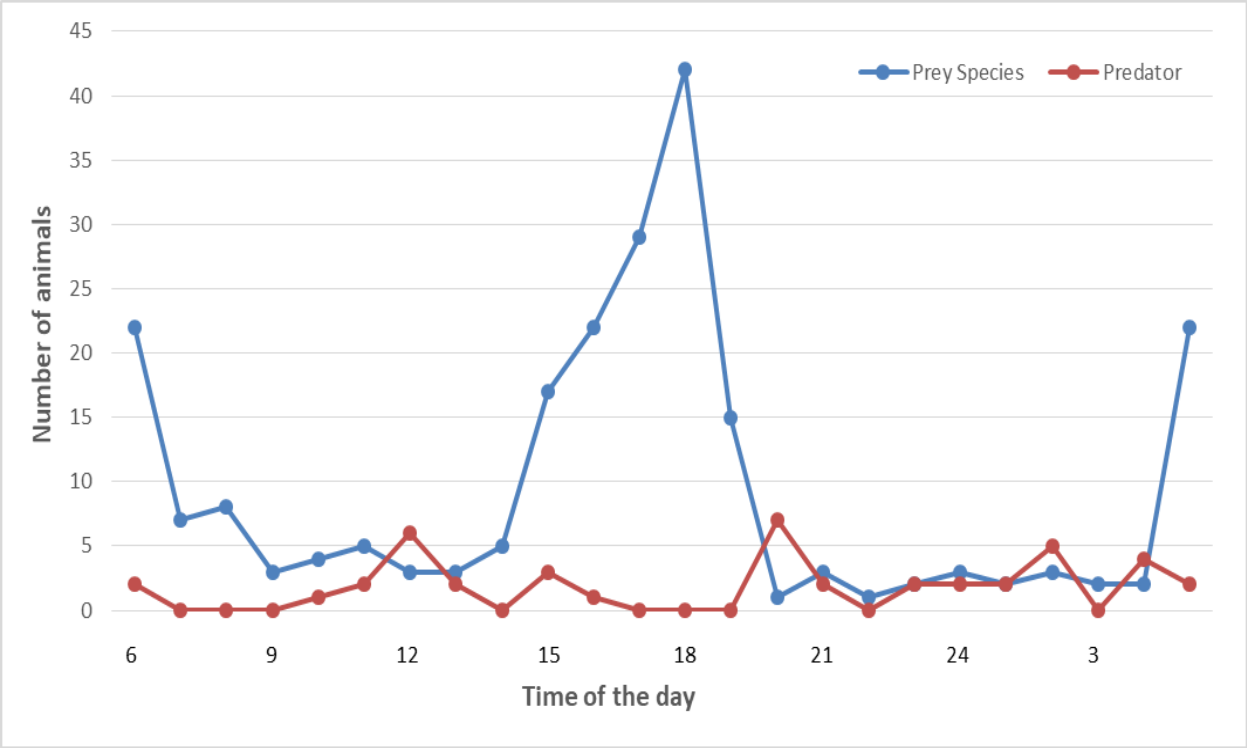

Figure 4 Use Pattern of artificial waterholes by predator and prey species

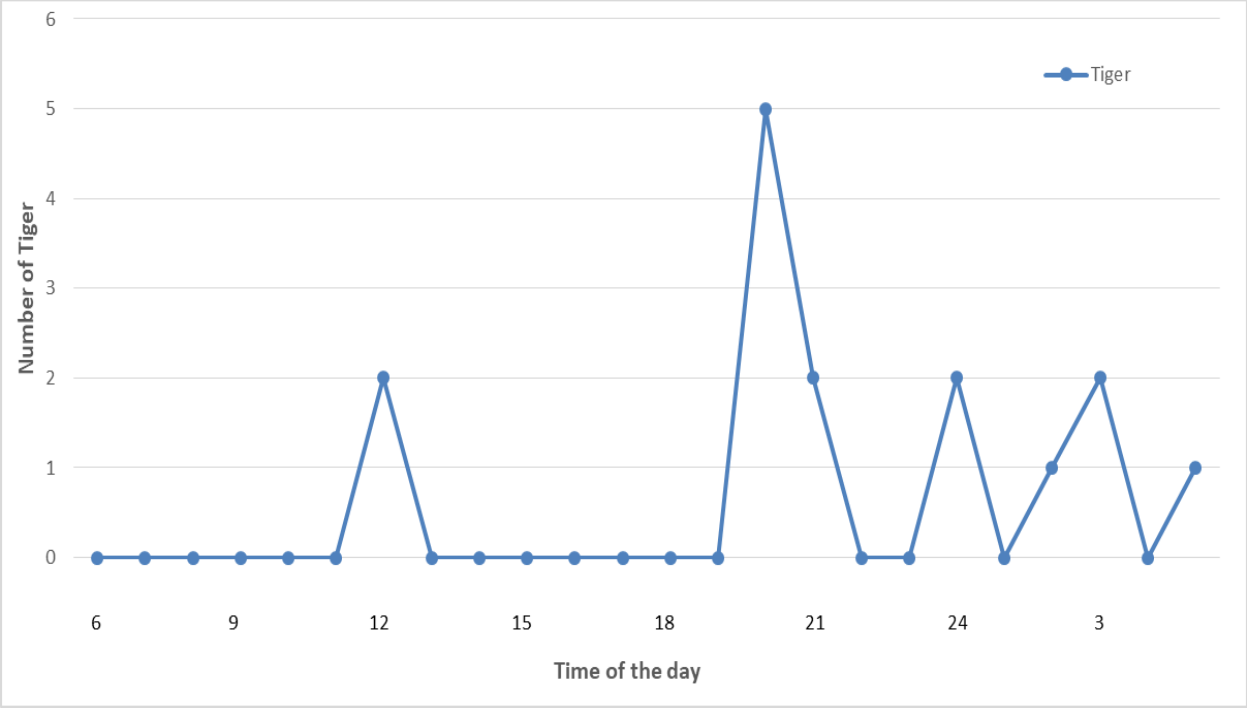

Figure 5 Waterholes use pattern of tiger

4. DISCUSSION

Artificial waterholes constructed alongside the wildlife habitat are well-maintained in the Karnali floodplain compared to the Babai floodplain, contributing to a higher density of wildlife species in the Karnali floodplain area. Resource availability, including access to water sources, is a crucial factor influencing habitat preference for animals (Rantanen et al., 2010). Among the artificial waterholes, RCC Lamkauli stands out for its exceptional species diversity, attributed to its strategic location and efficient water supply system. This waterhole is equipped with a solar boring system, ensuring a reliable water supply. Remarkably, it is situated 1.9 km away from human settlements, minimizing human disturbance, although a forest road or track is within 80 meters.

Additionally, the waterhole is located at the edge of Lamkauli Phanta, one of the largest grasslands, providing an excellent habitat for wildlife. Furthermore, the permanent water source, Khaura River (a tributary of the Karnali River), is located 4.37 km away from RCC Lamkauli.

Figure 6 (a)

Figure 6 (b)

Figure 6 (c)

Figure 6 (d)

Figure 6 Different animal using the waterholes in BNP (a) A young adult tiger; (b) A herd of spotted deer; (c) Group of Rhesus monkey and spotted deer; (d) A herd of wild elephant.

Similarly, Kuwabhar waterhole exhibited the lowest diversity of wildlife species, primarily due to its proximity to the National Highway (East-West Highway), which experiences constant disturbance from vehicular traffic. The National Highway not only fragments the wildlife habitat but also severely disrupts the movement of animals, leading to roadkill incidents in BNP. For the calculation of biodiversity index, one waterhole from each type of habitat (forest, grassland, and boundary line) was selected. Even within the Karnali floodplain, the density of wildlife species varies, possibly influenced by the presence of elephant herds around certain waterholes. During the study period, elephants were observed in nine different waterholes, and signs of their indirect presence were noted in four other distinct waterholes. The substantial presence of elephants may deter other species from utilizing these waterholes, as elephants' dominance in these areas interferes with other animals' access to water sources.

