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Research Article

Mathematical Modeling Considering Agricultural and Non-Agricultural Habitats for Biological Losses on Roads

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Abstract. Mathematical modeling has been a significant tool in biological sciences for several decades. Modern agricultural practices have had numerous effects on different aspects of ecosystems, particularly on animal populations. This research focuses on road collisions involving wildlife and emphasizes the effects of agricultural and non-agricultural surrounding lands. Using non-parametric Mann-Whitney U and Spearman's Rank tests, as well as SPSS software, the study found that the highest number of wildlife deaths, especially for mammals, birds, and reptiles, occurred in areas surrounded by natural regions (non-agricultural lands). Furthermore, the study found that the number of casualties was highest in the middle month of spring and those morning observations resulted in more collisions than evening ones. The correlation coefficients confirmed a significant relationship between the frequency of accidents and the type of surrounding landscape. Additionally, the researchers proposed a logistic mathematical model to investigate the relationship between animal losses and vehicle collisions. After identifying the equilibrium points, the study analyzed the solution behavior around these points.

Keywords. Agricultural Surrounding, Road Mortality, Differential Equation.

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1 Introduction

Wildlife road casualties could be considered as a kind of human-animal conflict and it seems that changing our attitudes would play an important role in the severity of this conflict. The recent strategic changes in transportation and communication were led to extensive damage to the environment, including the loss or death of millions of animals and thousands of people every year [1]. In the UK, about one million animals, and in the United States between 725,000 and 1,500,000, are annually killed on different roads [3]. Fortunately, the effects of human transportation on road's surrounding habitats have been widely investigated [18]. The fragmentation of such kinds of habitats not only disrupts the natural processes of ecosystems but also threatens creatures' lives through population decline or even their extinction [7].

Road mortality occurs due to four basic reasons: animal, human, road, and climatic parameters [6]. In the first category, the species with smaller bodies and higher fertility rates can make up for their loss of population more quickly than the larger ones which enjoy lower growth and fertility rates. Secondly, the drivers' awareness and their environmentally oriented attitudes, traffic level, exposure time, and driving speed are among the human-related factors; the expansion of roads network, their width and types, the surrounding habitats, and the existence of natural or artificial crossings could be considered as the road-related parameters; and finally, the natural-climatic factors Such as clean air, atmospheric phenomena and the season may play a remarkable role on roads' casualties [2]. This mortality is not limited to the road surfaces as they influence the ecosystem food chains, especially in arid and semi-arid areas. They are also indirectly linked to the death of animal infants when they lost their parents and enjoy little chance of survival. Despite the importance of wildlife lives on the roads, unfortunately, not much work has been done regarding this phenomenon in Iran.

The main objectives of this paper include:

- Evaluating the effects of agricultural and non-agricultural surrounding ecosystems on roads' wildlife mortality;
- Suggesting a mathematical model for prediction of this kind of loss.

Furthermore, we summarize the following sub-objectives below.

- Assessing wildlife casualties in different road points and spring months;
- Providing some solutions to likely reduce these deaths.

2 The Study Area

The studied road is a part of Iran's East Asian Road (97E), located between the two cities of Taybad and Torbat-e-Jam, with an approximately 60-kilometer length, nearby Iran and Afghanistan borderline (Dogharoon Customs). Its width is about 7 meters and its maximum allowed driving speed is 95 kilometers per hour. Based on the information provided, it appears that this particular point on the road in Iran does not fall within any of Iran's four environmental management zones. Additionally, it experiences a high volume of traffic on a daily basis, with peak traffic occurring between 11 am and 1 pm during winter months, and between 5 pm and 7 pm in warmer seasons.

