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Table of Contents: Volume 9 Number 16 30 August, 2014

# ARTICLES

## Research Articles

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Scientific Research and Essays

*Full Length Research Paper*

# Microclimatic gradients in transition zones of Andean forest: A case study of Purace National Park

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**This study investigated two transition zones (matrix-forest edge-interior gradient) associated to forest fragments with different degrees of intervention, in an Andean paramo ecosystem located in Puracé National Park (Colombia). The relationship between the structures of vegetation and the spatial dynamics associated with microclimatic variation in each patch of woodland was determined in order to establish the Depth of Edge Influence (DEI). In each fragment, the vegetation was evaluated using transects of 80 x 2 m perpendicular to the margin, corresponding to 30 m of the matrix and 50 m into the woodland. All woody plants were identified, the heights and dominance was the most relevant features to determining the structure of the forest edge. Microclimatic data (humidity, sunlight exposure, air and soil temperature) were measured in transects and mapped using interpolation for determining the spatial dynamics in each gradient and the behavior of the variables associated with the DEI. The results obtained indicate that the change of microclimatic variables was significant in the margin-forest edge-interior gradient when comparing the forest fragments. The differences are related to the degree of human intervention, since the pressure exerted on certain plant species determined the spatial arrangement of these plants in the gradient. On mapping the dynamics of the microclimatic variables and their relationship to the distance in the gradient, a depth of edge influence was identified of 10 m for the fragment with less intervention (Woodland 2) and 20 m for the one with most intervention (Woodland 1).**

**Key words:** Paramo, ecotone, edge effect, gradient, microclimate.

## INTRODUCTION

One of the main threats to paramo ecosystems in Colombia is fragmentation (Armenteras et al., 2003). Landscape ecology defines fragmentation as the breaking up of a habitat, ecosystem or land-use type into smaller patches (Llausàs and Nogué, 2012), isolated from each other in a matrix of different habitats (Haila, 2002; Di Giulio et al., 2009; Conceição and de Oliveira, 2010). Fragmentation involves changes in the biotic and abiotic factors of these patches of Andean forest (Sarmiento, 2002; Aubad et al., 2008), where microclimatic

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variations are found between the edge of the forest fragments and the matrix. This variation has been attributed to the increase of the transition zones, where the influence of the matrix on the fragment generates significant changes in humidity, air temperature, light exposure, evapotranspiration and wind speed from the edge inward, which lead to substantial changes in the ecological processes and biological communities (Davies-Colley et al., 2000; Fletcher, 2005; Harper et al., 2005; Porensky and Young, 2013).

The transition zones are frontier habitats whose ecological characteristics are different from the adjacent habitats (Ries et al., 2004), consisting of two or more adjacent edges separated by a border zone. Border is the outer edge of an element of the landscape where the atmosphere is significantly different from the inside, presenting various microclimatic, soil and biological characteristics (Hardt et al., 2013). A characteristic of these environments is the interaction between them, which means that they have a controlling influence on the flows of material and energy that occur among different components of the units that they make up (Didham and Ewers, 2012). Microclimatic gradients in the transition zones play an important role as they are closely related to the plant communities that they comprise and the structure shown by the dominant species (Hoffmann et al., 2004).

The generation of forest edges in the Andean páramo ecosystems of the Cauca Department in southwestern Colombia has increased as a result of human activities (disturbance regime) carried out in the area (logging, burning, tourism and agricultural frontier expansion) causing the degradation of these natural systems (Martínez et al., 2009). This situation, has created transition zones where the microclimatic changes are exerting a significant control on the distribution and availability of plant species that make up the woodland patches and on the depth of edge influence (Mosquera and Figueroa, 2009).

On the basis of the above review of literature and the problem of land cover change and fragmentation in paramo. The present study aims to evaluate the dynamic of microclimatic variables in the transition zones, establishing the depth of edge influence in forest fragments with two degrees of intervention in those ecosystem; this research will be useful for further planning and management of the selected conservation area and also will be effective to enhance the environmental management of high Andean national parks.

## METHODS

### Study area

The study area is located in the northeast of Puracé National Park (PNNP) in the municipality of Puracé (Cauca), between the maximum and minimum geographical coordinates of N: 2°22'54.99'' - W: 76°19'49.89'' and N: 2°21'21.61'' - W: 76°22'09.17''. It is named the *Laguna de San Rafael* sector with 3,300 and 3,450 masl. The average temperature ranges between 9 and 12°C. It has a unimodal-biseasonal rainfall with an average annual rainfall of 2,284.39 mm, classifying the San Rafael area as wet seasonal (Rangel, 2002). The vegetation cover forms a mosaic characterized by patches of Andean páramo woodland within an herbaceous matrix consisting mainly of a grassland-frailejón mixture (Figure 1).

Selection of the sampling sites (transition zone) was carried out. Two wooded areas (patches) were chosen with similar conditions of slope, sunlight exposure and aspect. The two areas featured different levels of intervention and were identified as woodland W1- with a high degree of human intervention and woodland W2, having less intervention. Nevertheless, both of the patches chosen have forest edges of the closed type which are characterized as an area covered with dense vegetation composed by similar species to those found before the disruption (Didham and Ewers, 2012).

### Characterization of microclimatic variables in the transition zones

Six transects were established in two forest fragments (Patch) with different degrees of intervention, considering a presence-absence matrix analysis which included activities like logging, cattle grazing, burning, tourism and the expansion of agricultural frontier. For each patch, measurements were taken in the morning (08 h 00 – 10 h 00), in the middle of the day (12 h 00 – 13 h 00) and in the afternoon (15 h 00 and 16 h 00) for three consecutive days each month per four months, taking into account the direction of the transects (south-north, northeast and northwest) and the climate dynamics of the area (rainfall) (Figure 2a). Each transect was 80 m totally length, 50 m extended into the woodland and 30 m into the adjacent area (matrix). The border is considered the initial point from which these distances are established (Figure 2b).

Solar radiation, relative humidity, air and soil temperature were the microclimatic variables evaluated in the edges, considering the methodological references outlined by Williams-Linera et al. (1998). The first three parameters were measured at 1m height above ground level. To measure solar radiation, a heavy duty light meter model 407026 and datalogger module, model 3800340 (Extech), were used. The logger recorded five data every 15 s for a time of 3 s. The air temperature and relative humidity were recorded with a Thermo-hygrometer (CE). Soil temperature was measured at a depth of 5 cm using a soil thermometer (Brixco). Measurements were made every 10 m from the boundary into the forest fragment and every 5 m from the boundary towards the matrix.

### Study of vegetation architecture in the matrix-edge-fragment gradient

In each transect (matrix-edge-fragment) defined for the study of microclimatic variables, nested plots were established to identify the structure of plant communities (abundance and height), determining the presence of species in three vegetation strata: Arboreal, shrub and herbaceous (Figure 3).

### Spatial analysis of microclimatic gradients in the transition zones

To study the spatial distribution of the microclimatic variables in the defined gradients, an interpolation procedure was used, based on longitudinal registration at each of the points where the parameters of solar radiation, relative humidity, air and soil temperature were sampled. The ArcGIS 9.2 platform was used, running the Kriging interpolation technique that has been applied to similar analyses