Given that elephants are considered keystone species, their significant influence on the utilization of waterholes is well-documented (Sungirai and Ngwenya, 2016). Usage of waterholes by tigers is predominantly observed during nighttime, reflecting their nocturnal nature. However, instances of tiger presence at waterholes during noon were also noted, possibly linked to the

hunting behavior of this predator. Tigers are known to be more active at night, leveraging their superior night vision and exceptional hearing for hunting after sunset (Holomuzki, 1986; Carter et al., 2012). In contrast, prey species were found utilizing the waterholes throughout both day and night, suggesting their continuous activity across a 24-hour cycle (Hayward and Slotow, 2009). The preference for hunting near water sources is a common behavior among predators, with carnivores like lions demonstrating a tendency to hunt within 2 km from a waterhole in all seasons (Davidson et al., 2012).

Among herbivores, grazers typically demand more water than browsers, and the water intake can vary with age and reproductive status, such as during pregnancy. The daily drinking activity patterns of wildlife are influenced by factors such as waterhole distribution and accessibility. In our study, all selected waterholes were fully utilized by wildlife species, reflecting the significance of freely accessible and evenly distributed water sources for ungulates (Cain et al., 2012; Crosmary et al., 2012; Hayward and Hayward, 2012). Various factors influence an animal's decision to visit a specific water point, including distance from their selected habitat, resource availability, alternative resources, resource quality Sungirai and Ngwenya, (2016), interspecific and intraspecific competition Valeix et al., (2007), vegetation surrounding the water point Sungirai and Ngwenya, (2016), Burger, (2001), and the presence of predators (Valeix et al., 2009).

Our results (Table S1 & S2: Supplementary materials) align with these predictions, suggesting that water availability, waterhole characteristics (such as water depth and pool size), and landscape features (including the maximum waterhole area, proximity to other waterholes, and human disturbance, particularly the distance to the nearest village or park guard post) play a crucial role in influencing the utilization of waterholes by tigers and their prey species. The daily waterhole usage patterns of prey species and predators were observed to be quite similar in both Bardia National Park (BNP) and Parsa National Park (PNP) in Nepal. Both BNP and PNP are situated in the lowland Terai of Nepal within the Terai Arc Landscape. However, there are notable differences between the two parks. BNP, in particular, boasts a larger number of distributed artificial waterholes and is generally swampier and less arid compared to PNP.