3 The Survey Method

The research data were collected based on post-event (causal-comparative) observations. The monitoring period was 42 days in three months, randomly two weeks monthly, twice a day, between 07:00 and 08:00 am. and between 5:00 and 6:00 pm. Considering the surrounding lands, the road was divided into three separate sites; site No. 1 (0-20 km from Taybad to Torbat-e Jam) surrounded by ridged areas and residential settlements (including one small town and two villages), site No. 2 (20-40 km) is almost entirely located inside the pristine rangelands and plains; and site No. 3 (40-60 km), passing through a small town, completely was surrounded by dispersed agricultural and industrial lands. The vehicle traffic volumes for all three sites were manually calculated. Determination of differences levels with the road's spatio-temporal coordinates was done by the Mann-Whitney U Test calculator and the correlation and communication relationships were determined using Spearman's Rank correlation coefficient. The means were compared using the Mann-Whitney U test and the obtained statistics were analyzed using SPSS 16 and Excel 2013 software.

4 The Field Results and Discussion

A total of 130 animal deaths were recorded in three categories: mammals, birds, and reptiles (Table 1, Figure 1). Mammals (including unspecified cases) with 113 deaths (87% of whole observations) showed the highest mortalities among the cases. Small mammals like hedgehogs and ground squirrels were significantly more than the larger mammals such as dogs, jackals, foxes, and sheep. No remnants of any large wild mammals such as leopards, deer, or boars were found in the study area.

Only 6 days (14% of recorded days) were without casualties and in another 36 days (86%) accidents occurred in one of two shifts, morning or evening, or both. 72% of cases were recorded in three beginning days of weeks, while only 18.5% of casualties were observed in three weekend days. 75% of the cases occurred in the morning hours which was significantly higher than the evening records (Figure 2). The number of occurrences in site No. 2 (64 cases) was more than the other two sites, followed by sites No.1 (41 cases) and No.3 (25 cases) respectively (Figure 3). 98% of the days recorded at least one morning death, while about 70% of researched days experienced evening casualties (Table 2).

April was bloodier than the other months, followed by March and May, respectively (Figure 4). As the weather got warmer, the frequency of dual daily casualties increased

Table 1: Number and type of lost species on different sites

Species	Site1	Site2	Site3	Total	Average	S.d.
Hedgehog	15	26	10	51	17	6.7
Ground squirrel	3	8	4	15	5	2.1
Fox	1	3	-	4	1.33	1.2
Jackal	1	4	-	5	1.7	1.7
birds	8	5	2	15	5	2.4
Reptiles	1	1	-	2	0.7	0.47
Domestic animals	6	3	1	10	3.3	2.05
Unknown	6	14	8	28	9.3	3.4
Total	41	64	25	-	-	-
Average	5.12	8	3.12	-	-	-
Standard deviation	4.5	7.8	3.7	-	-	-

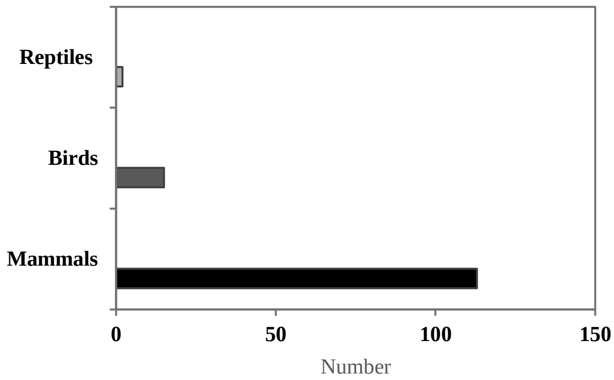

Figure 1: Numeral comparison of lost animals.

Table 2: Frequency of lost animals at different times

Species	**Frequency** (Number)	**Frequency** (%)	Morning records	Evening records
Hedgehog	51	39	39	12
Ground squirrel	15	11.5	12	3
Fox	4	3	3	1
Jackal	5	4	4	1
Birds	15	11.5	11	4
Reptiles	2	1.5	2	-
Domestic animals	10	8	9	1
Unknown	28	21.5	18	10
Total	**130**	**100**	**98**	**32**
Mean	16.25	12.4	12.25	4
Standard deviation	15.27	11.7	11.3	4.24