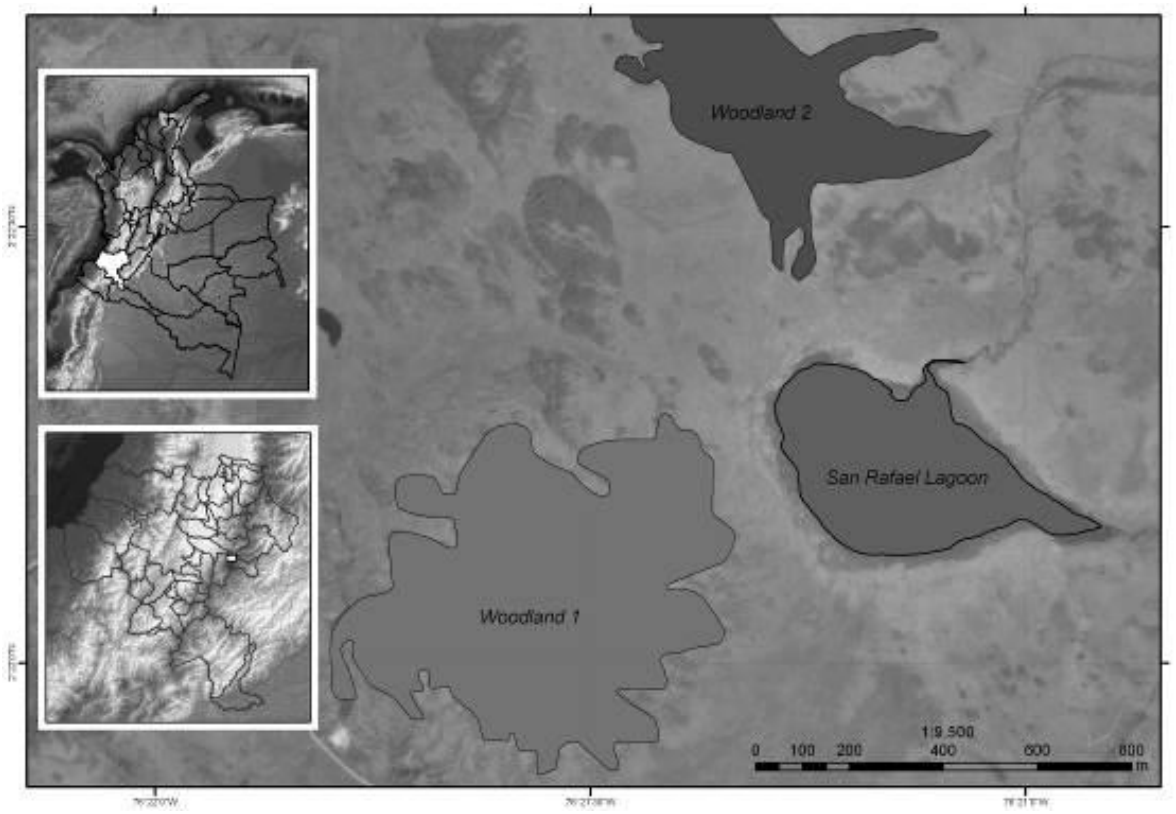



**Figure 1.** Map of study area.

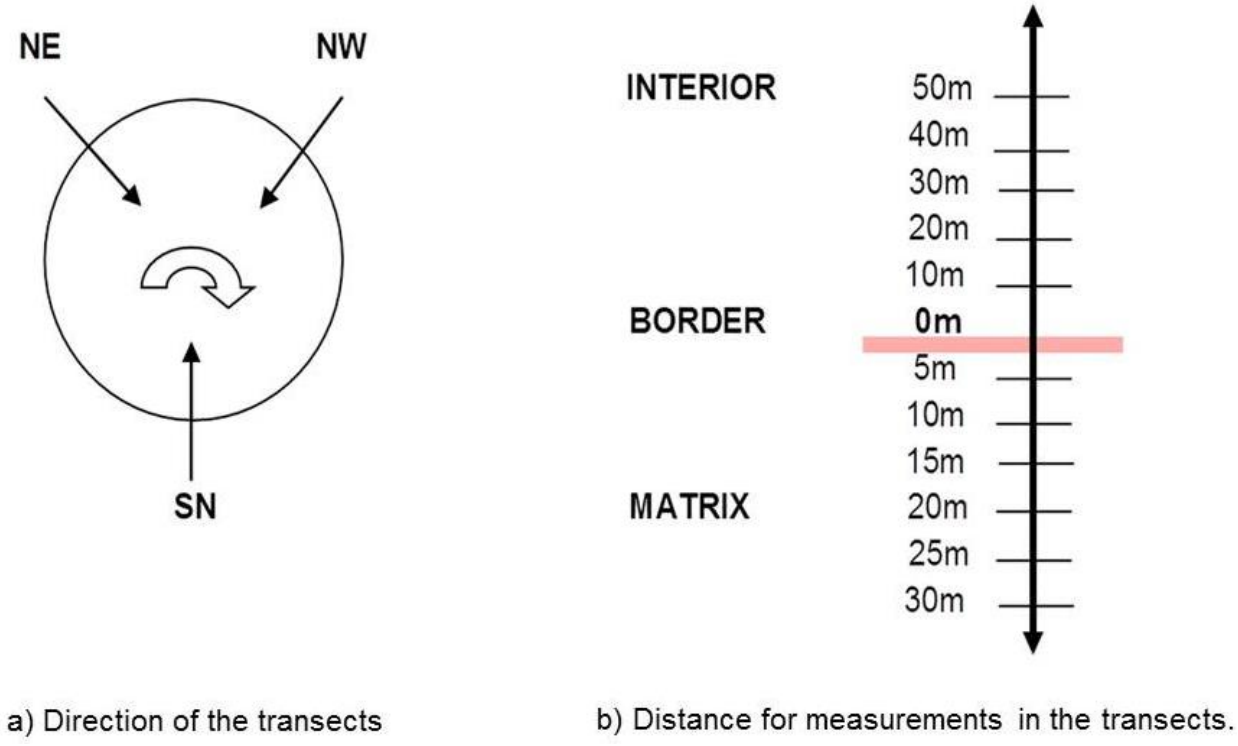



**Figure 2.** Microclimatic variables assessment; (a) Direction and (b) Distance for measurements in transects.

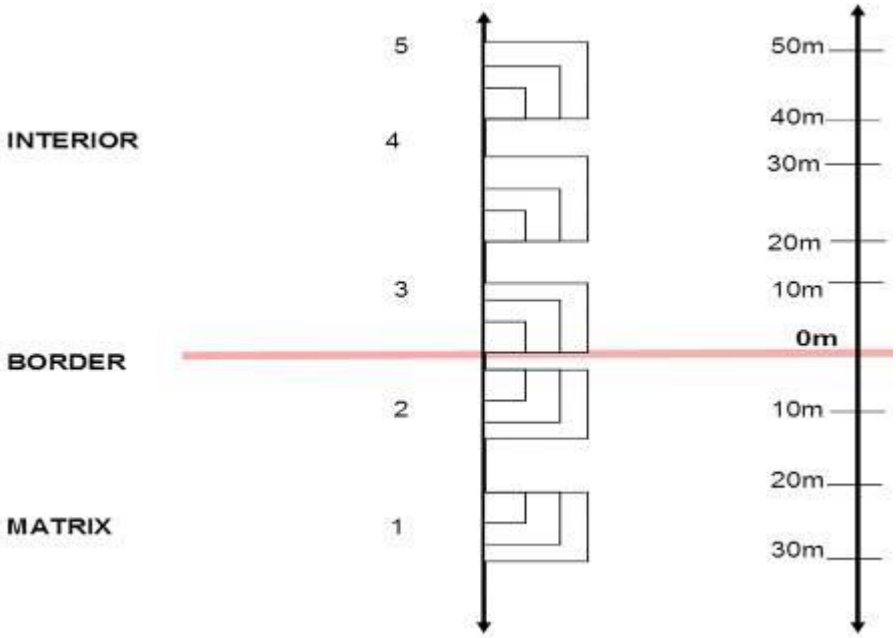



**Figure 3.** Nested plots established for the identification of plant species across the matrix-edge-fragment gradient.

(Liu et al., 2006; Mubiru et al., 2007). Essentially this geostatistical method allows the analysis of the spatial variation of the microclimatic variables (attribute Z in the series of points), considering a statistically homogeneous distribution along the gradient. The procedure was developed following these steps:

i) Generation of map points for each gradient: Based on geographical coordinates and the azimuth of each transects, each sampling points was mapped. The location of each point and its attribute (environmental variable) was saved in a Geo-database for ArcGis.
ii) Application of interpolation method: The Kriging method was used to generate a map with the distribution of microclimatic variables in each gradient for the two patches.
iii) Mapping the DEI in the woodland fragments: A map overlaying process integrating plant cover with the surface map of microclimatic variables was carried out to determine the depth of edge influence in each forest fragment. The obtained data were collated with the results of the statistical analysis to confirm the variations found.

**Data analysis**

The analysis done for the microclimatic variables along the gradient (matrix-edge-fragment) in the two transition zones was as follows:

(i) Parametric test, such as factorial ANOVA, complemented by multiple comparison tests for homogeneous variances (data for the sites satisfy homogeneity of variance: Levene: $p > 0.05$). This was done in order to analyze whether the hours the samples were taken (8 h 00-10 h 00, 12 h 00 -13 h 00, and 15 h 00 to 16 h 00) had any influence on the sites (forest W1, showing more human disturbance and W2 with less) and on the type of location (matrix-edge-fragment), or if instead they acted independently.
(ii) Similarly, a Pearson correlation test was performed to observe how distance affects each variable measured at the three different hours (measurement times). To get a better representation of the data obtained over the four months, the average of these data was used, taking account of the fact that the statistical analysis indicated no significant differences in the incidence of the months and the time of sampling in the variables measured.

The statistical tests were performed using the statistical program SPSS version 11.5. With regard to the plant species, a floristic similarity study (Jaccard quantitative index) was conducted for the two sampled forest fragments and a cluster analysis carried out in order to identify the distributed species along the matrix-edge-fragment gradient. This analysis was carried out using TWISPAN giving a measure of similarity or dissimilarity between groups of plots, so that a reliable classification could be performed.

The human impact degree was established by qualitative analysis, a presence-absence matrix was applied to determine the existence of human activities in selected fragments. To define the impact degree, the accumulation of activities in each unit (fragment) was estimated establishing a proportionality relationship in which the most number of interventions found was the higher human impact degree (Table 1). As seen in Table 1, the degree of human impact of W1 corresponds to a rate of 100% due to the many man-made activities, whereas for W2 the rate is 25%.

## RESULTS

### Species composition in transition zones

In terms of the species composition for the two forest types, it was found that the family with the highest number of individuals in the two patches is *Cunoniaceae*, with 53 individuals, equivalent to 13.25% of the total of individuals for woodland W1, followed by *Melastomataceae* family, with 11.5% (46 individuals),

**Table 1.** Human impact degree in the forest fragments studied.

| Fragment of woodland / Activities | Woodland 1 (W1) | | Woodland 2 (W2) | |
|---|---|---|---|---|
| | **Presence** | **Absence** | **Presence** | **Absence** |
| Logging | X | | | X |
| Burning | X | | | X |
| Cattle grazing | X | | | X |
| Tourism | X | | X | |
| Total | **4** | **0** | **1** | **3** |
| Proportion | **4:0** | | **1:3** | |
| Degree | **Impact(100%)** | | **Less impact (25%)** | |

*Asteraceae* with 11% (44 individuals), *Chloranthaceae* and *Clusiaceae* families with 9.75% (each with 39 individuals). For woodland W2, it was found 60 individuals from *Cunoniaceae* family, 15.62%, *Melastomataceae* with 10.9% (42 individuals), *Asteraceae* with 10.4% (40 individuals), *Ericaceae* with 7.2% (28 individuals) and *Poaceae* with 6.25% (24 individuals). For both fragments, the *Weinmannia mariquitae* and *Hedyosmum cumbalense* species are those that show the highest density and relative frequency, being the top value for individual abundance species and a spatial distribution extending uniformly into the forest fragment. They are followed by *Clusia multiflora* for W1 and *Symplocos quitensis* for W2. Towards the matrix, the species that show the highest relative frequency, for both woodland fragments, are *Espeletia hartwegiana*, *Calamagrostis effusa* and *Cortaderia nitida*. The most representative species for the two forest types are:

(i) W1 (high human impact)
Interior: *W. mariquitae* and *C. multiflora*
Edge: *Diphostephium shultzii, Hesperomeles obtusifolia, Miconia salicifolia, Monina obtusifolia and Gaiadendron punctanum* (exclusive to the transition zone).
Matrix*: Hypericum valleanum, C. nítida* and *E. hartwegiana.*
(ii) W2 (low human impact)
Interior: *W. mariquitae, H. cumbalense* and *S. quitensis.*
Edge: *Diphostephium spinulosum, E. hartwegiana.* and *G. punctanum* (exclusive to the transition zone).
Matrix*: C. nítida, C. effusa* and *Blechum loxense*

In addition to these, in both patches several species were found distributed across the whole gradient, including *Pernettya prostrate*, *Diphostephium tricopus* and *Pentacalia floribundum*. Considering the individuals sampled in the two patches of forest, a total of 86 species were found, of which 19 were exclusive to W1, 22 to W2, and 45 shared (52.33%). The two regions shared 28 families out of a total of 42, six families appearing exclusively in W1 and eight only in W2. The Jaccard index (0.52) shows low similarity for the two forest fragments, because the W1 patch had more human activities (livestock, logging and burn), additional to the climatic factors acting differently upon the two woodlands.

In a similar way, the cluster analysis indicated that the three locations had specific vegetation which determines the arrangement of the matrix-edge-forest gradient for each patch (Table 2).

## Microclimatic variables in transition zones

The microclimatic variables data for the four sampling months were averaged to determine the trend of the values along the gradient (matrix-edge-fragment); in the following Table 3, the values are compared for each type of forest. The data obtained from the statistical analysis for each environmental variable measured in the two forest types are presented below, to determining the incidence of these factors on the behavior of the variables. The numbers in bold represent the significant values with a confidence interval of 95%, the signs (+) and (-) in the correlation indicate the type of correlation given for the variables (Table 4).

## Spatial dynamics associated with microclimatic variation in each forest fragment

For the spatial dynamics analysis, four maps were made in which the measured microclimatic variables (relative humidity, air temperature, soil temperature and light exposure) were compared in both forest types and the three established transects in order to determine the depth of edge influence (DEI) in the different woodland fragments. The interpolation map generated shows that there is differentiation between the woodland interior and the matrix, the relative humidity measured in both forest types is higher inside the forest than in the matrix. The top human impact woodland, W1, reveals a strip towards the forest edge area in which the matrix-edge-fragment gradient can be made out (darker colors to the inside that begin fading towards the edge and the matrix) and in a direct correlation with the relative humidity values

**Table 2.** Plant height in relation to the gradient established in the two forest types.

| | Location | Gradient (distance) | Plant species with the highest top | Plant height - average (m) |
|---|---|---|---|---|
| Woodland 1 (high human impact) | Matrix | -30 m | *Cortaderia nitida* | 1.0 |
| | | -25 m | *Hypericum valleanum* | 1.2 |
| | | -20 m | *Espeletia hartwegiana* | 1.5 |
| | | -15 m | *Pentacalia tricopus* | 1.6 |
| | | -10 m | *Miconia salicifolia* | 1.8 |
| | Edge | - 5 m | *Diplostephium shultzii* | 2.2 |
| | | 0 m | *Herperomeles obtusifolia* | 2.6 |
| | | 10 m | *Gaiadendron punctanum* | 4.0 |
| | Interior | 20 m | *Monina obtusifolia* | 7.0 |
| | | 30 m | *Weinmania mariquitae* | 10.0 |
| | | 40 m | *Clusia multiflora* | 11.0 |
| | | 50 m | *W. mariquitae* | 12.0 |
| Woodland 2 (low human impact) | Matrix | -30 m | *C. nitida* | 0.5 |
| | | -25 m | *Calamagrostis effusa* | 0.7 |
| | | -20 m | *Blechum loxense* | 0.9 |
| | | -15 m | *C. nitida* | 1.5 |
| | | -10 m | *E. hartwegiana* | 1.4 |
| | Edge | - 5 m | *Diplostephium spinulosum* | 1.6 |
| | | 0 m | *G. punctanum* | 4.3 |
| | | 10 m | *Hedyosmun cumbalense* | 6.3 |
| | Interior | 20 m | *W. mariquitae* | 8.0 |
| | | 30 m | *Symplocos quitensis* | 9.0 |
| | | 40 m | *W. mariquitae* | 12.0 |
| | | 50 m | *W. mariquitae* | 14.0 |

**Table 3.** Averages and standard deviation of microclimate variables measured in the matrix-edge-fragment gradient for the two forest types.

**Woodland W1 (High human impact)**

| Distance (m) / Variable | Matrix | | | | | | Woodland fragment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 25 | 20 | 15 | 10 | 5 | 0 | 10 | 20 | 30 | 40 | 50 |
| Relative humidity (%) | 55.0 | 59.0 | 60.5 | 61.1 | 62.6 | 64.2 | 65.5 | 66.1 | 71.7 | 76.6 | 80.1 | 82.6 |
| SD | 1.29 | 0.82 | 0.68 | 0.41 | 1.05 | 0.97 | 0.94 | 0.99 | 1.5 | 2.32 | 2.20 | 2.37 |
| Air temperature (°C) | 15.8 | 15.4 | 15.0 | 14.6 | 14.4 | 13.8 | 13.4 | 13.0 | 12.0 | 11.4 | 10.5 | 10.1 |
| SD | 0.72 | 0.10 | 0.38 | 0.42 | 0.44 | 0.15 | 0.15 | 0.29 | 0.39 | 0.44 | 0.28 | 0.33 |
| Soil temperature (°C) | 11.5 | 11.4 | 10.8 | 10.5 | 10.3 | 10.0 | 9.5 | 8.7 | 8.3 | 7.9 | 7.7 | 7.5 |
| SD | 0.12 | 0.15 | 0.41 | 0.30 | 0.42 | 0.29 | 0.34 | 0.11 | 0.08 | 0.35 | 0.24 | 0.25 |
| Light exposure (lux) | 34.6 | 31.6 | 29.7 | 28.1 | 26.7 | 24.8 | 22.8 | 9.5 | 4.5 | 2.8 | 2.3 | 1.8 |
| SD | 1.37 | 0.49 | 0.46 | 0.25 | 1.08 | 1.36 | 1.55 | 0.31 | 0.35 | 0.25 | 0.58 | 0.14 |