In PNP, predators like tigers were found to utilize the waterholes in the morning and at night, while prey species predominantly utilized them during the day, even though they were active both during the day and night. The pressure for prey species to use waterholes stems from the need to avoid the presence of predators in these areas (Edwards et al., 2017). Moreover, prey species often exhibit temporal variations in their activity to reduce competition with potential predators (Cloyed and Eason, 2017). Interestingly, our study in BNP revealed a contrasting temporal use of waterholes by tigers and their prey species. However, it's essential to note that our study was based on selected waterholes, demanding a broader and more detailed examination of all waterholes in the park and its buffer zone for a clearer understanding. The short duration of our study restricted our ability to assess seasonal and substantial waterhole utilization by tigers and their prey species. Additionally, the limitation of camera deployment only in one part of the waterholes also influenced our findings.

Supplementary materials

Table S1 Bio-physical and environmental parameters of artificial waterholes.

S.N.	Coordinates	Name of artificial waterholes	Source of water	Shape	Depth (meter)	Habitat
1	X - 564934 Y - 3129638	Chisapani range post tal	Solar boring	Oval	0.3	Mixed Sal Forest
2	X - 551117 Y - 3145865	Guthi machan pokhari	Solar boring	Rectangular	1.2	Grassland
	X – 532589 Y - 3148434	Bhurigau chital pokhari	Solar boring	Irregular	1	Mixed Sal Forest
4	X 535514 Y - 3159291	Kharivatti Pani tanki pokhari	Water Tank	Circular	0.4	Mixed Sal Forest
5	X – 531562 Y - 3156433	Khairvati bata motipur jane bato Pokhari	Rain water	Rectangular	1.3	Mixed Sal Forest
6	X – 541949 Y - 3138111	Rammpur Boring Pokhari	Solar boring	Rectangular	1	Mixed Sal Forest
7	X – 551393 Y - 3146461	Guthi Kathkuwa Pokhari	Rain water	Rectangular	0.5	Boundary line
8	X - 554661	Thuloshree Pokhari	Rain water	Rectangular	0.7	Grassland

	Y - 3143455					
9	X - 524810 Y - 3153549	Sano Baghaura Phanta Pokhari	Rain water	Oval	1.4	Boundary line
10	X - 526454 Y - 3154879	Chandramukhi Pokhari	Solar boring	Rectangular	1.5	Mixed Sal Forest
11	X - 528021 Y - 3157196	Jarayo Tal	Rain water	Irregular	0.8	Mixed Sal Forest
12	X - 528083 Y - 3160019	Hatti/Ganesh Tal	Solar boring	Irregular	1.2	Mixed Sal Forest
13	X - 526375 Y - 3159820	Balkuni Pokhari	Solar boring	Rectangular	1.5	Mixed Sal Forest
14	X - 528899 Y - 3159313	Dhanesh tal	Solar boring	Circular	0.7	Boundary line
15	X - 531499 Y - 3157431	Kuwabhar Highway Pokhari	Rain water	Rectangular	0.4	Mixed Sal Forest
16	X - 525225 Y – 3154216	Baghaura North Pokhari	Rain water	Rectangular	0.5	Mixed Sal Forest
17	X - 526815 Y - 3161437	Tirbhuj Pokhari	Rain water	Oval	0.4	Mixed Sal Forest
18	X - 529580 Y - 3156859	Sarju Tal	Solar boring	Circular	0.3	Boundary line
19	X - 527832 Y - 3153728	Lower lamkauliphanta pokhari	Solar boring	Ireegular	1.8	Grassland
20	X - 524845 Y - 3149022	Chitkaiya pokhari	Rain water	Irregular	0.2	Mixed Sal Forest
21	X - 526177 Y – 3155374	Google Tal	Rain Water	Rectangular	0.5	Mixed Sal Forest
22	X – 532376 Y - 3158101	Khayervatii jane bato mathi ko pokhari	Solar boring	Rectangular	0.4	Mixed Sal Forest
23	X - 532986 Y - 3154670	Amreni Sital pokhari	Rain water	Rectangular	0.4	Mixed Sal Forest
24	X - 528322 Y - 3154605	Upper Lamkauli RCC machan pokhari	Solar boring	Rectangular	1.7	Grassland

Table S2 Distance to potential human impacts and permanent source of water

S.N.	Name of Artificial Waterholes	Distance to Post/Human settlement area (in meter)	Distance to Permanent source of water (in meter)	Distance to near Road/track (in meter)
1	Chisapani range post tal	90 Chisapani Post	850	130
2	Guthi machan pokhari	430 Guthi Sector	680	370
3	Bhurigau chital pokhari	860 Bhurigau Post	1025	30
4	Kharivatti Pani tanki pokhari	1540 Kharivatti Post	3300	5
5	Khairvati bata motipur jane bato Pokhari	1450 Amreni Post	5220	190
6	Rammpur Boring Pokhari	100 Rammapur Sector	1150	110
7	Guthi Kathkuwa Pokhari	620 Guthi Sector	1240	210
8	Thuloshree Pokhari	690 Thuloshree Post	680	1350
9	Sano Baghaura Phanta Pokhari	1750 Gaidamachan Post	750	230
10	Chandramukhi Pokhari	2575 Gaidamachan Post	2590	160