(Figure 5). Hedgehogs and ground squirrels showed the highest number of deaths in May. The birds were included cockroaches, starlings, pigeons, and doves (with 11, 2, and 1 deaths, respectively), and domestic animals and livestock have consisted of

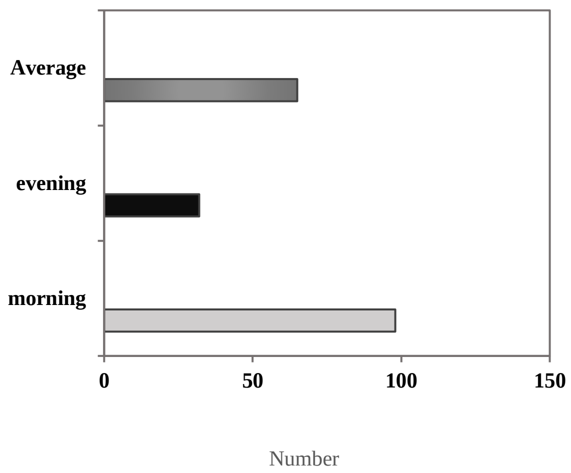

Figure 2: Numeral comparison of lost animals at different times.

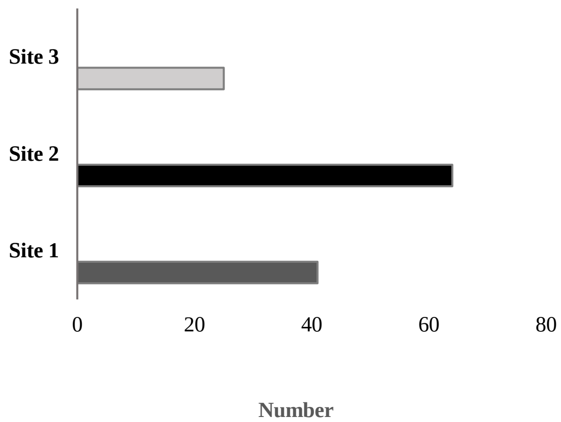

Figure 3: Numeral comparison of lost animals at each site.

dogs, cats, and sheep (7, 2, and 1 deaths, respectively). The species were not evenly distributed on the sites. Although hedgehogs and ground squirrels showed more deaths in site No. 2, they were registered in all three sites. Birds were also often present at all sites, almost in equal numbers. The record for reptiles at site No. 3 was zero, and two for the other two sites. Unknown cases (28 cases) were also found in all three sites. Fox deaths were approximately similar to jackals (4 and 5, respectively) and site No. 1 recorded the highest mortalities for domestic animals.

Most of the casualties occurred at site No. 2 which enjoys a perfectly smooth road with no slowdown factor, surrounded by pristine pastures, natural vegetation, and open plains (non-agricultural lands). At the same time, the lowest number of samples was observed in site No. 3, surrounded by agricultural and industrial areas, near larger population centers with higher traffic densities. This finding confirms another research result that suggests a direct and negative relationship between traffic volume and the

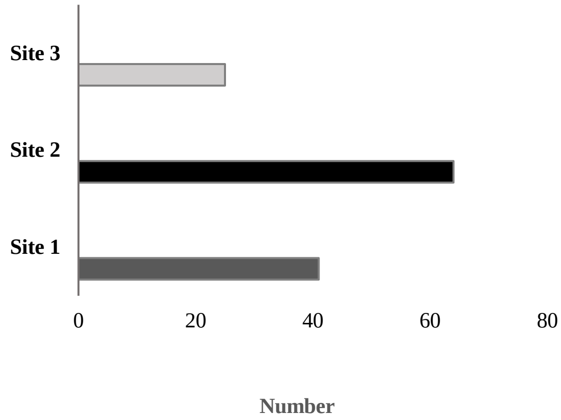

Figure 4: Number of accidents in different months of spring.