**Woodland W2 (Low human impact)**

| Distance (m) / Variable | Matrix | | | | | | Woodland fragment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 25 | 20 | 15 | 10 | 5 | 0 | 10 | 20 | 30 | 40 | 50 |
| Relative humidity (%) | 58.8 | 60.3 | 61.2 | 62.4 | 62.8 | 63.2 | 65.3 | 67.3 | 73.5 | 78.6 | 82.0 | 85.5 |
| SD | 0.79 | 0.41 | 0.27 | 0.71 | 0.61 | 0.32 | 0.85 | 0.53 | 1.34 | 2.47 | 2.08 | 1.38 |
| Air temperature (°C) | 15.0 | 14.7 | 14.4 | 14.2 | 14.0 | 13.5 | 13.0 | 12.5 | 11.6 | 10.8 | 10.1 | 9.6 |
| SD | 0.28 | 0.32 | 0.37 | 0.17 | 0.31 | 0.12 | 0.06 | 0.24 | 0.18 | 0.13 | 0.10 | 0.37 |
| Soil temperature (°C) | 11.1 | 10.7 | 10.6 | 10.2 | 10.0 | 9.6 | 9.2 | 8.4 | 8.0 | 7.7 | 7.5 | 7.0 |
| SD | 0.17 | 0.25 | 0.14 | 0.14 | 0.18 | 0.15 | 0.22 | 0.05 | 0.10 | 0.14 | 0.03 | 0.06 |
| Light exposure (lux) | 30.8 | 28.8 | 27.4 | 25.8 | 23.8 | 23.2 | 21.1 | 6.3 | 1.9 | 1.0 | 0.6 | 0.4 |
| SD | 2.60 | 2.05 | 1.82 | 1.86 | 0.39 | 1.29 | 1.91 | 0.11 | 0.05 | 0.13 | 0.03 | 0.04 |

**Table 4.** The p-values (significance) for the ANOVA test.

| Factors | Relative humidity | Air temperature | Soil temperature | Light exposure |
|---|---|---|---|---|
| Sampling hour | 0.18 | 0.82 | 0.17 | **0.051** |
| Site (W1 - W2) | **0.00** | 0.70 | 0.06 | **0.042** |
| Location (matrix, fragment) | **0.00** | **0.00** | **0.00** | **0.00** |
| Distance | **0.00** | **0.00** | **0.03** | **0.00** |
| Sampling hour-Sites interaction | 0.29 | 0.96 | 0.06 | 0.77 |
| Sampling hour-Location interaction | 0.45 | 0.72 | 0.36 | 0.07 |
| Sampling hour-Distance interaction | 0.72 | 0.69 | 0.99 | 0.89 |
| Sites–Location interaction | 0.19 | 0.25 | 0.67 | 0.20 |
| Pearson correlation (Distance) | **0.00 (+)** | **0.00 (-)** | **0.00 (-)** | **0.00 (-)** |

recorded. In forest W2 with less human impact, the edge-fragment gradient is not so clearly displayed due to the fact that the relative humidity in these forests is more homogeneous (the presence of higher values of relative humidity towards the forest edge can be attributed to the architecture of the plant species) (Figure 4).

The maps of air and soil temperature (Figures 4 and 5) indicate that the data are not significant because it is not so clear where the forest edge extends toward the matrix-edge-fragment gradient. This is consistent with the statistical significance analysis for the measurements of microclimatic variables (Table 3), in which it is specified that the air and soil temperature variables are not significant for this type of variable measured in the two forest types. However, the higher values were found towards the matrix and lower inside the forest. As relative humidity, the light exposure map reveals a darker strip towards the interior of the forest fragment (from 10 m onwards in W2 and 20 m in W1) and fading towards the matrix and forest edge, due to the availability of plant species (shrubs and grasses present in the matrix and forest edge) that configure the gradient (Figure 5).

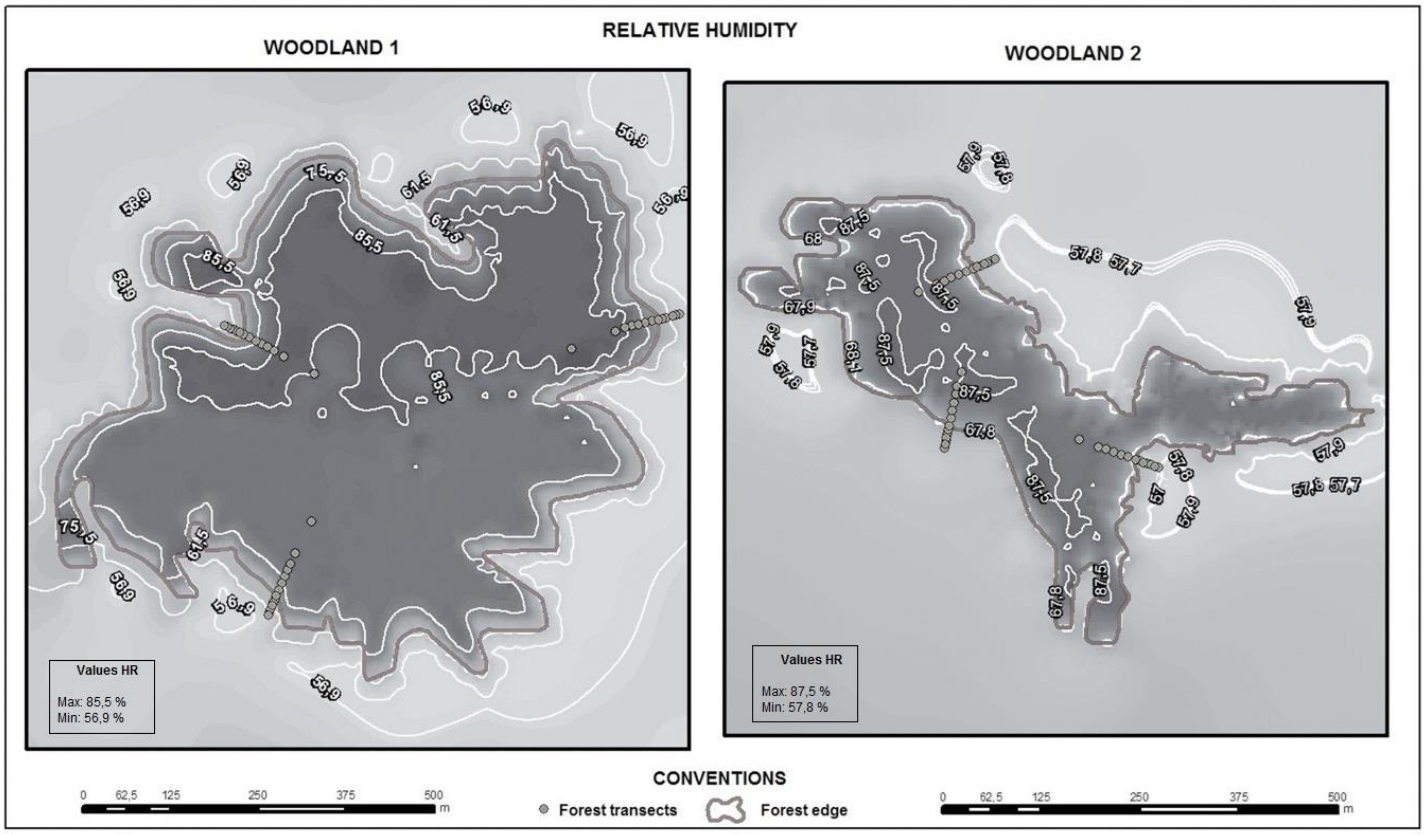
## ANALYSIS AND DISCUSSION

According to the results, the relative humidity showed a clear distinction between the matrix and the forest fragment. At the matrix, this variable has lower values ranging from 55 to 57% for both woodland types, but increase toward the forest interior to reach 87% in the low human impact forest (W2) and 85% for the higher impact fragment (W1)(Figure 6). Similarly, a homogeneous behavior is presented from the matrix up to 10 m in W2, from this point, the relative humidity increases toward the core of the forest; while in the W1 forest the variable increases since 20 m. The increase in relative humidity inside the forest W2, from 10 m, is favored by the vegetation architecture where the majority of species in the arboreal strata are *W. mariquitae* and *S. quitensis*, with heights between 9 and 14 m keeping the forest humidity. The significance and correlation tests, show that sampling hours (08 h 00 - 10 h 00, 12 h 00 - 13 h 00 and 15 h 00 - 16 h) do not influence the meaning of the data; however, the intervention degree, location and distance do significantly influence the variable, but there is no interaction between the factors (acting independently).

The air temperature for the two forest types ranged between 16 and 9°C, showing changes in function of distance and location type (matrix-interior) (Figure 6). The trend for this variable in the matrix-edge-fragment gradient showed higher values outside the forest, reaching 16 ºC for W1 and 15 °C for W2. Inside the forest, the values vary from 9 to 10 ºC respectively. There was a change in the variable (decrease) at 10 m inside the forest for W1 and 20 m for W2, due to vegetation cover and moisture conditions found in the two areas. The sunlight exposure, air and soil temperature, decline across the gradient inverse to relative humidity.

Soil temperature measured in the two patches showed a similar dynamic to air temperature, the sampling hour had no effect on the variable, although distance and location were significant (Figure 6). Along the gradient, the value for soil temperature declines steadily, with higher values in the matrix (9 and 12°C) and lowers inside the forest (8 and 7°C). In forest W1 this variable changes significantly at a depth of 10 m, while in the W2 forest this change occurs at 20 m. The human activities have reduced vegetation cover increasing the light penetration inside the patch, promoting the presence of low bushes such as *Diplostephium, Hypericum* and *Espeletia* toward the edge, creating the transition zone.

Considering the four variables, the light exposure was the only showing influence. In this study, this variable is the most susceptible to the edge effect found in the disturbed fragments (Figure 6). A clear distinction was seen between the interior of the fragment and the matrix for the light exposure, in the matrix was found higher values varies from 21 to 35 lux while data inside the forest ranges from 0.4 to 10 lux in the two patches. The graphical variation for this variable has a pronounced inflection point at 10 m inside the forest W1 and 20 m for W2, showing two independent data groups.



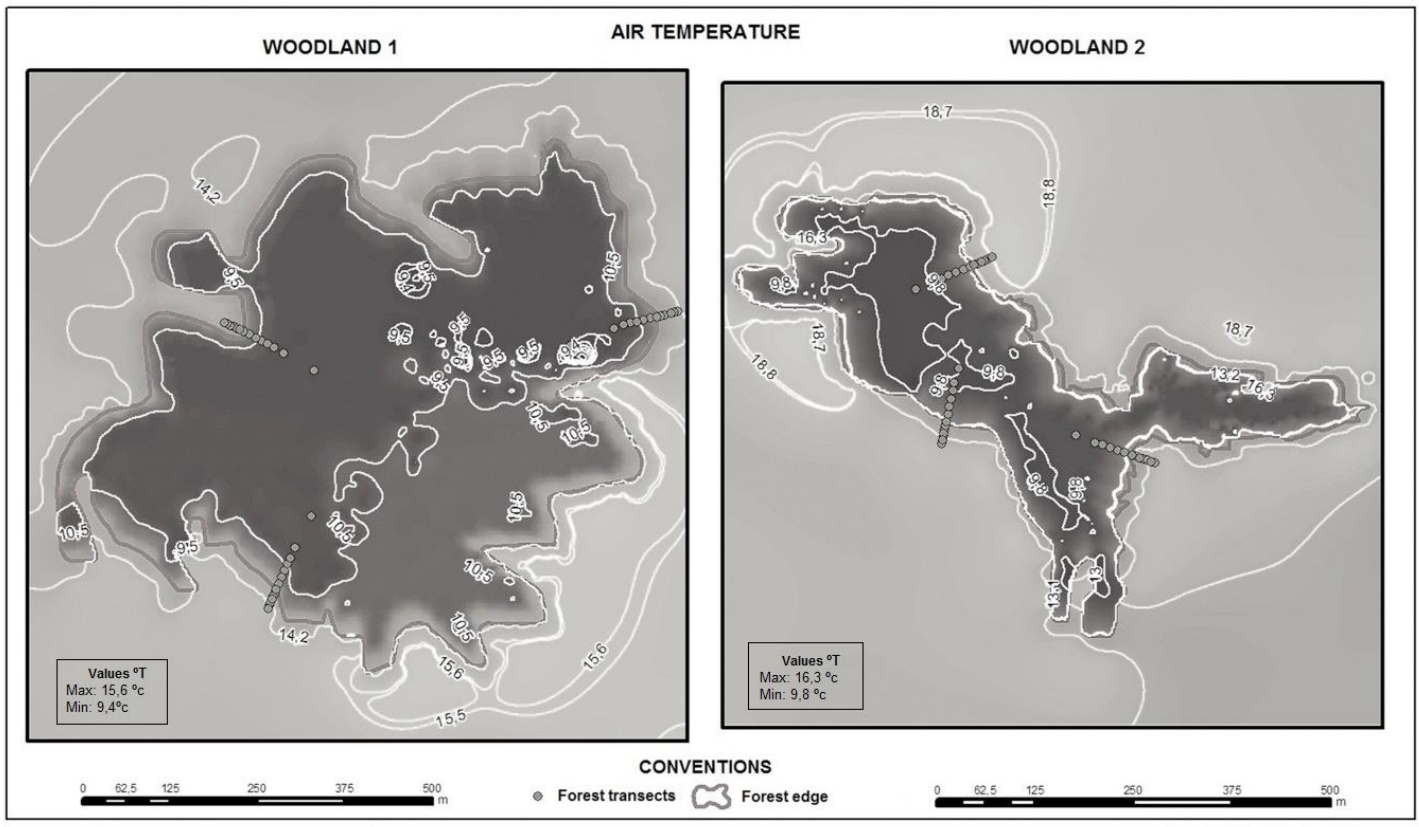
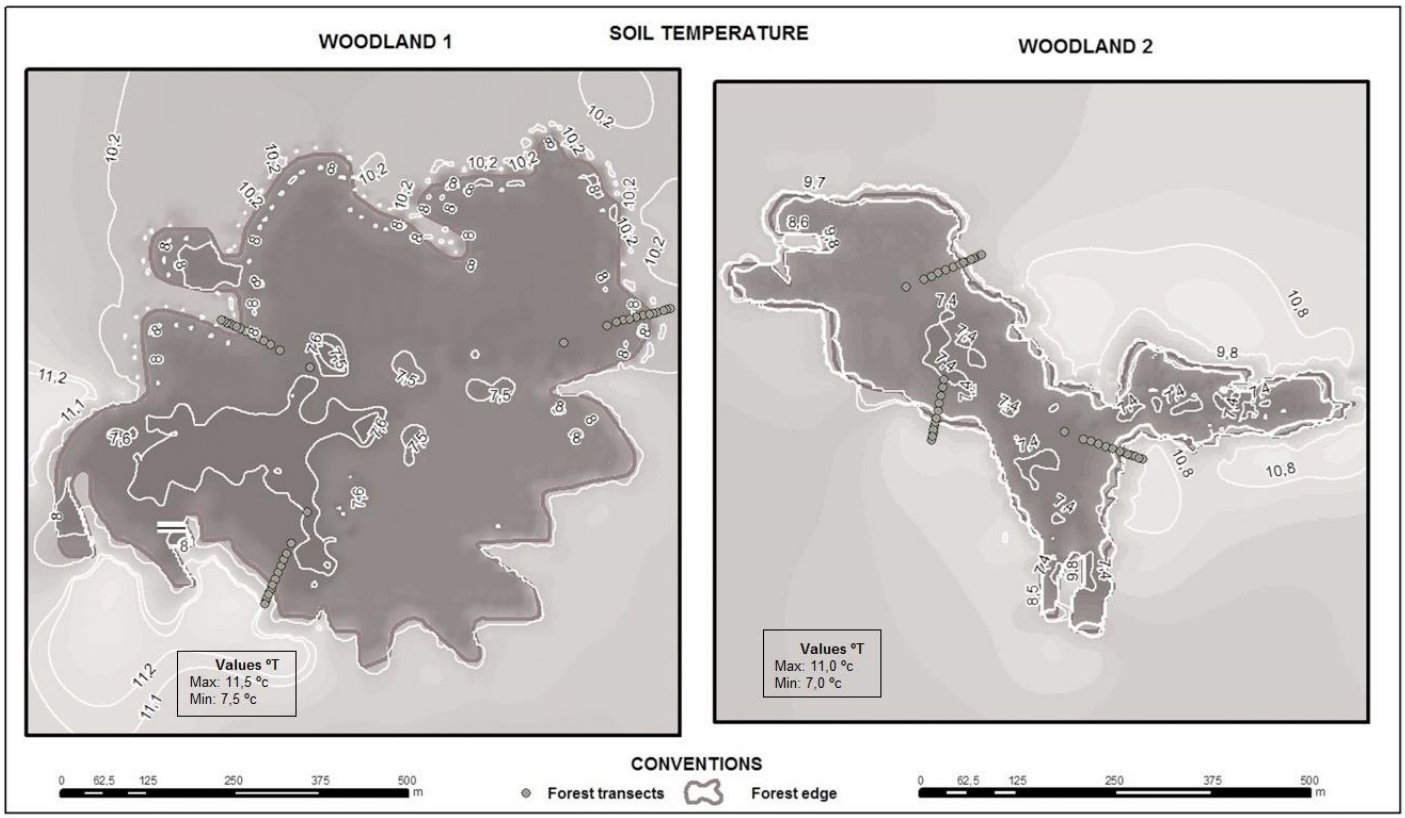