11	Jarayo Tal	2630 Laguna Post	2550	25
12	Hatti/Ganesh Tal	2680 Laguna Post	2315	40
13	Balkuni Pokhari	1290 Laguna Post	800	35
14	Dhanesh tal	3110 Laguna Post	2130	55
15	Kuwabhar Highway Pokhari	2520 Amreni Post	5000	100
16	Baghaura North Pokhari	1520 Gaidamachan Post	1215	100
17	Tirbhuj Pokhari	2980 Laguna Post	470	90
18	Sarju Tal	3020 Amreni Post	2180	75
19	Lower lamkauliphanta pokhari	1080 Bankhet Post	3750	40
20	Chitkaiya pokhari	510 village	450	40
21	Google Tal	2370 Gaidamachan Post	1370	220
22	Khayervatii jane bato mathi ko pokhari	3210 Amreni Post	4010	240
23	Amreni North Pokhari	1100 Amreni Post	1350	240
24	RCC Lamkauli Phanta Pokhari	1925 Bankhet Post	4370	80

Table S3 Details of Artifical Waterholes in BNP

S.N.	GPS Location		Name	Nearest Sector/Post	Remarks
	X	Y			
1	522841	3149471	Kingfisher Phanta (1) Pokhari	Hattimachan Post	No Solar
2	522908	3149758	Kingfisher Phanta (2) Pokhari	Hattimachan Post	No Solar
3	523203	3151091	Kalaban Pokhari	Hattimachan Post	No Solar
4	522462	3148797	Tallo King Fisher Pokhari	Hattimachan Post	No Solar
5	523403	3147904	Chittal Phanta Pokhari	Hattimachan Post	No Solar
6	522562	3147233	Chingari Pokhari	Hattimachan Post	No Solar
7	523748	3147618	HQ Machha Pokhari	Thakurdwara Sector	With Solar Boring System
8	525129	3151545	Khauraha Cross Mathillo Pokhari	Thakurdwara Sector	No Solar
9	522847	3148122	Bagdhaua Tal (South of Jhadkapatti Phanta)	Thakurdwara Sector	No Solar
10	525042	3149653	Damaru Pokhari	Thakurdwara Sector	No Solar
11	526576	3151009	Gobrela Gate Pokhari	Thakurdwara Sector	With Solar Boring System
12	524845	3149022	C Pokhari (Chitkaiya Chowk)	Thakurdwara Sector	No Solar
13	524240	3148839	NTNC Phanta Pokhari	Thakurdwara Sector	No Solar
14	525616	3152536	Bathaniya Pokhari	Thakurdwara Sector	No Solar
15	525662	3150145	Tiger Top Pokhari	Thakurdwara Sector	With Solar Boring System
16	525892	3151116	Gobrela Gate West Pokhari	Bankhet Range Post	No Solar
17	528342	3155484	Y Pokhari	Bankhet Range Post	With Solar Boring System
18	528322	3154605	Lamkauli RCC Machan Pokhari	Bankhet Range Post	With Solar Boring System
19	527832	3153728	Lamkauli Phanta Bich Pokhari	Bankhet Range Post	With Solar Boring System
20	526370	3152594	Gaida Pokhari (Near Lamkauli Chowk)	Bankhet Range Post	With Solar Boring System
21	528118	3154249	Lamkauli Kuwa Pokhari	Bankhet Range Post	No Solar