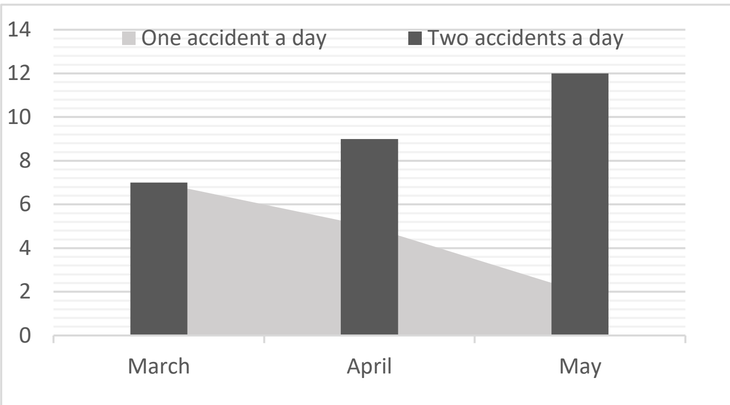

Figure 5: Frequency of once or twice accidents in spring.

severity of road casualties, probably because of the sensitivity of animals to traffic and their avoidance of approaching crowded roads [20]. Unlike other studies, [5, 17], in this study the weekend traffic was less than the early weekdays, probably because of the geopolitical situation of the Taybad district. Although Dogharoon Customs is located in this district, most of the cargo flow (from the origin of Bandar Abbas Customs) is transited from another road.

Early morning is a favorable time for natural life and slow-movement animals such as hedgehogs and ground squirrels or low-level flying birds such as cockroaches and doves. Animals' behavior change, more traffic load, higher car speeds, fewer drivers' visibility, and their more drowsiness were the main reasons for larger losses records. Similar results have been obtained by Mohammadi et al. [10] and Mayle and Staines [8]. Hedgehog deaths were much higher than other species, which was in contrast to some other studies [4]. Since in semi-arid regions, roadside margins are more densely green in early spring due to runoff, this may lead small herbivores like hedgehogs to close the roads. Of course, chasing the traditional paths, searching for a mate, or finding a new realm, in addition to neglecting the obstacles, could play an important role in generating these circumstances [2]. The fewer number of large mammals may be due to their smaller population in the environment or because of their more natural speed and visibility on the roads [11]. The higher morning mortality of jackals is in line with the animal's nocturnal lifestyle, but is in contrast to their usual abundance around residential areas [9].

The better the conditions for birds to live and nest on both sides of the road (sites No.1 and No.2), the higher the presence of these creatures in these areas, resulting in higher mortality. Short flight altitudes also increase the risk of accidents by vehicles. A lower record of bird deaths at site No.3 (agricultural surrounded lands) confirms the results of other research showing that birds are disturbed by traffic and may refrain from nesting or feeding near roads, although they rarely stop crossing there. At the same time, these results are in contrast to another study in Tanzania [6] which demonstrated the highest road casualties occurred for birds and then mammals. Since the wildlife lost on different road classes such as highways and freeways are not available, it cannot be said that increasing the road width is a factor to improve habitat or reduce road mortalities. However, due to the narrowness of the studied road and the lack of warning equipment, this volume of casualties confirms the results of some researchers which showed a positive relationship between the class of road and wildlife casualties [7]. The results of the Mann-Whitney U test showed that, at 95% and 99% levels, there was no significant difference between the number of wildlife losses on the road at sites No.1 and No.2 as well as No.1 and No.3, but it was significant between sites No.2 and No.3 (Table 3). These results also showed that the correlation coefficient between losses of different species is 0.567, which indicates an average relationship between losses of different species and the significance of this correlation. The correlation coefficient between losses in different sites was 0.004, indicating no relationship between losses in different sites.