**Figure 4.** Data interpolation maps relative humidity and air temperature for the two types of forest.



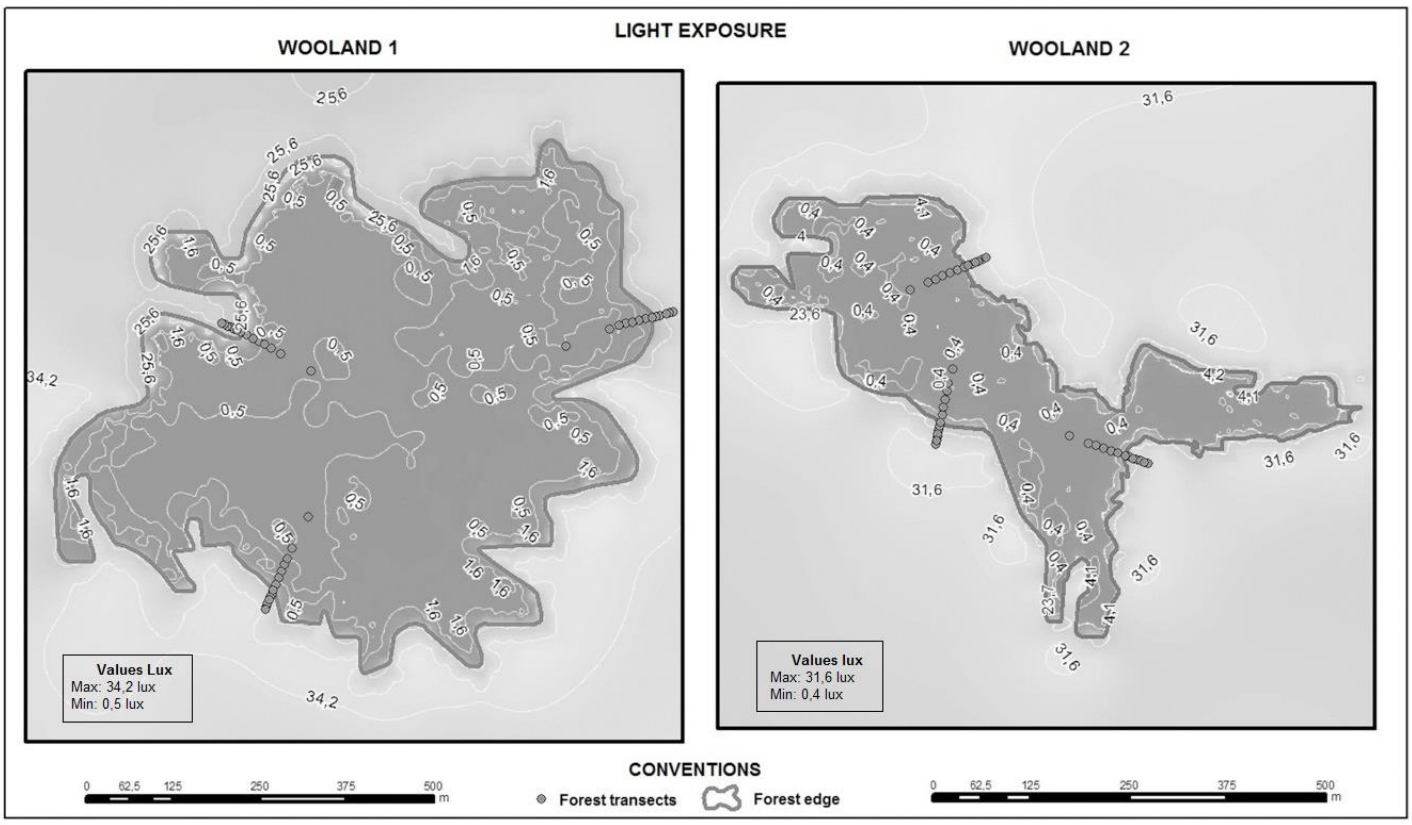




**Figure 5.** Data interpolation maps soil temperature and light exposure for the two forest types.

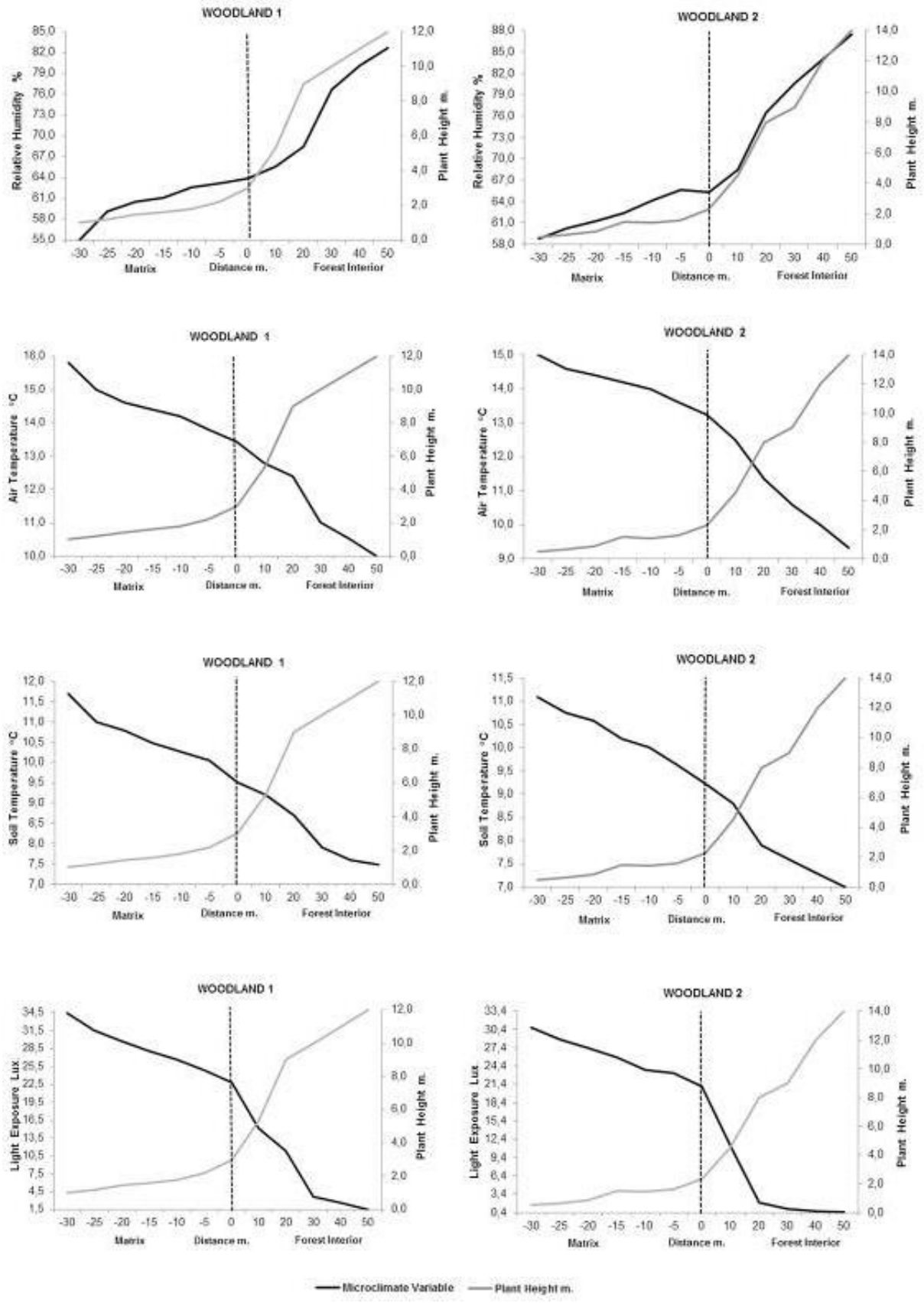



**Figure 6.** Microclimatic variable measurements (black solid line) vs. plant height (gray solid line), the names of the plant species are found in Table 4.

The change in the light exposure for the two patches is determined by mature tree structures and dense canopies toward the core of the fragments. The tree species present in W1 was *W. mariquitae*, *C. multiflora* and *M. obtusifolia* whit heights between 7 and 12 m, in W2 patch *W. mariquitae*, *S. quitensis* and *H. cumbalense,* with heights between 9 and 14 m. Correlations among distance and measured variables were significant mostly negative, then an increase in the distance toward the forest core reduce the value of light exposure, air and soil temperature. In contrast, the correlation for relative humidity was positive; so inside the forest is wet while the exterior (matrix) is drier.

Relative humidity and light exposure had a significant influence in both forest areas evaluated, reporting high values of light exposure in W1, with a lower relative humidity. In contrast, W2 was more humid, with less light due to the structure and composition of the vegetation cover. This is related to microclimatic parameters for forest edges usually depending on or correlating with the vegetation structure (Hennenberg et al., 2005; Mosquera et al., 2009).

Integrating the data of microclimatic variables and the distribution of vegetation in the two forest types, especially the relative humidity and light exposure, it was identified for W1 an edge influence (DEI) of a 20 m depth into the forest and a 10 m DEI for W2. The DEI found for W2 (10 m) relates to the type of surrounding matrix, with shrubs taller than those of W1 (*W. mariquitae, H. cumbalense*), and forest edge species (*D. spinulosum E. hartwegiana* and *G. punctatum*) that allow climate regulation in the forest interior, thereby reducing the microclimate effects of the matrix, lending it a self-regulatory capacity.

In contrast; the DEI reported for W1 (20 m) results from logging, cattle grazing, burning and tourism in the area, reducing the arboreal strata and leads to microclimatic changes, affecting the structure of vegetation and the environmental conditions beneath the canopy (Hennenberg et al., 2008; Montenegro and Vargas, 2008).