22	527666	3154760	Deuta Tal/Star Pokhari	Bankhet Range Post	With Solar Boring System
23	529096	3154231	Jagatram Pokhari	Bankhet Range Post	With Solar Boring System
24	527633	3152873	Bankhet Pokhari	Bankhet Range Post	With Solar Boring System
25	527278	3153133	Lakauli Two Square Pokhari	Bankhet Range Post	No Solar
26	526687	3152840	Lamkauli Chowk Pokhari	Bankhet Range Post	No Solar
27	529355	3157440	Bagh Pokhari	Motipur Post	With Solar Boring System
28	530607	3154919	Motipur-Amreni Cross Pokhari	Motipur Post	No Solar
29	529814	3155479	Laligurans Pokhari	Motipur Post	With Solar Boring System
30	530292	3158779	Umanga Pokhari (Kuwabhar)	Amreni Post	No Solar
31	532985	3154656	Ambasa Old Post Pokhari	Amreni Post	No Solar
32	533021	3151583	Balati Pokhari	Amreni Post	No Solar
33	532895	3155455	Amreni Haribansa Pokhari	Amreni Post	With Solar Boring System
34	531562	3156433	Sital Pokhari (South of Khayarbhatti Chowk HW)	Amreni Post	No Solar
35	530486	3159284	Kuwabhar Check Post Pokhari	Amreni Post	No Solar
36	531499	3157431	Khayarbhatti Chowk West X Pokhari	Amreni Post	No Solar
37	529580	3156859	Sarju Tal	Amreni Post	With Solar Boring System
38	532376	3158101	Kuwabhar V Pokhari	Amreni Post	No Solar
39	531938	3155444	Amreni Highway Pokhari	Amreni post	No Solar
40	531733	3155009	Amreni Post Pokhari	Amreni post	With Solar Boring System
41	529912	3158754	Asna Pokhari Kuwabhar (Two water Hole)	Amreni Post	Boring Only
42	531568	3158402	Kuwabhar Kharayo Pokhari	Amreni Post	Boring Only
43	531416	3156185	Niure Pokhari	Amreni Post	No Solar
44	533406	3154373	Balati Nahar Pokhari	Amreni Post	No Solar
45	529991	3160035	Shikari Pokhari	Amreni Post	With Solar Boring System
46	525603	3153397	Harry Chowk Pokhari	Gaidamachan Post	No Solar
47	525585	3155764	Rhino Release Tal	Gaidamachan Post	With Solar Boring System
48	526962	3161444	Ghaite Pokhari	Gaidamachan Post	No Solar
49	524810	3153549	Naya Bagaura Phanta Pokhari	Gaidamachan Post	No Solar
50	524433	3153822	Sawari Camp Phanta Pokhari	Gaidamachan Post	No Solar
51	525225	3154216	T Pokhari	Gaidamachan Post	No Solar
52	525287	3151094	Salak Pokhari	Gaidamachan Post	No Solar
53	526454	3154879	Chandramukhi Pokhari	Gaidamachan Post	With Solar Boring System
54	527725	3156083	Khodau Tal	Gaidamachan Post	With Solar Boring System
55	524917	3153492	Harry Chowk Pokhari	Gaidamachan Post	No Solar

56	525034	3154843	Nepalganj Cross Pokhari	Gaidamachan Post	No Solar
57	526177	3155374	Google Pokhari	Gaidamachan Post	No Solar
58	526815	3161437	Tented Camp (2) Pokhari	Lagunamachan Post	No Solar
59	527688	3158033	Thulokhalla K Pokhari	Lagunamachan Post	With Solar Boring System
60	526592	3158792	Patachuli Tal	Lagunamachan Post	No Solar
61	527038	3158624	Deshbahadur Tal	Lagunamachan Post	No Solar
62	528691	3160194	Ganesh Tal Chowk	Lagunamachan Post	No Solar
63	528065	3160987	Kamal Pokhari	Lagunamachan Post	With Solar Boring System
64	527880	3161939	Damodar Pokhari	Lagunamachan Post	With Solar Boring System
65	528021	3157196	R Pokhari (Khodau Tal mathi)	Lagunamachan Post	No Solar
66	525910	3158585	Lagunamachan Post Pokhari	Lagunamachan Post	With Solar Boring System
67	526375	3159820	Hatti Tal	Lagunamachan Post	With Solar Boring System
68	528133	3160009	Ganesh Tal	Lagunamachan Post	No Solar
69	528899	3159313	Dhanesh Tal	Lagunamachan Post	With Solar Boring System
70	529049	3160566	Baliram Tal	Lagunamachan Post	With Solar Boring System
71	527432	3161718	Kuilar Ghari Pokhari /Puspa Pokhari	Lagunamachan Post	With Solar Boring System
72	529066	3165170	Chure Phedi 1 no. Tal	Karnali Chisapani Post	No Solar
73	529536	3164195	Chure Phedi 2 no. Tal	Karnali Chisapani Post	No Solar
74	529912	3161108	Morang Pokhari	Karnali Chisapani Post	No Solar
75	528619	3164768	Karnali Asafal Pokhari	Karnali Chisapani Post	No Solar
76	527122	3164195	Lalmati Pokhari	Karnali Chisapani Post	With Solar Boring System
77	527994	3165124	Lalmati Pokhari (North of Lalmati Chowk HW)	Karnali Chisapani Post	No Solar
78	532905	3161166	Githe Khola (1) Pokhari	Khayarbhatti Post	No Solar
79	535916	3160133	Khalla Pokhari	Khayarbhatti Post	No Solar
80	536141	3160199	Khayarbhatti Danda Pokhari	Khayarbhatti Post	No Solar
81	535514	3159291	Pani Tank Pokhari	Khayarbhatti Post	No Solar
82	533441	3160958	Githe Khola (2) Pokhari	Khayarbhatti Post	No Solar
83	535514	3160291	Khayarbhatti (1) Pokhari	Khayarbhatti Post	No Solar
84	536327	3160122	Khayarbhatti (2) Pokhari	Khayarbhatti Post	No Solar
85	532215	3157162	Khayar Chamber Pokhari	Khayarbhatti Post	No Solar
86	536299	3160364	Khayarbhatti Post Pokhari	Khayarvatti Post	With Solar Boring System
87	538315	3159007	Dhadbas Road Pokhari	Dhadbas Post	No Solar
88	539254	3156862	Danbatal Ukalo Pokhari	Dhadbas Post	No Solar
89	540344	3156446	Danabtal Rasilo Pokhari	Dhadbas Post	No Solar
90	544592	3152608	Lamidamar East Pokhari	Lamidamar Post	No Solar
91	543607	3151594	Lamidamar Pokhari	Lamidamar Post	No Solar
92	542820	3153053	Lamidamar Chowk Pokhari	Lamidamar Post	No Solar
93	542652	3151828	Lamidamar Post Pokhari	Lamidamar Post	No Solar

