Rural land use design based on an evaluation of insect ecological sensitivity

Comment [REV1]: TITLE CAN BE IMPROVED. I BELIEVE THE AUTHORS ARE NOT PROPOSING ANY RURAL LAND USE DESIGN.

SOME KEYWORDS ARE MISSING IN THE TITLE (E.G., IMPACT OF LAND USE ON INSECT ECOLOGY AND BURUNDI).

Abstract

Insects are found in almost all ecosystems and are responsible for several essential functions. They aerate the soil, pollinate blossoms, and control plant diseases. The ecological importance of insects cannot be underestimated: they form the basement of the food pyramid and affect agricultural ecosystems and human health. All organisms are co-evolved and are dependent each other. Human activities cause adverse effects in the insect´s environments. Opening forests and other natural areas for agricultural activities affect the insect ecosystems. Land, which is the foundation of human activities, is also the home of insects. Insects have been competing with humans for the products of our labor ever since the soil cultivation began. In this research, we evaluated the impact of land use on insect ecology. In one village of Burundi, where the most important land occupation is agriculture, we evaluated the effects of cropland, settlement, forestry system, and humid areas on insect ecology. We named it "insect ecological sensibility" and considered it in our study area. The entire village area is used as agricultural land and settlement. Artificial forestry and pastures, especially the absence of protected areas and ecological corridors, are the main points that negatively affect insect ecology in the study area.

Key words: insect ecological sensitivity, insect ecology, Burundi, rural land use, GIS and insects.

Introduction

Animal and plants have co-evolved and interwoven strong relations each other. The biotic and abiotic relationships make life in any area. Humans, one of the animal kingdom's members in these complex relationships and whose health depends on the life of biodiversity, influence the ecosystem's life (Chivan and Bernstein 2010, Yonglong *et al.* 2015, Morand and Lajaunie 2019). Insects are a critical part of biodiversity in terms of numbers and biodiversity services. More than 80% of animals and more than 50% of all identified beings are insects (Schowalt 2020). Although they are keystone species in many ecosystems, more than 80% of all existing insects are unidentified yet. Some species may even disappear before being identified (Gullan and Cranston 2014, Schowalt 2016).

The world is in a growing need to feed the increasing population. On the other side, humanity competes for economic growth. The only resource to attend the increasing food and financial needs in rural areas is the land (Garnett 2013, Marcos-Martinez 2017). Rural areas are considered as a big biodiversity reservoir. Biodiversity tends to decrease because of various effects. Forests have been cut and replaced by farms and field crops. Natural landscapes have been replaced by artificial landscapes, mostly agriculture, which only promotes few plant species. Rapid land use changes affect rural biodiversity. Agriculture and settlement are the most proeminent land use types (Kleijn 2009, Haines-Young 2009).

Since 2005, Burundi's political strategies are encouraging the increase of rural farming. This type of farming reduces natural lands that host native species. In their plan to open new agricultural fields, there is no ecological consideration. Many indigenous trees are disappearing. Considering the species interdependence, disappearing trees also cause the disappearance of insect species. Burundi's climate has two well-defined seasons: a rainy and a dry season. During the dry season, local people are encouraged to farm on swamps and marshes. Marshes and wetlands are among the most significant water banks, after lakes and oceans. People drain water from swamps and wetlands to open new farmlands. Consequently, thousands of species living in these ecosystems are disappearing. Marshes and swamps play a significant role in reducing climate change. This means that their destruction may accelerate climate change (Zhaoqing and Zhou 2013, Romanowski 2013, Weller 1994). The increasing Burundian population increases land pressure in different ways. The new generation needs a place for farming and settlement. Some natural lands are open to agriculture. The increase in population edemands the opening of new agricultural areas. The fact that each family has many children causes the lands to be divided by inheritance laws. The fragmentation of lands increases soil erosion and biodiversity loss.