Different research considered the human intervention in forest fragments as determinant in woodland dynamics at local and regional scales, since the type and intensity of the disturbance can alter the structure and floristic composition of lowland and mountain forests (Fahrig, 2001; Ramírez-Marcial et al., 2001; Montenegro and Vargas, 2008). That explain the changes observed in the transition zone of W1 patch, where the microclimatic conditions and successional processes are altered, forming a type of edge habitat composed by low-height vegetation (Gascon et al., 1999; Rodríguez et al., 2007; Mosquera et al., 2009).

The results would allow classify the forest edge found as “closed” according to the reported studies of Williams-Linera et al. (1998) and Didham and Lawton (1999) for open and closed forest edge types, considering the closed edges have a lower affectation by abiotic factors, such as sunlight radiation and wind, than those with an open type edge (over 20 m).

In this study, several species (*P. prostrata, P. tricopus and D. floribundum*) were found to be distributed across the gradient for both forest types. These species become vital in the forest conservation and regeneration, as they could facilitate the vegetal succession, allowing in the future the establishment of arboreal strata typical of mature forest softening the influence of the paramo open matrix.

Finally it is proposed that plant species found in the boundary zone could be included in further studies, as they constitute important elements in the restoration of forest fragments, due to their tolerance of both habitats. These same species could promote the forest expansion and contribute to regulating environmental conditions, creating a stable and protected habitat. Thereby, success in the conservation of areas with degraded forest edge (transition) zones is necessary to consider the particular characteristics of the forest border, as these areas can either help facilitate the process or prevent it in cases where they only help to maintain degradative trends in the woodland patches, precluding the development of species from the forest into the matrix (Brotons et al., 2005; Armenteras et al., 2009; Riutta et al., 2012; Dupuch and Fortin, 2013).

## Conclusions

The DEI for the forest fragments tested was determined in a range from 10 to 20 m, considering the dynamics of the environmental variables measured (relative humidity, air and soil temperature, and light intensity) and the presence of forest edge species in the gradients (matrix-edge-interior). This DEI range is proposed for forest fragments with similar conditions. Microclimatic differences were found in the two forests studied (W1 and W2), the forest W1 is more exposed to microclimatic changes resulting from perturbations such as cattle grazing and burning. Those conditions determine the availability of specific environments and the vegetation arrangement to configure the matrix-edge-interior gradient in each forest type. The results reveal the consequences of ecosystem fragmentation on Colombian high Andean landscapes and provide key information to focus future research on the edge effect in paramos. This information, enhance the understanding of microclimatic zones in andean forest patchs to improve the environmental management plans to conserve natural areas susceptible to fragmentation.

## Conflict of Interest

The authors have not declared any conflict of interest.

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## GLOSSARY

**Border zone:** Line between the edges of adjacent elements in landscape.
**Depth of edge influence (DEI):** The extent to how far the edge effects on forest boundaries can penetrate into the patch.
**Edge effect:** Set of biotic and abiotic effects of the matrix on the forest fragment, which is manifested in changes within the fragment causing variations in the composition and abundance of species at the outer edge of a patch.
**Forest edge:** Outer forest area that shows the edge effect. This zone is characterized by high density and diversity of species that usually predominate in the outer part of the border.
**Paramo:** Complex and varied natural ecosystem, endemic to the tropical Andes of Venezuela, Colombia, Ecuador and Peru, since 3,500 to 4,800 masl. It is characterized by low temperatures (7 to 16°C) with sudden climatic changes.
**Transition zone**: Semi permeable zone that allows the movement of materials and organism through the landscape units. Two different edges and a border zone arrange the boundary or transition zone.

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Scientific Research and Essays

*Full Length Research Paper*

# Mobile electronic system ıntegration placement optımızatıon wıthın ankara by usıng genetıc algorıthms

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**Due to the increase in criminality, surveillance of society is increasing all over the world. When it comes to urban management just is not right to talk about security aspect. Safety management systems used in the study, the city of surveillance technology and placement methods which are used in the field were investigated. MOBESE, carry out a combination of a lot of function such as transportation, health care, city architecture and emergency response units. These systems are proceeding in parallel with technological advances in the development of urban safety management systems to benefit works. However, planning, infrastructure, installation, management and adapting to changing conditions should be conducted in at the deep. MOBESE is costly, complex and difficult to keep up to date, because application areas of MOBESE are very large cities. In this study, the genetic algorithm solution to the problem of Ankara City in the settlement of the MOBESE and as a result sought out the settlement plan has been optimized. Genetic algorithms demonstrate successful results in classical solutions, time-consuming and difficult to solve problems of this type of hosting of many variables and different criteria. This problem has been resolved by the method used in the solution, and the application has been tested for functionality and reliability.**

**Key words:** City security management system, mobile electronic system ıntegration (MOBESE), genetic algorithms, optimization, surveillance.

## INTRODUCTION

Following the emergence of modern state understanding, monitoring and surveillance activities of cities have been executed by governments and improvements have been supported. In today's world, in parallel with increasing magnitudes of criminality and terror crimes, surveillance over society is intensified (Karakehya, 2009; Güven, 2012). Today, all world countries design these systems suitably to their own cities and have been using these systems for a long time. In this regard, KGYS was established in Ankara. System is also known as

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**Abbreviations: KGYS**, City Security Management System; **MOBESE**, Mobile Electronic System Integration.

**Table 1.** Location data representing gene structure of candidate placement points.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Areas | Ulus Atatürk Statue Junction | Ulus metro exit | Ulus Osmanlı Junction | Talatpaşa Blv. Opera junction | TCDD station junction | Hipodrom st. Karabekir st. Junc. | Tandoğan junction | Celal bayar bıvd. | Rüzgarlı st. istanbul st entry | Rüzgarlı st Çankırı st. Entry | Ulus itfaiye square | Talatpaşa blvd - gençlik park | İstanbul st. k. Karabekir st. Junc. | C. Bayar blvd K. Karabekir st.junc. | Ulus sports complex entry | AKM entry | Atatürk Blvd. Telekom entry Atatürk Blvd Talatpaşa Blvd [illegible] | | Rüzgarlı St. Mid. exit | Büyükşehir building front. |
| ny | 85 | 70 | 50 | 20 | 75 | 10 | 80 | 10 | 65 | 60 | 65 | 30 | 35 | 40 | 50 | 55 | 65 | 40 | 35 | 20 |
| ty | 85 | 65 | 90 | 70 | 60 | 65 | 70 | 60 | 55 | 50 | 65 | 50 | 55 | 60 | 30 | 40 | 45 | 45 | 25 | 55 |
| gc | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| ydb | 4 | 2 | 3 | 3 | 3 | 3 | 3 | 4 | 2 | 2 | 2 | 3 | 3 | 3 | 1 | 1 | 1 | 3 | 1 | 0 |
| bg | 3 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 2 | 1 | 1 | 3 |
| ayb | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| ak | 90 | 80 | 75 | 70 | 80 | 50 | 60 | 20 | 45 | 50 | 65 | 30 | 45 | 60 | 50 | 50 | 20 | 45 | 10 | 65 |
| kb | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| hb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

MOBESE. With the system, public order and security services for the region, traffic flow and congestion control, detection of violation of rules and surveillance of large areas are provided (Ekinci, 2011; Obuz, 2009).

MOBESE, considering its benefits, became a critical part of city management. MOBESE application is costly and complex, sensitive to change due to direct connection with human factor and is affected by nature and weather conditions. Before application, it is imperative to make a very good analysis of area and execute with a plan that will provide the maximum benefit (Ekinci, 2011).

Purpose of the application is defined as generally lowering the setup costs of the system while maximizing the obtained benefit (Çakar, 2009). With the model constructed in the study, it is aimed to find a placement model for KGYS in Ankara city center using genetic algorithm method (Temel, 2009). Structure of the application includes assumptions, system setup parameters and constraints (Sag, 2008).

## MOBESE PLACEMENT OPTIMIZATION WITHIN ANKARA BY USING GENETIC ALGORITHMS

In a planned MOBESE or a MOBESE with a revised plan of placement, parameters determining install conditions and values belonging to placement points show a related property. For this reason, changes among parameters can be modeled mathematically.

### Modelling

In the problem, chromosome structure consists of hybrid valued genes. This structure is due to the flexible structure of genetic algorithm, in other words everything being unplanned and unscheduled (Gökay and Çağatan, 2002; Paki et al., 2002). In a chromosome formed to represent a possible placement point, genes are coded including following information. 1st gene: Population density information (ny); 2nd gene: Traffic density information (ty); 3rd gene: Input-output information (gc); 4th gene: Road state (boulevard, street, area, junction) information (ydb); 5th gene: Environment-building security information (bg); 6th gene: Infrastructure information (ayb); 7th gene: Region weight coefficient (ak); 8th gene: Red light violation point information (kb); 9th gene: Speed limit violation information (hb). In a problem consisting of 9 pieces of information, position data of cameras are [ng, ty, gc, bcka, bg, ayb, ak, kb, hb]. Example chromosome structure islows: [ 65,6,0,1,0,1,25,1,0 ].

The main purpose in the study is determining possible placement points (chromosomes) in the city (population). For this reason, first population containing N chromosomes (20 in application) which will be the possible solution of placement problem is constructed according to the data in the Table 1.

### Genetic algorithm's implementation steps

Which member of candidate points cluster will be subjected to placement process will be answered in the solution of the problem. Chromosome representing 1st candidate point in the implementation area from Table 1 is constructed. Other chromosome structures are constructed similarly:

$K_1$ =[ 85 85 0 4 3 3 90 1 0]

After population individuals are constructed, process of

finding the best individual can start. For every $k_i$, i $\in$ [1,100], chromosome $f(k_i)$ suitability value is calculated using the formula:

$$f(k) = \frac{\sum_{i}^{n} f(x_i)}{100}$$

For $k_1$ =[ 85 85 0 4 3 3 90 1 0] $f(k_1) = \frac{\sum_{i}^{n} f(x_i)}{100}$=(85+85+0+4+3+3+90+1+0)/100=2.71

Every individual in the population is subjected to the same process. As $f_{\max}$ =2.71, chromosome representing the optimum placement point in 1st generation is $k_1$ chromosome.

Selection strategy using roulette wheel is used. Firstly, to find the total suitability value of population $K = \sum_{i=1}^{0} f(k_i)$ formula is used:

$$\sum_{i=1}^{0} f(k_i) = 2.71 + 2.22 + 2.24 + 2.18 + 1.66 + 1.32 + 2.18 + 0.98 + 1.72 + 1.67 + 2 + 11.7 + 1.39 + 1.67 + 1.38 + 1.53 + 1.36 + 1.37 + 0.76 + 1.5 = 33.01$$

After this process, roulette wheel is designed using the calculations of the probabilities of selection of chromosomes in next generation. Selection probabilities of individuals are calculated cumulatively (Coşkun, 2006).

$$p(x_i) = \frac{f(k_i)}{K} \qquad p_1 = \frac{k_1}{K} = 2.71/33.01 = 0.0820 \quad q_1 = 0.0820$$

After determining selection intervals for each chromosome, 20 numbers are determined randomly for each chromosome in [0,1] interval. Roulette wheel is spun 20 times, and the number area produced in each step (number that comes when the roulette wheel is spun) selects the individual that is represented by that area (Table 1). As a result of this selection, despite chromosomes with high suitability value having a higher probability of selection, chance of selection for individuals with lower suitability exists. Cumulative probabilities of being selected as belonging to all the chromosomes are added together (Table 2).

1st population of the 2nd generation formed as a result of selection is constructed as follows:

$K_1 = K_{1(\text{old})}$ =[85 85 0 4 3 3 90 1 0]

$K_2 = K_{20(\text{old})}$=[20 55 0 3 3 3 65 0 1]

Process following the formation of new population is crossing for forming chromosomes with better suitability values than chromosomes from the previous population. It is not necessary to apply crossing to every individual in the population. A crossing ratio is determined for some individuals of population to pass to next population without being subjected to crossing. In the study, considering the size of the population, values defined by Shaffer et. al. (1989) for crossing are used (Erişen, 2011). Crossing ratio is selected as 0.75. A random number is produced for every individual in the population in the interval [0,1]. If this number is smaller than crossing ratio, individual is subjected to crossing. If the number is larger, crossing is not applied:

$r_1 = 0.012$, $r_2 = 0.982$, $r_3 = 0.156$, $r_4 = 0.659$, $r_5 = 0.397$, $r_6 = 0.165 \ldots\ldots r_{20} = 0.834$

Chromosome numbers to be crossed are determined as follows. Crossing ratio is multiplied with the number of individuals in the population. As crossing will be applied between even numbers, if the result is odd, one is subtracted to round to even.

In the application, crossing ratio is ( $p_c$ ) 0.75, chromosome size in the population is ( $p_b$ ) 20, therefore * $p_c$ = $p_b$ 20*0.75=15, 15-1=14 chromosomes will be subjected to crossing.

In order to subject individuals to crossing, a random crossing point is needed to be determined. In the chromosome, genes after the crossing point are substituted mutually. Two new off springs are created as a result (Tozan, 2007).

Randomly determined numbers for each chromosome previously are compared to $p_c$, If $r_i < p_c$, chromosome represented by this number is selected for crossing. Otherwise chromosome is not selected for crossing.

As $r_1 < p_c$ 0.012<0.75 1st individual is selected for crossing

As $r_2 > p_c$ 0.982>0.75 2nd individual is not selected for crossing.