Table 3: The test results for the relationship between casualties and sites

Result	Asymp. Sig. (2-tailed)	Z	Mann-Whitney U	Group
No significant difference in levels 95% & 99%	0.012	-2.506	935.500	Sites 1 & 2
No significant difference in levels 95% & 99%	0.545	-0.606	467.500	Sites 1 & 3
Significant difference in levels 95% & 99%	0.001	-3.363	438.500	Sites 2 & 3

Regarding the loss of small mammals in comparison with larger ones as well as reptiles and birds, a significant difference was observed between sites No.1 and No.2 and between sites No.2 and No.3 at levels of 0.01 and 0.05. Statistically, there was a significant difference between the mortality of small mammals and larger mammals, reptiles, and birds at levels of 0.01 and 0.05. A correlation coefficient of 0.802 showed that there was a strong relationship between the number of small mammals' mortality and the number of bigger mammals, reptiles and birds' losses. A weak relationship and a significant difference were observed between different species and sites. There was a substantial relationship between losses of morning and evening times, but there was no correlation between the type of species and the time of accidents. The correlation coefficient of 0.0513 showed that there was a moderate and significant correlation between mortality on weekdays, but no correlation was found between species and days of the week. Also, no significant difference was observed between the number of casualties on Saturday, Sunday, and Monday, similarly for the weekend days. Still, there was a significant difference between the first three days of the week and the three days of the weekend. Also, there was no significant correlation between casualties numbers and the study months (Table 4).

Table 4: The relationship between road casualties and time of accidents

Result	Asymp. Sig. (2-tailed)	Z	Mann-Whitney U	Group
Significant difference in levels 95% & 99%	0	-8.722	0	Mornings and evenings

By investigating less than one hundred local drivers' views and their experiences regarding road accidents through the questionnaires as well as interviews, high speed, road traffic, and small size of animals were found among the main causes of accidents. The other six reasons were lack of road visibility in the dark, lack of concentration while driving, the slow movement of animals, sudden animal entry into the road, driver's drowsiness, and unfavorable weather conditions such as dust (Figure 6).

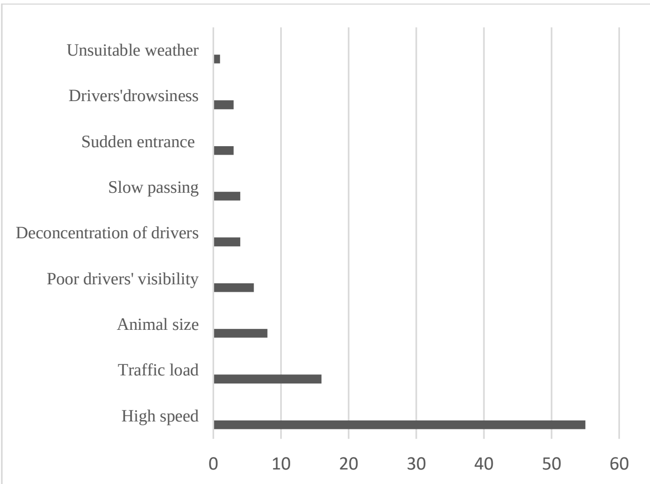

Figure 6: Reasons for accidents from local drivers' sight.

5 Modelling

In the following, we consider the ecological modeling of the deer population having two-species. The suggested model can be defined as a "wildlife species model" supposing a negative impact of vehicles on animals.

We assume that mortality and the other assumptions are as follows.

The mentioned animals, in the absence of vehicles, enjoy a logistic growth rate.

Also, all the collisions lead to wildlife casualties; while the animals will not affect the increase or the decrease in vehicles number. In other words, vehicles can be considered as a nuisance factor for animals crossing the road. The variables and parametric coefficients used in this research are t, x, y, a, b, c, M, h. Now, we consider the following hypothesis:

- The independent variable t which represents time;
- The dependent variables x and y indicate the number of animal populations and vehicles respectively;
- Parameters a and d illustrates the exponential growth rate of animals and vehicles respectively;
- Parameter b shows the animals' logistics growth rate;
- Parameter c indicates the impact factor of vehicles on animals;
- Parameter M represents the source capacity of the environment for wildlife;
- Parameter h indicates the harvesting factors for animals annually.