So far, the only consideration that is taking into account in rural land use is the socio-economical aspects. Little attention is given to the ecological sensibility. Ecology means the life of the plots. If ecology is not considered, lands will gradually lose their economic performance. Rural planning improves the living standard and economic well-being of communities found in relatively unpopulated areas rich in natural resources. Regarding land use and management, in the context of the rural regions, it seems that there are less scientific works about rural planning. The major reason is that many investments are made in urban areas. Businessmen/women from the towns come to exploit rural farms and return to the towns. These factors put rural ecosystems in danger. The Mukike district is located in one of the highest altitudes in Burundi (more than 2000 m a.s.l.), and encompasses the highest mountain of Burundi (Mount Heha: 2700 m a.s.l.). The district is made of a succession of several hills separated by streams and rivers. Mukike has a long mountain range (Congo-Nile ridge, which is the source of many streams). The Gisorwe village, in which agriculture is the main economic activity, is located in the western part, at the foot of the Congo-Nile ridge.

Insects bring various harms, including pests to crops, timbers, and stored products. They are vectors of many diseases (some are pandemic). On the other hand, insects are keystone species in all ecosystems. They are pollinators, seed dispersers, and source of food for many other taxa. They also recycle nutrients, maintain soil structure and fertility, and control populations of many other organisms (Gullan and Cranston 2014, Schowalt 2020). This means that land use should take care of insect population stability. That is why we formulated here the "insect ecological sensitivity". Ecological sensitivity stands for the impact of human interventions on the natural environment and is determined by the reactions of the ecosystem to the environmental changes caused by external and internal factors (Rossi *et al.* 2008, Liang and Li 2012, Zhang *et al.* 2012). Insect ecological sensitivity considers the main biotic and abiotic factors influencing insect ecology. In this study, we aim to determine the insect ecological sensitivity in the Gisorwe village.

Materials and methods

Study area

The Mukike district is one of the rural district of the Bujumbura province. It is located in the middle-western part of Burundi. Mukike covers an area of 147.44 km^2. Burundi faces wide range of altitude, from 741 m to 2664 m a.s.l. and has all tropical microclimates. The Mukike district is located 45 km apart from Bujumbura, the economic capital of Burundi. The main economic activity is agriculture. The study area is the Gisorwe village, which is one of Mukike district's villages, and is located between 3° 30' 50'' and 3° 32' 08'' of south latitude and between 29° 32' 51'' and 29° 31' 02'' of east longitude in the west foot of the Congo-Nile ridge. It covers an area of 420 hectares (Figure 1).

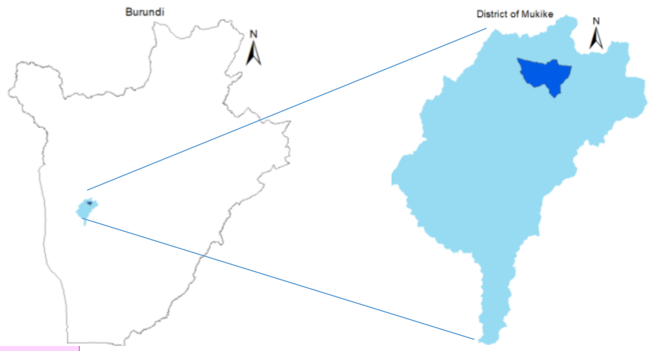

Figure 1: Location of the study area (Gisorwe village) in Burundi.

Data source

Raw geographical information system (GIS) data about Burundi were obtained from Institut Géographique du Burundi (IGEBU). Demographic data were obtained from the Office of the Mukike district.

Materials

The factors influencing insect ecological sensitivity were identified by the literature review. Field surveys were also conducted in the study area. Gullan and Cranston (2014) and Schowalt (2016) showed the factors that cause insect ecological and environmental problems. These factors vary according to the agroecological zone, region, and country. Field visits were conducted from February to August 2020. Farmers, researchers, and agriculture officers were interviewed and information about the area through open-ended questions was collected. GIS database were given by IGEBU.

Ecological sensitivity is the reaction level of the environmental change caused by internal and external factors. Insect ecological sensitivity is an ecological sensitivity in which the domain in insect ecology. Human activities dramatically affect insect ecology (Schowalt 2020). In this analysis, we evaluated the effects of the land use activities and their patterns in the insect environmental conditions.