After the individuals who will be subjected to crossing are determined, crossing point is determined randomly:

$K_1$ and $K_3$ are crossed after randomly selected 3rd gene

$K_1$ = [85 85 0 4 3 3 90 1 0] $\rightarrow$ $K_1$ = [50 90 0 4 3 3 90 1 0]

$K_3$ =[50 90 0 3 2 3 75 1 0] $\rightarrow$ $K_3$ =[85 85 0 3 2 3 75 1 0]

$K_4$ and $K_5$ are crossed after randomly selected 3rd gene

$K_4$ =[30 50 0 3 1 3 30 0 0] $\rightarrow$ $K_4$ =[80 70 0 3 1 3 30 0 0]

$K_5$ =[80 70 0 3 1 3 60 1 0] $\rightarrow$ $K_5$ =[30 50 0 3 1 3 60 1 0]

New population formed as a result of crossing is as follows.

$K_1$ = [50 90 0 4 3 3 90 1 0] $K_2$ = [20 55 0 3 3 3 65 0 1]

**Table 2.** Selection probabilities of chromosomes.

| Chromosomes | Suitability functions (F) | Selection probability (p) | Consecutive total selection probability(q) | Interval |
|---|---|---|---|---|
| 1 | 2.71 | 0.082 | 0.082 | 0-0.082 |
| 2 | 2.22 | 0.0672 | 0.1492 | 0.82-0.1492 |
| 3 | 2.24 | 0.0678 | 0.217 | 0.1492-0.217 |
| 4 | 2.18 | 0.0502 | 0.2672 | 0.217-0.2672 |
| 5 | 1.66 | 0.066 | 0.3332 | 0.2672-0.3332 |
| 6 | 1.32 | 0.0399 | 0.3731 | 0.3332-0.3731 |
| 7 | 2.18 | 0.066 | 0.4391 | 0.3731-0.4391 |
| 8 | 0.98 | 0.0296 | 0.4687 | 0.4391-0.4687 |
| 9 | 1.72 | 0.0521 | 0.5208 | 0.4687-0.5208 |
| 10 | 1.67 | 0.0505 | 0.5713 | 0.5208-0.5713 |
| 11 | 2.0 | 0.0605 | 0.6318 | 0.5713-0.6318 |
| 12 | 1.17 | 0.0354 | 0.6672 | 0.6318-0.6672 |
| 13 | 1.39 | 0.0421 | 0.7093 | 0.6672-0.7093 |
| 14 | 1.67 | 0.0505 | 0.7598 | 0.7093-0.7598 |
| 15 | 1.38 | 0.0418 | 0.8016 | 0.7598-0.8016 |
| 16 | 1.53 | 0.0463 | 0.8479 | 0.8016-0.8479 |
| 17 | 1.36 | 0.0411 | 0.8890 | 0.8479-0.8890 |
| 18 | 1.37 | 0.0415 | 0.9305 | 0.8890-0.9305 |
| 19 | 0.76 | 0.023 | 0.9535 | 0.9305-0.9535 |
| 20 | 1.5 | 0.0454 | 1.0 | 0.9535-1.0 |

$K_3$ = [85 85 0 3 2 3 75 1 0] $K_4$ =[80 70 0 3 1 3 30 0 0]

$K_5$ =[30 50 0 3 1 3 60 1 0] $K_6$ =[80 70 0 3 2 3 75 1 0]

$K_7$ =[50 90 0 3 1 3 60 1 0] $K_8$ =[35 25 1 1 1 3 10 0 0]

$K_9$ =[80 70 0 3 1 3 45 0 0] $K_{10}$ =[35 55 0 3 1 3 60 1 0]

$K_{11}$ =[20 70 0 3 1 2 70 0 0] $K_{12}$ =[50 30 1 1 3 3 50 0 0]

$K_{13}$ =[20 70 0 3 1 2 70 0 0] $K_{14}$ =[35 25 1 1 1 3 10 0 0]

$K_{15}$ =[65 65 0 2 1 3 65 0 0] $K_{16}$ =[65 65 0 2 1 3 65 0 0]

$K_{17}$ =[65 55 0 3 1 3 50 0 0] $K_{18}$ =[10 65 1 2 1 3 45 0 0]

$K_{19}$ =[50 90 0 3 2 3 75 1 0] $K_{20}$ =[55 40 1 1 3 3 50 0 0]

To provide the genetic diversity in the newly formed population as a result of crossing, mutation is applied using a certain probability value. For the mutation, for each gene of each individual, 180 random numbers are generated (20(individual)* 9 (gene)=180) in the interval [0-1]. ( $0 \leq r_i \leq 1$, $i \in [1,180]$)

Before the mutation process, following equation suggested by Bäck will be used to determine the mutation ratio:

$$\frac{1}{PopulationSize} \leq P_{MutationRatio} \leq \frac{1}{ChromosomeLength}$$

$\frac{1}{20} \leq P_{MutationRatio} \leq \frac{1}{9}$ From this mutation ratio ($P_m$) is determined as 0.05.

The subject to consider here is, due to the unique structure of the chromosome, genes belonging to chromosome are not in the same structure and properties. Because of this, each gene will be subjected to mutation with their own properties. Genes 1, 2 and 7 are valued between 0 and 100, while genes 3, 4, 5, 6, 8, 9 are valued with 1,0 code. Therefore, genes 1, 2 and 7 are substituted with values that round them to 100 while genes 3, 4, 5, 6, 8, 9 are evaluated with modifiers.

Due to the difficulty of the application, instead of this method, application of following method will yield better results (Bağış, 1996).

1. A random x number is generated between 0-9
2. If x value is 1,2 or 7, a random y number is generated between 0-100
3. If x value is not 1, 2 or 7, and current value is 0, y is generated as 1, if current value is 1, y is generated as 0
4. Gene values on chromosome is compared to this y

value.
5. If the generated y number is the same as the x[th] gene value of the chromosome, a different y value is generated.
6. If the x[th] gene value in the chromosome is different than y value, gene in the x position in the chromosome is found.
7. Y value is substituted in the place of this found value
8. Apply these steps to all chromosomes in the population.

As a result of mutation, chromosomes with changed genes are substituted with the old ones, forming the new population (Civril, 2009). New population formed as a result of mutation of population is as follows:

$K_1$ = [50 90 0 4 3 3 90 1 0] x=2, y=56 $\rightarrow$ $K_1$ = [50 56 0 4 3 3 90 1 0]
$K_2$ = [20 55 0 3 3 3 65 0 1] x=1, y=98 $\rightarrow$ $K_2$ = [98 55 0 3 3 3 65 0 1]
Suitability value of the new population is calculated again.
For $k_1$ = [50 56 0 4 3 3 90 1 0] $f(k_1)$ =(50+56+0+4+3+3+90+1+0)/100=2.11
For $k_2$ = [98 55 0 3 3 3 65 0 1] $f(k_2)$ =(98+55+0+3+3+3+65+0+1)/100=2.28
For $k_{20}$=[55 40 1 1 1 3 50 0 0] $f(k_{20})$ =(55+40+1+1+1+3+50+0+0)/100=1.51
As $f_{\max}$ =2.55 chromosome representing the optimum placement point in 2[nd] generation is $k_3$ chromosome.

If the generation number determined at the beginning of the application is not completed, all steps are exercised again from step 2.

$f_{t\max}$ values found as a result of every t generation are compared with each other. As a result of the comparison, chromosome giving the highest suitability value is giving the optimum placement plan. In the application, at the end of 2[nd] generation 3[rd] chromosome represents the best placement point.

Ulus Osmanlı Junction (3[rd] placement point in Table 1), represented with chromosome. $K_3$ = [85 85 0 3 2 3 75 1 1] represents the first point that needs placement. From the genes of the chromosome:

1[st] gene: 85, the area has a high population density
2[nd] gene: 85, the area has a high vehicle density
3[rd] gene: 0, the area is not an input-output point.
4[th] gene: 3, the area is a boulevard
5[th] gene: 2, area is in 2[nd] degree zone with respect to environmental safety
6[th] gene: 3, area is a 3[rd] degree zone with respect to infrastructure
7[th] gene: 75, area weight coefficient is high
8[th] gene: 1, red light violation system is required
9[th] gene: 1, as it is a boulevard, speed limit violation system is required

## Conclusions

Application gives the optimum placement plan output in accordance with inputs belonging to candidate placement points. Output here represents the best result given by the candidate placement points. Output number will get higher as number of candidate application points in the city increase. Optimum placement point obtained as a result of the application is expected to improve depending on the number of iterations. In the example application, it is aimed to find 1 point which will yield the optimum result from 20 placement points in the city. In an application that will include the entire city, iteration number will get higher as output number gets higher.

As a result, designed application meets the expectations and gives the possibilities of application for bigger areas. Placement process done via the program includes placement number belonging to hardware, code, camera number, county and region information, placement purpose, hardware type and installation address.

## Conflict of Interest

The authors have not declared any conflict of interest.

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Scientific Research and Essays

*Full Length Research Paper*

# Efficacy of compression application in instable intraarticular distal radius fractures, treated with external fixator

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**This research studied the efficacy of compression application in patients with instable intraarticular distal radius fractures. Here, results for 44 patients (32 males 12 females, mean age 36, distribution 21 to 59), with instable distal radius fracture, was retrospectively assessed. 22 patients who have received conventional closed reduction prior to external fixation and 22 patients, who have received compression in anterior-posterior plate, were included in the study. Same brand of external fixator was applied to all fractures and in addition, Kirchner wire was also used together with fixator for the fixation of fracture to a total of four cases, including two cases from compression group and two cases from control group. For two groups, radiologic AO classification was used. In both groups, radial curve angle, palmary curve angle and radial length data were compared. Functional results were assessed in line with Modified Sarmiento scale. Six of the fractures were open fractures. According to AO classification, 6 of the fractures were of type B1, 4 fractures B2, 14 fractures C2 and 10 fractures C3. The term of external fixation application was an average of 5 weeks in both groups and the follow up term of the patients was average 7.6 months (distribution 4 to 19 months). There were no significant differences from radiological aspect between the two groups ($p>0.05$). In the functional assessment, the results of the patient group, subject to reduction with compression technique, were better compared to control group ($p<0.05$). The application of compression in the treatment of instable and intraarticular distal radius fractures, improve clinical and radiological outcomes. This described technique, is an easily applicable and safe method.**

**Key words:** Radius fracture, external fixator, intraarticular fracture.

## INTRODUCTION

The frequency of radius lower end fractures is around 15 to 20% among extremity fractures (Pogue et al., 1990). In these frequently seen fractures, the chosen treatment method affects results (Sarmiento et al., 1975). method must provide the restoration of radial length, radial inclination and palmary tilt and in addition, must allow a good functional result (Fernandez, 2000; Sanders et al., 1991).

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**(a)**

**(b)**

**Figure 1.** (a) Patient's preoperative AP and (b) Lateral radiographs of instable intraarticular distal radius fractures.

While closed reduction and plaster fixation is successful in the treatment of simple radius lower end fractures, problems are encountered in the treatment of instable intra-articular distal radius fractures (IADRF) (Sanders et al., 1991; Young and Rayan, 2000). In the treatment of these fractures, application of open reduction and internal fixation method is technically difficult and may fail in the restoration of many parts (Young and Rayan, 2000). Successful results may be obtained with external fixation, following closed reduction (Huch et al., 1996). External fixation is a method, which may be easy and quick; by displacement with ligament taxis or by distracting impacted fragments, it may maintain the continuity of reduction (Hanel et al., 2002; Trumble et al., 1994). However, metaphases separation problem could not be completely resolved with this method.

Different types of fractures occur in the intraarticular distal radius depending on regional anatomy and type of injury (Bass et al., 1995; Tsukazaki et al., 1993).

As there is no only single method or material for the treatment of distal radius fractures, surgeons should be familiar with all alternatives (Rogachefsky et al., 2001; Trumble et al., 1998). Determination of most appropriate methods and materials for different types of distal intraarticular radius fractures is only possible through comparative studies (Grala et al., 2005; Margaliot et al., 2005; McQueen et al., 1992).

In our study, in the treatment of IADRF, the radiological and functional results in the patients, who were applied external fixation, following closed reduction, made by applying compression force to restore metaphases separation, were compared to the results of the patients, who received standard reduction and external fixation.

## MATERIALS AND METHODS

The results for 44 patients (32 males 12 females, mean age 36, distribution 21 to 59), with IADRF, was retrospectively assessed after obtaining the consent of the ethical board of our hospital. 22 patients (Group 1) who were applied closed reduction by applying anterior-posterior reduction in the fracture line before external fixation, and 22 patients (Group 2) who were applied conventional closed reduction technique, were examined as 2 separate groups (Figüre 5a and b). The x-ray archives and file records of the patients were accessed and in addition, they were invited to follow-up and were assessed radiologically. The fractures were grouped according to AO classification radiological. Patients with no neurological deficits, with closed epiphysis and intra-articular fractures, whose pre-surgery straight x-ray and tomography could be achieved, were enrolled in our study (Figure 1a and b). The patients, who had metaphyseal fractures, unrelated to the joint, which did not come to last visits and did not participate in post-operative rehabilitation processes, were excluded from the study. All clinical and radiological assessments and measurements were made by the same orthopedist.