94	542162	3152039	Lamidamar Phanta (1) Pokhari	Lamidamar Post	No Solar
95	542775	3152237	Lamidamar Post North Pokhari	Lamidamar Post	No Solar
96	541873	3152146	Lamidamar Phanta (2) Pokhari	Lamidamar Post	No Solar
97	541642	3153434	Puranpur Pokhari (South of Road)	Lamidamar Post	No Solar
98	540387	3155230	Apkholital Pokhari	Lamidamar Post	No Solar
99	548137	3149915	Ratamate Phanta (1) Pokhari	Ratmate Post	No Solar
100	548125	3149202	Ratamate Phanta (3) Pokhari	Ratmate Post	No Solar
101	545913	3150704	Deurali Kalinara Road Pokhari	Ratmate Post	No Solar
102	548192	3149562	Ratemate Phanta (2) Pokhari	Ratmate Post	No Solar
103	545748	3151417	Deurali Pokhari	Ratmate Post	No Solar
104	542233	3147922	Gaidaphanta Pokhari Kalinara	Kalinara Post	No Solar
105	545319	3147529	Kalinara (1) Pokhari	Kalinara Post	No Solar
106	540917	3149130	Kalinara (2) Pokhari	Kalinara Post	No Solar
107	553658	3145571	Chittal Phant (1) Pokhari	Guthi Sector	No Solar
108	553551	3145423	Chittal Phanta (2) Pokhari	Guthi Sector	No Solar
109	551117	3145865	Guthi Phanta Machan Pokhari	Guthi Sector	With Solar Boring System
110	551279	3145775	Guthi Phanta Machan South Pokhari	Guthi Sector	No Solar
111	551386	3146443	Guthi Kuwa Pokhari	Guthi Sector	No Solar
112	551086	3146703	North Guthi Phanta Pokhari	Guthi Sector	No Solar
113	550830	3146061	West Guthi Phanta Pokhari	Guthi Sector	No Solar
114	552149	3146971	Guthi Sector North (1200 m) Gautam Pokhari	Guthi Sector	No Solar
115	550848	3145617	Guthi Gaidatal	Guthi Sector	No Solar
116	552283	3145926	Guthi Kathe Machan Pokhrai	Guthi Sector	No Solar
117	550522	3147527	Major Khola Pokhari	Guthi Sector	No Solar
118	550787	3145243	Guthi Dovan Natural Ghol	Guthi Sector	No Solar
119	556494	3142367	Rohini Pokhari	Thuloshree Post	No Solar
120	552285	3144313	Sanoshree Phanta Sano Pokhari	Thuloshree Post	No Solar
121	552653	3144158	Sanoshree Phanta Santosh Pokhari	Thuloshree Post	No Solar
122	552988	3144033	Sanoshree Gaida Pokhari	Thuloshree Post	No Solar
123	556590	3142365	Gaida Tal Pokhari (Eastern Thuloshree Phanta)	Thuloshree Post	No Solar
124	552314	3144437	Shanoshree Pokhari	Thuloshree Post	No Solar
125	554219	3143951	Simal Pokhari Thuloshree phanta	Thuloshree Post	No Solar
126	554661	3143455	UK Pokhari Thuloshree phanta	Thuloshree Post	With Solar Boring System
127	553967	3143762	Thuloshree Pokhrai	Thuloshree Post	No Solar
128	560133	3142059	Shiva Tal	Shivapur Post	No Solar
129	559842	3141912	Shivapur Phanta (2) Pokhari	Shivapur Post	No Solar
130	558764	3142588	Babiyachaur Simalghari Pokhari	Shivapur Post	No Solar
131	559700	3141100	Morungi Khola Pokhari	Shivapur Post	No Solar
132	560065	3142225	Shivapur Post North East Pokhari	Shivapur Post	No Solar
133	559330	3142114	Shivapur Phanta (1) Pokhari	Shivapur Post	No Solar
134	557128	3143670	Babiyachaur Pokhari	Shivapur post	With Solar Boring System
135	563033	3140396	Dhanushe Phanta (1) Pokhari	Sivapur Post	No Solar