Research Methods

Identification of insect ecological sensitivity (GIS-based insect ecological sensitivity analysis)

As our study aims to determine the sensibility of insect ecology, our primary criteria are deduced from the main factors of insect ecology. In **"Rural land use design based on an evaluation of insect ecological sensitivity,"** the significant finding is the threat of human land use to the life of insects. Our criteria focuses on the following factors: altitude, agriculture, light pollution, roads, settlements, and artificial forest exploitation. In our GIS-based analysis, we measured the area occupied by each factor. We confront each area and respective threats on insect severity. We established maps showing different factors' area. This GIS method was reinforced by insect samples collected in the field from each factor area. Analysis of variance (ANOVA) was used to compare the insect samples.

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Agriculture (cropland) factor: Agriculture is significant in insect habitat loss. Before installing crop fields, natural habitat is destroyed. A broad range of pesticides is used during field exploitation to protect crops. These pesticides kill pests and natural enemies.

Settlement factor: Rural or urban settlements occupy fields that insects live. Even if we have some insects which are enemies in most cases, they are different from the indigenous ones. Settlement is always associated with insect habitat destruction.

Road factor: As an essential ecologic factor, roads destroy natural habitat by the place it occupies and its buffer (segmentation of habitat).

Light pollution factor: Nightime lights destroy insect ecology by disrupting insect phenology. Insects like moths mate at night are attracted by the light so that they cannot mate. On the other side, insects that could rest at night are attracted by night lamps, they stay flying long time, experiencing a lot of early deaths.

Pastures and artificial forest exploitation factor: Insects need a quiet habitat without human intervention. Carpenter bees need dried logs to make galleries (for laying eggs). Moths and butterflies need stable places for pupae and diapause. Herbivores and other insects need stable and optimal conditions to perform their ecosystem role at different trophic levels.

Results and discussion

Elevation. The Gisorwe village is located between 2171.18 m and 2587.34 m a.s.l. (altitude difference of 416.16 m) (Fig. 2). We tested if the altitude influences the insect population in the village. Temperatures change with elevation, hence the change in environmental factors (Rahbek *et al.* 2019). Several studies have shown that the effect of elevation on species diversity varies between locations and taxonomical groups (McCain 2009). In our study area, we collected a sample of insects at four different spots at different altitudes (there was a difference of 100 m of altitude between two consecutive points). Every sample was collected at an area of 10 × 10 m and all samples were taken in plots with similar soil cover (pastures). The sample of insects that we collected showed no difference in species (Table 1). Our systematics analysis limited at the order level. The main orders considered were *Coleoptera*, *Hymenoptera*, *Diptera* and *Lepidoptera*. The ANOVA analysis ($p = 0.9352$, $p > 0.005$) showed no difference between samples collected at different altitudes of the village. This proves that the difference in altitude in the Gisorwe village is insufficient to cause differences in the insect diversity. The Gisorwe village belongs to the same eco-elevation spectrum. No previous entomological studies were performed in these villages.

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Comment [REV7]: PLEASE, MOVE TO THE MATERIALS AND METHODS SECTION.

Comment [REV8]: CHECK THE CORRECT WAY TO PRESENT ANOVA RESULTS. I BELIEVE IF SOMETHING LIKE F(2,27) = 1.655; p = 0.015), WHERE 2 = TWO-WAY ANOVA; 27 = DEGREE OF FREEDOM; 1.655 = F-VALUE.

Table 1: Number of sample species collected in four spots.

Site	Order	Species	Site	Order	Species	Site	Order	Species	Site	Order	Species
1	Hymenoptera	20	2	Hymenoptera	17	3	Hymenoptera	11	4	Hymenoptera	20
1	Coleoptera	25	2	Coleoptera	32	3	Coleoptera	33	4	Coleoptera	24
1	Lepdoptera	10	2	Lepdoptera	12	3	Lepdoptera	9	4	Lepdoptera	12
1	Diptera	15	2	Diptera	19	3	Diptera	16	4	Diptera	16

$p = 0.9352$ ($p > 0.05$).