Three of fractures were open fractures and according to Gustily-Anderson classification, 4 fractures were of type II and 2 fractures were of type III open fractures. 34 of the fractures were in dominant arm, including 32 on the right and 12 of the fractures were in left arm. Etiological factors consisted of high-energy trauma in 30 patients (20 traffic accidents, 8 patients falling from high places, 2 work accidents) 8 patients simple falling and 6 patients sports activities. According to AO classification, 6 of the fractures were of type B1, 4 fractures B2, 14 fractures C2 and 10 fractures C3 (4). The term, from the formation of fractures until surgical intervention was mean 3 days (1 to 5 days) and the term of stay in hospital was mean 5 days (distribution 2 to 7 days).

### Surgical technique

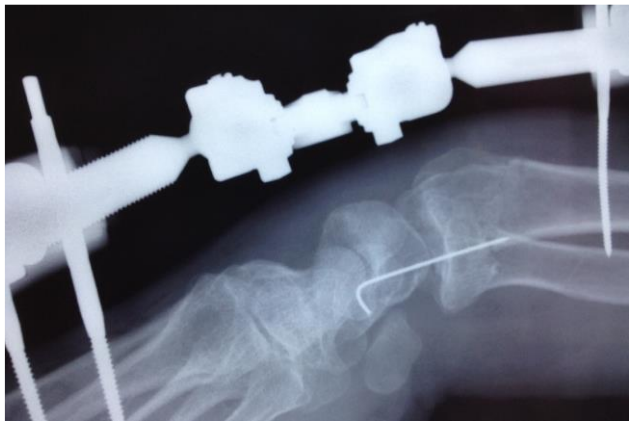
All cases were operated under axillaries peripheral block anesthesia, using fluoroscopy. The compression group was first applied a longitudinal traction of 8 to 10 kg, using finger traps. Then a surgical cover is placed on the volar of wrist, after flexion and ulnar deviation is provided in the wrist; compression was applied 6 to 8 times in anterior-posterior plane from dorsal of the wrist with the fist of the surgeon (Figure 2a and b). After it is seen that the reduction was provided with scope, in all fractures, after 2 Schanz nails of 4 mm to radius and 3 mm to metacarpus, distraction was made with the same brand of articulated external fixator (Biomet®) (Trumble et al., 1994).

The second group was also applied conventional reduction procedure distraction with the Biomet® type external fixator performed following closed reduction under fluoroscopy; the upper limit for distraction was the second finger reaching the distal palmar

(a)

(b)

**Figure 2.** Methods of compression group was first applied to (a) longitudinal traction and (b) compression:



(a)

(b)

**Figure 3.** Patient fragments were (a) reduced and (b) fixed with K-wires.

flexor fold with passive flexion (Figure 5a, b and 6a, b). For additional stability, some patient's fragments were reduced and fixed with K-wires. Two patients from both groups (totaling 4 patients) were administered K wire together with fixator (Figure 3a and b).

The term of external fixation application was an average of 6 weeks in both groups and the follow up term of the patients was average 7.6 months (distribution 4 to 19 months) (Figure 4a and b).

After the surgery, starting from the first day, active and passive finger exercises started. In the third week, Kirschner (K) wires were withdrawn and wrist was moved. In the sixth week, fixation was removed and rehabilitation program was initiated. The patients were assessed functionally during pre-surgery and their final visits and their ROM compared (Figure 7a and b).

For radiological assessment, radial curve angle, palmary curve angle and radial length data were compared (Table 1).

For functional assessment, the Modified Sarmiento scale system, prepared by Sarmiento et al. based on Gartland and Werley system, was used (Akmaz et al., 2003; Schaaf et al., 2010) (Table 2).

### Statistical assessment

As standard measurement values, radial curve angle was mean 23° (distribution 13 to 33°), palmary curve angle, mean 10 to 12° (distribution 4 to 22°) and radial length average 12 mm (distribution 10 to 18 mm).

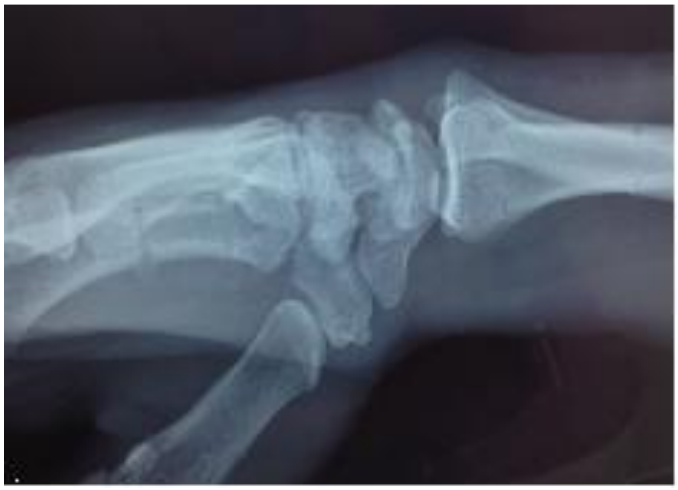
Statistical analyses were performed using both groups. The changes in the measurement results in pre-operative and post-heal x-rays, were compared with two sample t test, and it is assessed whether the provided data are within the standard reference values, aimed to be provided with a chi-square test (Kural et al., 2010; Mudgal and Jupiter, 2008).

So differences between the two groups were analyzed using the chi-square test, Mann-Whitney U-test, and Sample t-test where appropriate. The results were evaluated with a 95% confidence interval, and a *p* value of less than 0.05 was considered significant (Kiliç et al., 2009; Oyen et al., 2011).

In functional assessment, subjective-objective scores and median nerve compression data according to Modified Sarmiento scale were classified as excellent (0 to 2), good (3 to 8), moderate (9 to 14) and poor (> 15) and were assessed with Mann-Whitney U Test.

## RESULTS

In our age, ımproved methods of communication and the ease of reaching information allow patients to participate more in the treatment process. The contemporary



(a)

(b)

**Figure 4(a, b).** Same patient postoperative 6 month radiographs

(a)

(b)

**Figure 5(a, b).** Preoperative radiographs of conventional closed reduction technique used groups.

approach to intra-articular and comminuted distal radius fractures is to determine the best fracture-specific treatment method, with consideration of the main goals (Gereli et al., 2010; Sügün et al., 2012).

The limitations of our study are along with the small number of patients, failure to assess the efficacy of the treatment separately in young and elderly patients and lack of longer follow-up terms. It is known that radiographic angular changes may continue for up to one year. Concerning this issue, prospective studies with greater number of patients with longer follow-up term, are required.

In both groups, although reference values, deemed as standard are achieved and acceptable results are provided; in functional assessment, the results of the patient group, reduced with compression technique were better compared to other group ($p<0.05$).

We think these good results in our study were contemplated to be related to the correct placement of fragments with compression.

## DISCUSSION

The fractures of lower end of radius are complicated fractures, which reach into the joint and caused by high-energy trauma. The treatment methods for these fractures are diverse and complicated (Wigderowitz et al., 2000). The provision of sufficient functional and radiographic results depended on careful planning prior to surgery and applied surgical technique; it is obvious that full joint movement depends on precise joint surface restoration (Khan et al., 2001). Proper classification before the treatment of distal radius fractures is important in the determination of treatment plan. Type C fractures according to AO classification, are difficult to treat surgically due to significant intraarticular extensions and metaphysis defects (Clayton et al., 2009). Multifragmentary nature of fracture shows the severity of trauma and its high energy (Fernandez, 2000).

In order to restore distal radius as close to original as possible, different treatment approaches have been

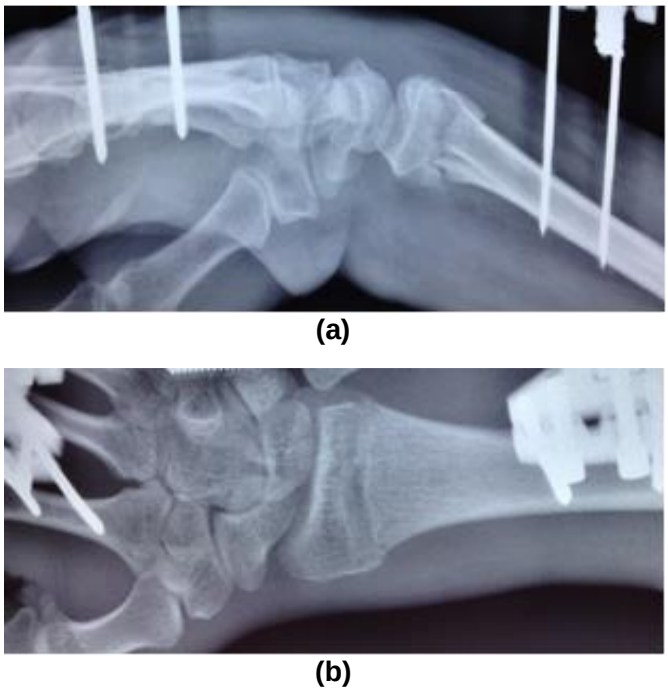


**Figure 6(a, b).** Postoperative radiographs of conventional closed reduction technique used groups.

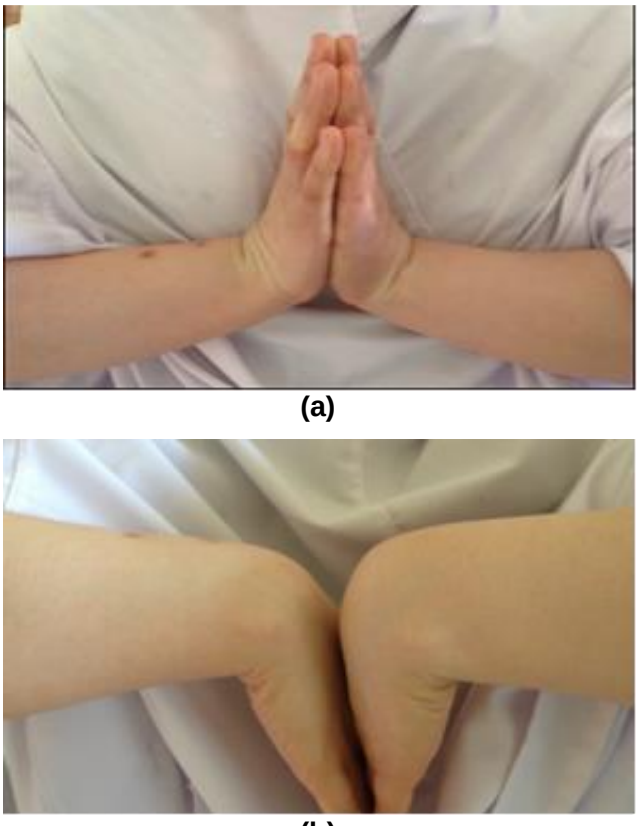


**Figure 7(a, b).** ROM of compression group.

developed and different complications have been seen in all of them. The anatomical nature of reduction gains importance for functional results. External fixation is frequently used in instable intraarticular and extraarticular distal radius fractures. This method helps in the reduction of fracture fragments with the effect of ligamentotaxis (Kamano et al., 2005). In radius lower end fractures, as the fragmentation in joint face and cortex increases, loss in radial length, decrease in radial curve angle and palmar curve angle increases.

Trumble et al. (1998) have determined that in single cortex fragmentation in young patients, closed reduction alone and K wire fixation was sufficient in provision of radial length and in intraarticular fractures with two or more cortex fragmentation, fixation for preservation of radius length, such as severe reduction and external fixator were required (Kelsey et al., 2005).

Grala et al. (2005) have determined stiffness in wrist and fingers and reflex sympathetic dystrophy in cases, where complete reduction cannot be provided in long lasting distractions with ligamentotaxis effect of external fixators, bridging the joint (McQueen and Caspers, 1998).

Margaliot et al. (2005) have emphasized the importance of the placement of all small fragments, precisely to their respective locations for complete movement of joint in distal radius fractures, fixed with K wire, where losses in palmar curve angle are seen (Leung et al., 2000).

Improved new imaging methods providing better understanding of fractures and elucidation of the effects of all injury type on fracture formation and factors leading to instability have given way to new reduction and fixing methods and materials appropriate for the fracture, resulting in today's treatment options in distal intraarticular radius fractures (Leung et al., 2000; Gereli et al., 2010).

Different types of fractures may occur due to the anatomy of the intraarticular distal radius and the effects of forces in different directions. It is often not possible to have a successful outcome using the all time same approach and materials for different types of fractures (Gehrmann et al., 2008; Gereli et al., 2010).

In IADRF, following treatment, median nerve compression findings may be seen (Goldhahn et al., 2008). With the used compression technique, no damage finding in the median nerve was found and even, the number of patients, showing compression findings was less than the control group. While in one patient in compression group, had these complaints, in two patients in control group, median new compression findings were detected.

The other complications of external fixation; Reflex sympathetic dystrophy, fixation loss, pin tract infections, injury to the sensory branch of the radial nerve, and joint stiffness in the wrist are amongst the known (Gereli et al., 2010).