136	562812	3140516	Dhanuse Phanta (2) Pokhari	Sothkhola Post	No Solar
137	565357	3139377	Sothkhola Pokhari	Sotkhola Post	No Solar
138	563033	3140396	Dhanuse Pokhari (1)	Sotkhola Post	No Solar
139	565032	3139332	Sothkhola Bagar Pokhari	Sotkhola Post	No Solar
140	563330	3140049	Dhanushe Danda Pokhari	Sotkhola Post	No Solar
141	569261	3136753	Chepang Post Pokhari	Chepang Range Post	No Solar
142	567488	3137418	Mulghat Machan Pokhari	Chepang Range Post	No Solar
143	568270	3137295	Mulghat Phanta Pokhari	Chepang Range Post	No Solar
144	532589	3148434	Bhurigaun Chittale Pokhari	Bhurigaun Range Post	With Solar Boring System
145	533556	3148552	Dumreni (1) Pokhari	Bhurigaun Range Post	No Solar
146	534476	3148847	Bhurigaun Fireline (1) Pokhari	Bhurigaun Range Post	No Solar
147	535122	3147017	Bhurigaun Fireline (2) Pokhari	Bhurigaun Range Post	No Solar
148	533752	3145048	Sainawar Post Pokhari	Sainawar Post	No Solar
149	534468	3145394	Khum Tal	Sainawar Post	No Solar
150	533760	3146504	Dumreni Pokhari	Sainawar Post	No Solar
151	534798	3145744	Sainawar Pani Pokhari	Sainawar_post	With Solar Boring System
152	537840	3141818	Theni Khola Pokhari	Parewaodar Post	No Solar
153	537517	3142008	Budhikhola Pokhari	Parewaodar Post	No Solar
154	538079	3140443	Rammapur Temporary Check Post Pokhari	Parewaodar Post	No Solar
155	537777	3142409	Nahar (1) Pokhari	Parewaodar Post	No Solar
156	537478	3142572	Nahar (2) Pokhari	Parewaodar Post	No Solar
157	537339	3144025	Parewaodar Post Pokhari	Parewaodar Post	With Solar Boring System
158	541949	3138111	Rammapur Pokhari (Near Rescue Centre)	Rammapur Sector	With Solar Boring System
159	541869	3138792	Jakhar Pokhari	Rammapur Sector	No Solar
160	543533	3138569	Khajuri Pokhari (Rammapur Chure)	Rammapur Sector	No Solar
161	543964	3139231	Danda Pokhari (Rammapur Chure)	Rammapur Sector	No Solar
162	542272	3138972	Dale Pokhari	Rammapur Sector	No Solar
163	542547	3139198	Rammapur Chure Pokhari	Rammapur Sector	No Solar
164	542333	3139033	Rammapur Chure Phedi Pokhari	Rammapur Sector	No Solar
165	546963	3137572	Dhakaila Machan Pokhari	Dhakaila Post	No Solar
166	546652	3136856	Dhakaila Post Pokhari	Dhakaila Post	With Solar Boring System
167	548331	3132470	Thumani (1) Pokhari	Thumani Post	No Solar
168	548464	3132051	Thumani (2) Pokhari	Thumani Post	No Solar
169	547597	3133605	Thumani (3) Pokhari (West of Post)	Thumani Post	No Solar
170	553182	3131002	Bhastal Post Pokhari	Bhastal Range Post	With Solar Boring System
171	551706	3132101	Belauli Sichai Pokhari	Bhastal Range Post	No Solar
172	558212	3129252	Betahani Post Pokhari	Betahani Post	No Solar
173	560411	3131243	Betahani Pokhari	Betahani Post	No Solar
174	561039	3131156	Betahani Ranjha Pokhari	Betahani Post	No Solar
175	557626	3130200	Betahani Machan Pokhari	Betahani Post	No Solar
176	564934	3129638	Chisapani Post Pokhari	Chisapani Range Post	With Solar Boring

					System
177	564966	3129734	Chisapani Dry (1) Pokhari	Chisapani Range Post	No Solar
178	564664	3130960	Chisapani Dry (2) Pokhari	Chisapani Range Post	No Solar
179	563540	3130989	Chisapani Tharubas Pokhari (2)	Chisapani Range Post	No Solar
Total			179 Water Hole		39 with Solar Boring system & 2 with only Boring