Light pollution. Among 71 households in our study area, only ten households had solar electricity lighting overnight. Light pollution threatens biodiversity by changing night habits of insects, amphibians, fish, birds, bats and other animals: disruption of foraging patterns, increased predation risk, disruption of biological clocks, increased mortality on roads, and disruption of dispersal movements through artificially lighted landscapes (Beier 2006, Gauthreaux Jr. and Belser 2006, Moore et al. 2006). Insects are mostly affected by photopollution (Eisenbeis 2006). Artificial lights disrupt the day-night equilibrium of insects (Frank 2006, Lloyd 2006). Insects are attracted by artificial light sources. The first effect is the death by exhaustion (Smith 2009, Sanders and Gaston 2018). Most insects' affected biological activities are flight, vision, defense against predators, oviposition, courtship/mating, and feeding/foraging (van Langevelde 2017, Li et al. 2019, Manriquez et al. 2019). Light pollution can therefore harm insects by reducing total biomass and population size and changing the relative composition of populations, all of which with potential to affect the food chain. Furthermore, light pollution is considered an important driver behind some ecologic erosion (van Langevelde 2017). In our study area, mostly moths were attracted to lamps in the night. The nighttime light pollution caused by a number of 10 households is far from causing severe harm to the insect population in the village.

Road factor. The village has three unpaved roads with a total length of 3269 m. A potentially significant but under appreciated threat to insects is the road mortality. Studies have shown that insects are killed by road traffics in different ways (Baxter-Gilbert *et al.* 2015, Amanada *et al.* 2018). Given the extent of the global road network, billions of insects are likely to be killed on roads every year. These deaths are specially observed in cities and towns and on heavy highways (Andersson *et al.* 2017). The more active the traffic, the higher the insect mortality. Only one road (2076 m) has medium traffic of 10 cars per day (maximum of 20) in our study area. The other two (536 m and 657 m) are community roads that can stay without a car or a motorcycle for months. Except for some insects and larvae, which can die on the soil, flying insects can easily cross these roads without being hit by cars or humans. Roads are not a threat to insect ecology in the Gisorwe village.

Agriculture (cropland) factor. Agriculture is considered the second most important factor threatening the insects (Eggleton 2020). Agricultural pesticides can reduce insect population and diversity, which are important species for the ecosystem (Gibbs *et al*. 2009). Many pesticides are toxic to insects, birds, mammals, amphibians, and fishes. These have led to the population decline of many species living on farmlands (Boatman *et al.* 2007). In farmland habitats, population declines have occurred in about half of plants, a third of insects, and four-fifths of bird species (Robinson and Sutherland 2002). In our study area, agriculture occupies 45.17% (cropland and tea plantations) (Table 3). Both croplands and tea plantations are not good insect biotopes. Before their installation, natural habitat is destroyed. This means that some insects may also disappear. It follows the installation of new crops, sometimes monoculture; some insects will face shortage of foods. As the natural habitat has been destroyed, the natural ecosystem equilibrium is lost and some insects will become pests. Pesticides are the mostly used way to control pests; this justifies the use of pesticides in conventional agriculture. We recorded the use of two main insecticides: dimethoate and chlorpyrifos. The mostly used fungicide is dithane. All farmers are using pesticides in their fields. In tea plantations, we recorded the use of chemical fertilizers and weeds are regularly hoed or cut. This makes tea plantations an unstable habitat for insects.

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Pastures and artificial forest exploitations. Green spaces like pastures and forests would normally be the natural habitat of insects and another biodiversity. The more the environment is stable, the more insect populations are stable. Insects should be well conserved via efforts to preserve their habitats (Wolda *et al.* 1992). However, when humans exploit the forests and pastures, insect habitat is destroyed. In the Gisorwe village, pastures are permanently grazed, and grasses are often cut to be brought into stables or for composting. Many types of grasses are cut before they reach their flowering or maturity stages, depriving many insects of their food and habitat, as some insects feed on flowers. As they are made to be exploited, artificial forests lose their natural forest nature. In our study area, the main tree species found are *Eucalyptus maidenii*, *Eucalyptus saligna*, and *Acacia maerensii* (Table 2, Fig. 2), which are exploited for use in construction or transformed into charcoal. Woods and charcoals are sent to towns. Besides business, rural families collect firewood in these artificial forests. These practices are hazardous to insect ecology (Samways et al. 2020). Insects like carpenter bees (*Xylocopa sp.*) and other insects which use dried or decomposing logs are endangered species because they do not find logs or dried woods in nature (Raju and Lao 2006, He and Zhu 2020). *Eucalyptus sp.*, *Cupressus sp.* and *Acacia maerensii* are exotic species, this means that indigenous tree species were lost with some insect species (Payn *et al.* 2015, Perry *et al.* 2016). Some indigenous trees which are remaining should be unable to support indigenous insects. Furthermore, the surexploitation of firewoods and grasses for stables cannot allow the stability of the insect habitat.