All the above parameters are mathematically positive and based on the mentioned hypotheses, the following model is to be introduced:

$$\begin{cases} \frac{dx}{dt} = x(a - \frac{bx}{M} - cy - h), \\ \frac{dy}{dt} = dy. \end{cases} \tag{1}$$

In the above system, indeed, we entered some parameters such as carrying capacity and harvesting factor that hurt animal mortality. It is assumed that the mentioned animals, in the absence of the above factors, have a logistic growth rate. Also, the decrease in wildlife population does not affect increasing the number of poachers and vehicles.

Equilibrium points for system (1) and their stability are analyzed. Model (1) has a trivial equilibrium point which is the origin, and a nontrivial equilibrium point which is $(x, y) = ((a-h)\frac{M}{b},\ 0)$. Some related mathematical models and their application in ecology are discussed previously (see [12, 13, 14, 15]). Now, we are going to study equilibria by using the linearization method. Model (1) has two following equilibrium points:

Origin which is trivial equilibrium point and $E = (\frac{M}{b}(a-h),\ 0)$ as nontrivial equilibrium point.

Theorem 1. System (1) has no equilibrium point.

Proof. We should calculate the Jacobian matrix. Jacobian matrix of system (1) is giving by

$$J = \begin{bmatrix} a - 2\frac{b}{m}x - cy - h & -cxy \\ 0 & d \end{bmatrix}, \tag{2}$$

and so, the above Jacobian matrix at a trivial equilibrium point which is the origin may be written as

$$J\Big|_{(0,0)} = \begin{bmatrix} a-h & 0 \\ 0 & d \end{bmatrix}. \tag{3}$$

Thus, Jacobian matrix (3) has the following eigenvalues:

$$\lambda_1 = a-h, \quad \lambda_2 = d. \tag{4}$$

Moreover, Jacobian matrix (2) at the second equilibrium point, $E = (\frac{M}{b}(a-h),\ 0)$, is given by

$$J\Big|_{E} = \begin{bmatrix} 2h-a & 0 \\ 0 & d \end{bmatrix}. \tag{5}$$

Jacobian matrix (5) has the following eigenvalues

$$\lambda_3 = 2h-a, \quad \lambda_4 = d. \tag{6}$$

Paying attention to relations 4 and 6 and as regarding d is positive, we see that if $a > h$, the origin is an unstable node. Meanwhile, the origin is saddle point provided $a < h$.

Moreover if $h > \frac{a}{2}$, equilibrium point E is unstable node and in case of $h < \frac{a}{2}$, equilibrium point E is saddle point. Therefore, we see that system (1) has no shell profit. And so, the proof is complete.

□

6 Concluding

The obtained results lead to the following observations: (i) Converting roadside habitats to agricultural lands has been effective in reducing wildlife road casualties compared to rangelands and open plains. (ii) Most animal deaths occurred in areas surrounded by pristine pastures and natural vegetation (non-agricultural lands). (iii) Fewer wildlife casualties are expected in proximity to larger population centers and industrial facilities, as well as with higher traffic densities. (iv) Analyzing the solutions of the system allows for predicting the animal population, which is important in the area of environmental science. The road conditions studied were similar to those in other developed countries in terms of animal losses. Therefore, the information related to this research must be compared and complemented by various researchers at the national and international levels. To improve the conditions of wildlife connected to roads and increase public awareness and health related to this issue, the following measures are suggested: (i) Launching an interdisciplinary public awareness movement, such as the "#animal_lives_matter" hashtag created by some of the authors of this paper in cooperation with an NGO, the municipality, the road department, and other institutions. This can be effective at the national and international levels. (ii) Creating more legal and governmental support to protect the rights of wildlife. (iii) Developing more diverse predictive mathematical models to better understand interactions between wildlife species with man-made tools or human-related activities. (iv) Measuring the casualties' data based on the road class, spatial distribution, and wildlife dynamics at various seasons and years, as the data can sometimes contain unbelievable figures.

Declarations

Availability of supporting data

All data generated or analyzed during this study are included in this published paper.

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Competing interests

The authors declare no competing interests that are relevant to the content of this paper.

Authors' contributions

The main manuscript text is collectively written by all authors.

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