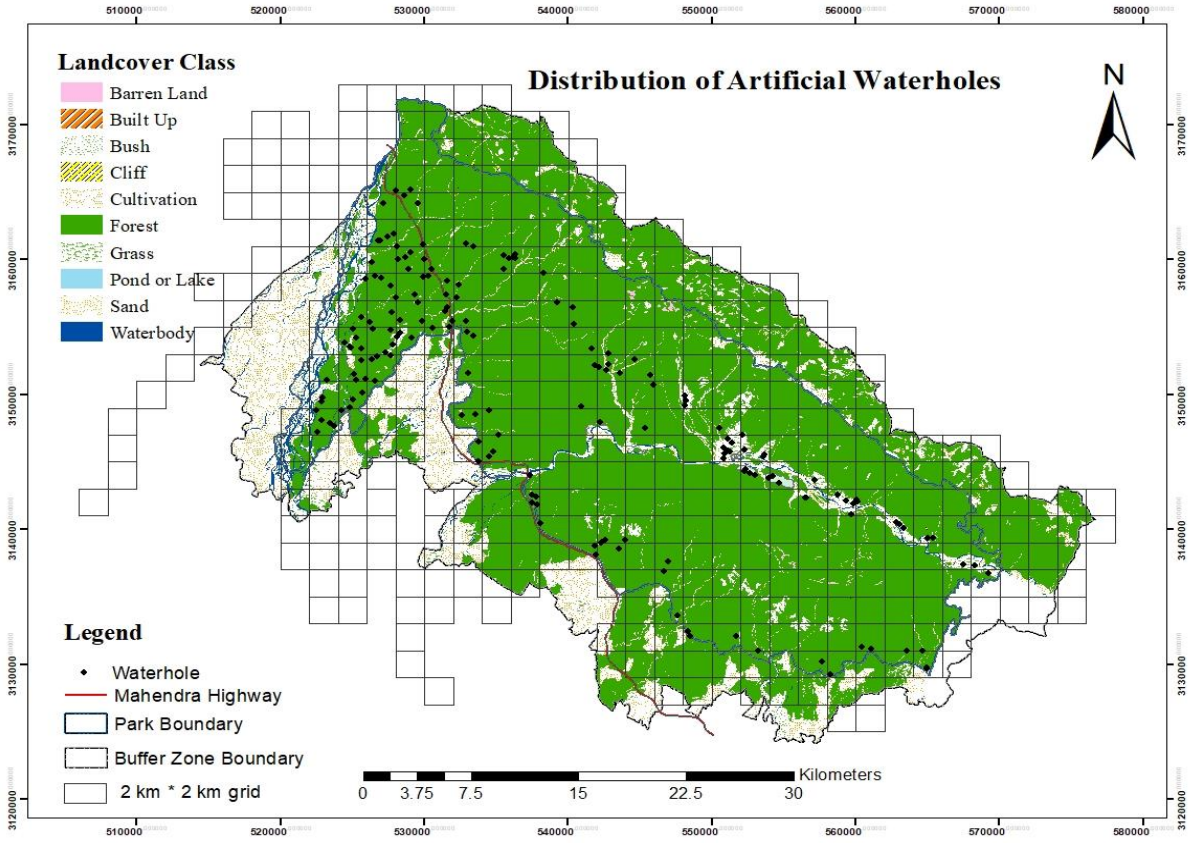

Figure S1 Selection of Artificial Waterholes with national tiger survey grid of 2km * 2km

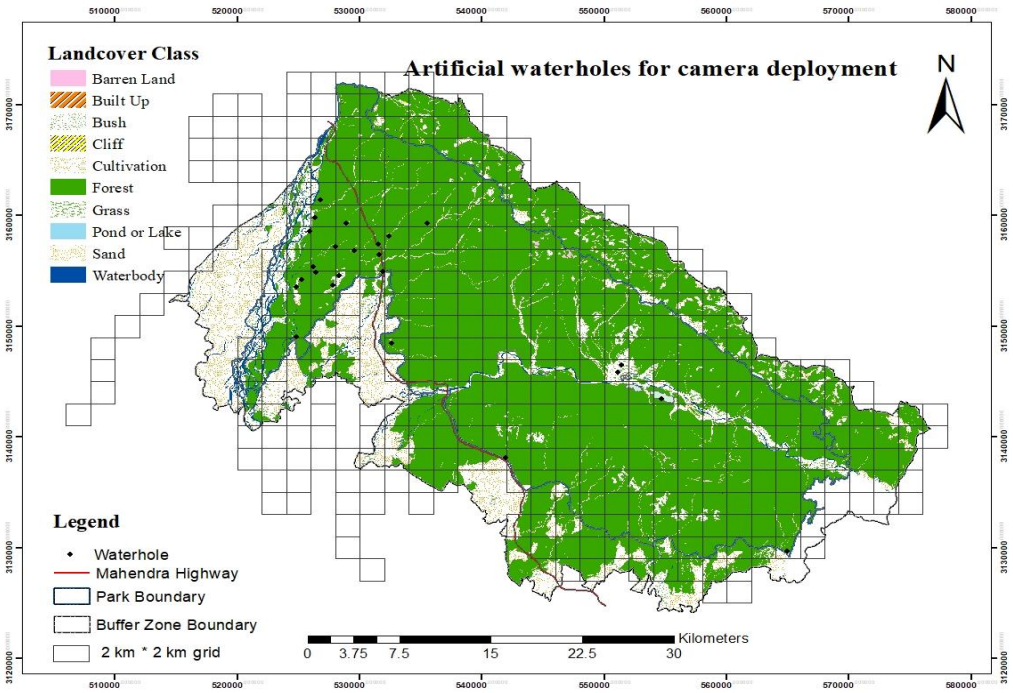

Figure S2 Map showing the camera traps deployed in waterholes

5. CONCLUSIONS

The distribution of artificial waterholes across the park is not uniform, with a notable lack in the eastern side. The usage pattern of waterholes by tigers is more active during the night or dusk, while prey species exhibit activity both during the day and night. It is advisable to avoid any disturbance at waterholes, such as repair, reconstruction, or enlargement, particularly in the late afternoon and evening. Touristic activities are encouraged, especially visiting specially constructed observatory points near the waterholes in the late afternoon and evening. However, it is crucial to ensure that these activities do not disturb the wildlife species. Additionally, as threatened species like tigers and elephants visit waterholes for various purposes, there is a high risk of poaching if due attention is not given to patrolling, monitoring, and regular research efforts.

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Conflicts of interests: The authors declare that there are no conflicts of interests.

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Ethical approval

The Animal ethical guidelines are followed in the study for species observation & identification.

Data and materials availability

All data associated with this study are present in the paper.

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