Table 2: tree species and their area.

Species	Area (m^2)	%
Eucalyptus sp.	475980.51	45.23064
Cupressus sp.	475587.91	45.19334
Acacia maerensii	4894.89	0.465143
Bamboos + other indiginous	12104.62	1.150257
Eucalyptus sp. + indiginous	83772.84	7.960619
Total	1052340.78	100

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Settlement. Settlement is an important element in insect ecology because before settling natural habitats are destroyed and buildings occupy entirely the soil. After settlement, there is frequent application of different chemicals to control different pests in households and the habitat becomes unstable for insects (Turnbull 1980). In our study area, 1.75% of the area is settlement (Table 4). A dispersed settlement like the one found in Gisorwe village would have no significant impact on the insect ecology if natural habitats surrounded it. Insect ecology is aggravated because settlements are surrounded by unstable ecosystems such as croplands, tea plantations, artificial forests, and pastures.

Comparison between different land-use classes. The Gisorwe village is located in the high altitudes of Burundi. The annual average precipitation is 769.2 m. It rains nine months per year. A big network drains the village with perennial small streams. The streams pass through valleys, mostly V-shaped valleys, with high slopes. Insect samples were collected from different classes of land use areas (Table 3) to make a global comparison between the main classes. This analysis was made to compare the consequences of different land use types. Because many valleys are cropland-covered, we decided to use a plot in the valley that is not cultivated. ANOVA analysis ($p = 0.0008$ ($p < 0.05$), has shown a big difference in insect populations between valleys, cropland, tea plantations, and pastures/artificial forests. A higher population is observed in noncultivated valleys. There is a big need to examine the effects of agricultural practices in the Burundi valleys. Figure 2 and Table 4 present respective areas and proportions of different land use classes. Their different effects on insect ecology allow us to establish different levels of **"insect ecological sensibility"**. In our study area, some factors are enough to threaten insect ecology. Other factors are not significant alone, but are significant because others aggravate them.

Table 3: Comparison of insect populations in main classes

Site	Order	Species	Site	Order	Species	Site	Order	Species	Site	Order	Species
Valleys	Hymenoptera	32	Cropland	Hymenoptera	5	Pastures+ Forests	Hymenoptera	16	Tea plantations	Hymenoptera	9
Valleys	Coleoptera	21	Cropland	Coleoptera	10	Pastures+ Forests	Coleoptera	33	Tea plantations	Coleoptera	3
Valleys	Lepdoptera	40	Cropland	Lepdoptera	6	Pastures+ Forests	Lepdoptera	20	Tea plantations	Lepdoptera	8
Valleys	Diptera	55	Cropland	Diptera	10	Pastures+ Forests	Diptera	24	Tea plantations	Diptera	11

P = 0.0008 (<.05).

Table 4: Comparison of different land use and their sensibility significance

Land Use (m^2)	**Land use class**	**Area (m^2)**	**%**	**Insect ecological sensibility level**
4199389.67	Cropland	1794152.24	42.72412	Sensitive and significant
	Settlement	73436.85	1.748751	Sensitive, insignificant but aggravated by other factors
	Stabilized road in soil	19614.42	0.467078	Sensitive and insignificant
	Artificial tree plantations	1072373.77	25.53642	Sensitive and significant
	Pastures	1137358.05	27.08389	Sensitive and significant
	Tea plantations	1052340.78	2.439744	Sensitive and significant

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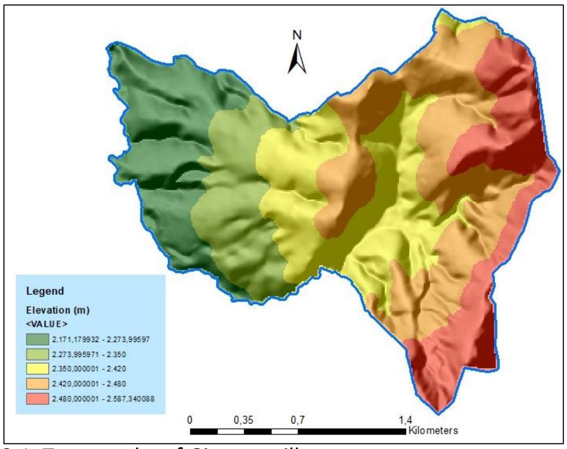
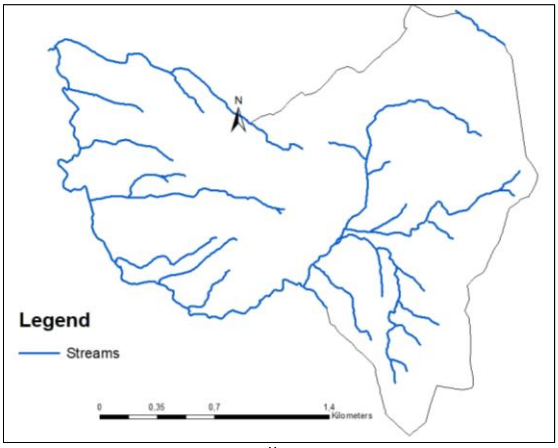
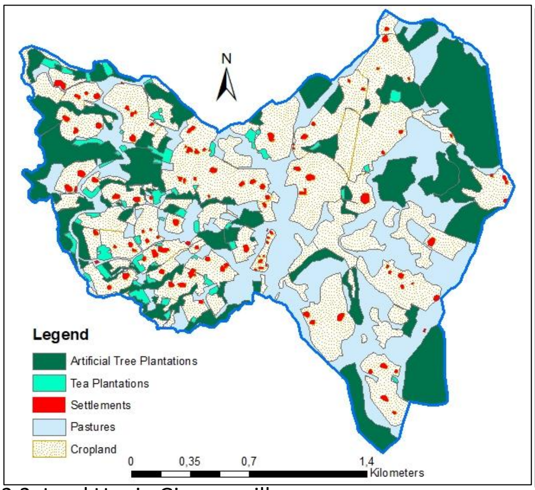


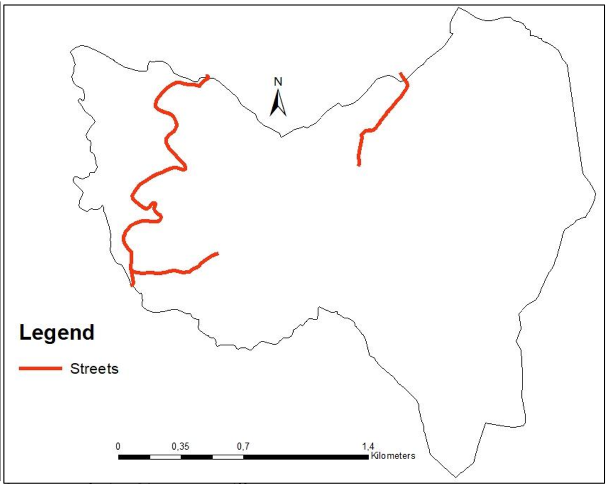
2.1. Topography of Gisorwe village



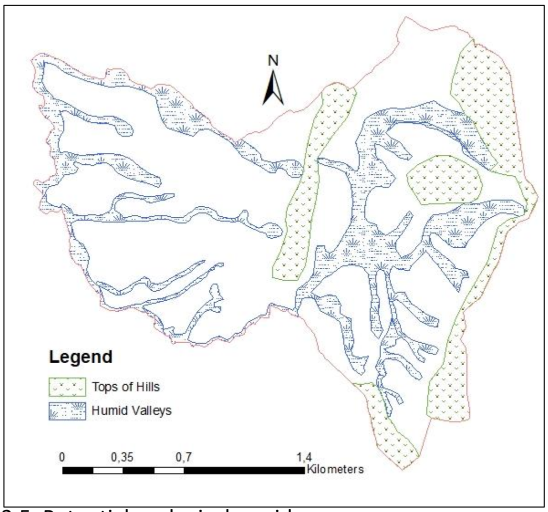
2.2. Streams in Gisorwe village



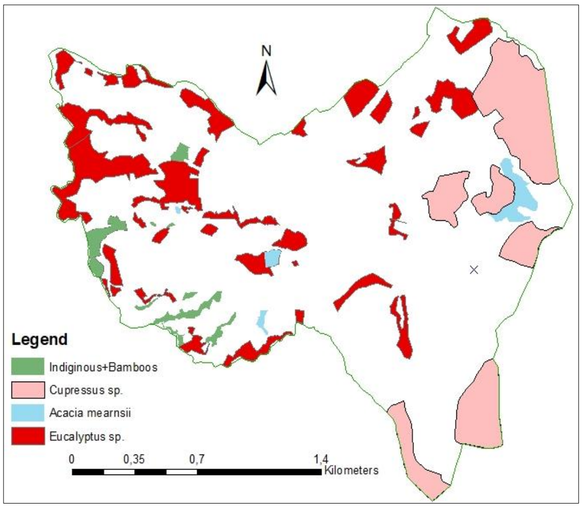
2.3. Land Use in Gisorwe village



2.4. Roads in Gisorwe village



2.5. Potential ecological corridors



2.6. Distribution of main tree species in the village of Gisorwe

Figure 2: Maps about insect sensibility in Gisorwe

Potential protected areas and ecological corridors. Streams and tops of hills need special protection for ecological conservation. Corridors are long, thin strips of habitat that connect otherwise isolated habitat patches. They are thought to reduce local extinction. Corridors have shown to serve as movement conduits for species of all animal taxa (Thomas 1991). Corridors influence the local foraging behavior of birds and free movements of pollinating insects, thus determining plant dispersal. As corridors effectively direct the dispersal of diverse taxa, these taxa are important in a broad range of ecosystem functions. Corridors have the potential to be valuable tools for landscape-scale conservation of diverse taxa and the biological processes that they direct (Hilty *et al.* 2020). Rivers and streams host a big population of species. Streams and their valleys have to be protected as the top of hills are a special place for water infiltration (forests ought to cover them) and serve as a connection between consecutive protected areas (ecological corridors). In our study area there is no protected areas neither ecological corridors.

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Conclusion

In this research of "**Rural land use design based on an evaluation of insect ecological sensitivity"** we researched the situation of insects based on rural land use in the Gisorwe village. There is no consideration of ecosystem or insect ecology in rural development and planning. This scenario has severe consequences on ecology and the environment in general. The entire village is in the same eco-elevation zone. We found that light pollution and road factor do not consist in serious ecological threats. Settlement, croplands, and exploitation of artificial forests and pastures are the big threats to insects ecology. Our study area does not present neither protected areas enor ecological corridors. In summary, the highly sensitive areas are: cropland and tea plantations, artificial tree exploitation, and pastures. The areas which would be kept as protected areas and ecological corridors are especially sensitive because they host all kind kinds of human activities. Land occupation in the Gisorwe village does not give much attention to the insect ecology.

References

Comment [REV14]: THIS SECTION NEEDS A CAREFUL REVISION:
1) REFERENCES ARE NOT IN ALPHABETICAL ORDER;

2) REFERENCES DO NOT FOLLOW THE STYLE OF THE JAERI JOURNAL (FOR EXAMPLE, JAERI USES ABBREVIATED FORM FOR JOURNAL´S NAMES).

3) THE LIST OF AUTHORS FOR THE THIRD REFERENCE (AMANDA EM, SHANON LG, MELISSA H, ERIK P, LENORE F) IS INCORRECT (IT SHOULD BE MARTIN AE, GRAHAM, SL., HENRY M, PERVIN E, FAHRIG L).

4) THERE ARE SEVERAL OTHER PROBLEMS.

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