We know that in distal radius fractures, excessive

**Table 1.** Radiographic measurement results.

| Group | Palmary curve angle (°) | | Radial curve angle (°) | | Radial length (mm) | |
|---|---|---|---|---|---|---|
| | Pre-operative | Post-operative | Pre-operative | Post-operative | Pre-operative | Post-operative |
| 1 | 26.5 | 10.1 | 15.5 | 23.1 | 7.3 | 12.4 |
| 2 | 25.3 | 13.1 | 14.1 | 20.2 | 8.2 | 11.5 |

**Table 2.** Assessment of functional results according to Modified Sarmiento scale; Subjective-objective median nerve compression scores.*

**A.**

| Pain | Movement restriction | Inadequacy | Activity restriction | Score |
|---|---|---|---|---|
| None | None | None | None | 0 |
| Rare | Mild | None | None | 2 |
| Rare | Mild | None when cautious | Yes | 4 |
| Frequent | Yes | Yes | Severe | 6 |

**B.**

| Movement | ROM | Score |
|---|---|---|
| Dorsiflexion | <45° | 5 |
| Palmary flexion | <30° | 1 |
| Ulnar deviation | <25° | 3 |
| Radial deviation | <15° | 1 |
| Supination | <50° | 2 |
| Pronation | <50° | 2 |
| Circumduction | Loss | 1 |
| Finger flexion | Does not reach distal crisis | 1 |
| Grabbing | Loss of strength | 1 |

**C.**

| Level | Score |
|---|---|
| Mild | 1 |
| Moderate | 2 |
| Severe | 3 |

*Functional result; sum of A, B and C: Excellent: 0-2; Good: 3-8; Moderate: 9-14; Poor: >15 ($p<0.05$).

distraction may not provide sufficient reduction of free fragments that do not respond to ligamentotaxis or involve the joint surface. Before open or K-wire augmented reduction, we can use the compresion method considered in these patients (Gereli et al., 2010; Sakai et al., 2008).

In both groups, radiological data has shown significant improvement post-operatively, compared to pre-operatively. There were no significant differences from radiological aspect between the two groups ($p>0.05$). The results of the patient group, reduced with compression technique was radiologically significantly better compared to the results of the other group ($p<0.05$).

## Conclusions

The radiological results in both groups were summarized in Table 1 and functional results in Table 3. In both groups, significant improvement was seen in radial curve angle, palmary curve angle and radial length data. There were no significant differences from radiological aspect between the two groups ($p>0.05$). In all patients, reference values, accepted as standard were reached in all patients. In the functional assessment between two groups, in 10 patients in compression group excellent, in 7 patients good, in 2 patients moderate and in 2 patients poor functional result was provided and in control group,

**Table 3.** Functional Assessment: For two groups, subjective-objective scores according to Modified Sarmiento scale and median nerve compression data.

| Sum of A, B and C | Excellent | Good | Moderate | Poor |
|---|---|---|---|---|
| Group 1 | 10 patients | 8 patients | 2 patients | 2 patients |
| Group 2 | 4 patients | 6 patients | 8 patients | 4 patients |

in 4 patients excellent, in 6 patients good, in 8 patients moderate and in 4 patients poor functional results were found.

The results of the patient group, reduced with compression technique was significantly better compared to the results of the other group ($p<0.05$). In one patient in compression group and two patients in control group, median new compression findings were detected. No complications were seen other than pin site infection in two patients.

## Conflict of Interest

The authors have not declared any conflict of interest.

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Scientific Research and Essays

*Full Length Research Paper*

# Persistent hydrophilicity for Titanium oxide ($TiO_2$) thin films by Silicon oxide ($SiO_2$) over nanolayers

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**$SiO_2$ thin layers in thicknesses (1, 5, 10, 18 nm) on $TiO_2$ thin layer in thickness 79 nm deposited by reactive RF sputtering technique. The deposited films were heat treated at temperatures (200, 400, 500, 600°C). The surface properties of thin films by atomic force microscopy (AFM), surface chemical composition by X-ray photoelectron spectroscopy (XPS) and self-cleaning effect in bi layers, were studied. In addition, enhanced hydrophilicity property in the films under the effect of annealed temperature and persistence without UV light illumination were evaluated.**

**Key words:** Nanolayers, X-ray photoelectron spectroscopy (XPS), hydrophilicity, annealed temperature.

## INTRODUCTION

Titanium oxide exhibits hydrophilicity and self-cleaning properties as exposed to UV. As $TiO_2$ surface is exposed to UV radiation, electron/hole pairs are created inducing an oxide-reduction reaction. To maintain the status of surface oxygen vacancies by OH groups that exist in atmospheric water, superhydrophilicity property (that is, water contact angle of near zero with surface) on the surface is generated (Wang et al., 1999; Sakai et al., 2001). However, a superhydrophilic surface is converted to an hydrophobic surface in the absence of UV illumination due to replacement of OH groups with atmospheric oxygen. As reported by other researchers (Machida et al., 1999; Ren et al., 2004; Guan, 2005; Lee et al., 2004; Maeda and Yamasaki, 2003; Yu et al., 2002) the addition of $SiO_2$ to $TiO_2$ enhances the hydrophilicity and it is maintained in dark without UV light radiation. According to X-ray photoelectron spectroscopy experiments, the formation of Ti-O-Si bond at the $TiO_2$-$SiO_2$ interface led to important changes in the electronic structure of over layer (Sanz et al., 1998). This changes enhanced the acid property of surface and result in improving hydroxyl groups at the surface of film (Guan et al., 2003, 2005), which led to increasing hydrophilicity and the surface of film maintained. In this work, $SiO_2$ was more physical and chemically stable than $TiO_2$ and also Si-OH surface bond was more stable than Ti-OH; also, bi-layer films was deposited with $SiO_2$(top)/$TiO_2$(under) (Komatsu et al., 1998; Guan et al., 2004). More recently, it was observed that $SiO_2$-$TiO_2$ interface is formed in the sufficiently high annealed temperatures (Permpoon et al., 2008). It was found that the thickness of $SiO_2$ on $TiO_2$ layer had important effect on increasing of hydrophilicity property (Hattori et al., 2000). In other researches, enhanced natural superhydrophilicity and its conservation in $TiO_2$-$SiO_2$ composite thin films or bi-layer films deposited in method of sol-gel at special temperatures and thickness have been investigated (Houmard et al.,2007; Liu et al., 2009). In this study, we deposited the

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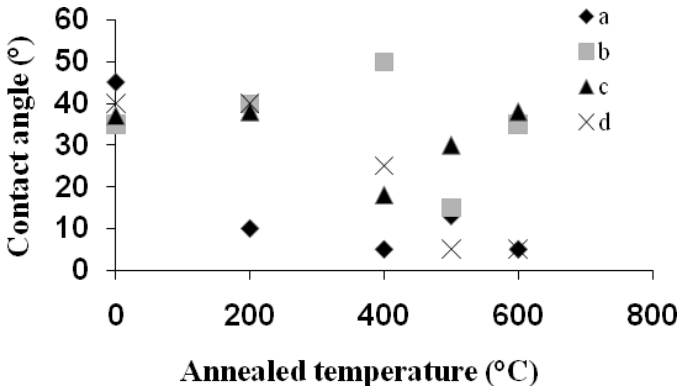


**Figure 1.** Water contact angle on surface of the as-deposited and annealed $SiO_2/TiO_2$ bilayer films in the absence of UV irradiation at room temperature for various thicknesses of the $SiO_2$ layer: a) 1, b) 5, c) 10, and d) 18 nm.

$SiO_2/TiO_2$ bi-layer films by using radio frequency reactive magnetron sputtering at different thicknesses of $SiO_2$ over layer and various annealed temperatures and evaluated the hydrophilicity and persistence in a dark place.

## EXPERIMENTAL DETAILS

### Fabrication of $SiO_2/TiO_2$ bilayer films

$SiO_2/TiO_2$ bilayer films were deposited on float glass substrates (Kaveh Glass Industry Group) by using radio frequency (RF) reactive magnetron sputtering. The base pressure of the sputtering chamber was ~$10^{-7}$ Torr (133322×$10^{-10}$ Pa). To grow the $TiO_2$ ($SiO_2$) target (with purity of 99.9%) was reactively sputtered at pressure of 100 m Torr (13.3322 Pa) in an $Ar/O_2$ (60/40) discharge gas. Thickness of the as-deposited-beneath $TiO_2$ layer was considered 80 nm, while thickness of the as-deposited $SiO_2$ over layer was adjusted 1, 5, 10 or 18 nm. Thickness of the deposited films was measured by using an interferential optical technique. The as-deposited bilayer films were then annealed at 200, 400, 500, 600°C in air for 30 min.

### Hydrophilicity and material characterizations

Surface hydrophilicity of the bi layer films was evaluated by measuring water contact angle on surface of the films. Experiments were performed under an ambient condition using a digital camera (with 2 mega pixel resolution) and suitable software (LB-ADSA). Before any experiment, surfaces of the films were washed with distilled water, acetic acid and ethanol. Then, a distilled water droplet was dropped on the film and water contact angle was measured with accuracy better than ±5°. Then, the super-hydrophilic samples (with the contact angle < 5° stored within plastic covers in dark to check any variation in the water contact angle of the films by elapsing the time (up to six weeks) under no UV irradiation. Super-hydrophilicity of the films was also studied by measuring the water contact angle under UV light illumination. In this work, a 6-W mercury (Philips) UV source with wavelengths ≥254 nm was used. To evaluate self cleaning effect, surface of the films was contaminated by the special oil and after exposure to UV illumination. To study the surface topography of the films, a Park Scientific Model CP-Research (VEECO) atomic force microscopy (AFM) was utilized at a non-contact mode. To investigate the surface chemical states of the films, X-ray photoelectron spectroscopy (XPS) was used. The XPS data were acquired by using a hemispherical analyzer with an AL $K\alpha$ X-ray source operating at energy of 1486.6 eV and a vacuum better than $10^{-7}$ Pa. The binding energy of the XPS peaks was calibrated by fixing the C(1s) peak to 285 eV. SDP Ver. 4.0 software was applied to deconvolute and analyze the XPS peaks. The peaks were deconvoluted by using Gaussian-Lorentzian components (90 to 10%) with a constant FWHM for each component after a Shirley background subtraction. The elemental compositions of the films were determined using area ratio of the deconvoluted XPS peaks and the sensitivity factor (SF) of each element in XPS.

## RESULTS AND DISCUSSION

### Hydrophilicity and self-cleaning

Figure 1 shows hydrophilicity of the $SiO_2/TiO_2$ thin films(with various thicknesses of the $SiO_2$ nanolayer ranging from 1 to 18 nm) annealed at the different temperatures of 200, 400, 500, 600°C, as compared to that of the as-deposited film, in the absence of UV irradiation. The as-deposited films in all thicknesses of $SiO_2$ nanolayer showed contact angles >35°. In case of the $SiO_2/TiO_2$ with thickness of 1 nm, very good hydrophilicity with contact angle ~5° at annealed temperatures of 400, 600°C and also thickness of 18 nm at annealed temperatures of 500, 600°C was observed. With regard to the above results, the annealing temperature in $SiO_2$ various thicknesses play an important role in enhanced hydrophilic property without UV irradiation.

To check the self-cleaning property of the bilayer films, we selected the films which initially presented a hydrophilic property with the water contact angle <20° in the absence of UV irradiation (based on the results of Figure 1). Then, the films were contaminated by the oil layer and exposed to the UV irradiation for 4 h. Table 1 shows water contact angle on surface of the contaminated $SiO_2/TiO_2$ bilayers before and after UV irradiation. It is seen that the oil contamination resulted in increasing the water contact angle of the films from >5° around 30°, indicating disappearing of the superhydrophilic property of the films. However, after 4 h UV irradiation the films showed their natural superhydrophilic property, indicating the role of the beneath $TiO_2$ layer as an effective photocatalyst for removing the oil contamination layer.

In order to study persistence of the superhydrophilicity of the film photocatalitically under UV irradiation, the water contact angles were measured in one week time intervals as shown in Figure 2. The $SiO_2$(5 nm)/$TiO_2$ annealed at 500°C was the longest superhydrophilicity (up to six weeks) among the samples. It should be noted that the superhydrophilicity of these films reappeared

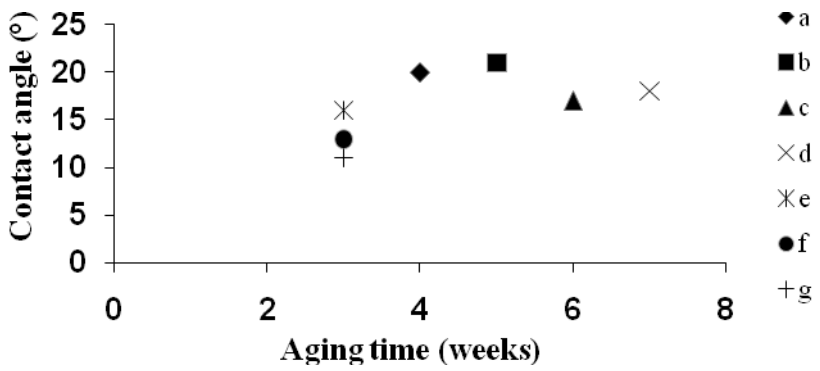


**Figure 2.** Persistence of water contact angle on surface of $SiO_2/TiO_2$ bilayers with the $SiO_2$ thickness (at the annealing temperature) of: a) 1 nm (400°C), b) 1 nm (500°C), c) 1 nm (600°C), d) 5 nm (500°C), e) 10 nm (400°C), f) 18 nm (500°C), and g) 18 nm (600°C).

**Table 1.** Results of the self-cleaning experiments.

| $SiO_2$ thickness | Water contact angle (°) | |
|---|---|---|
| | Oil contaminated state | UV irradiation time (4 h) |
| 1 nm (400°C) | 38 | 5 |
| 1 nm (500°C) | 33 | 5 |
| 1 nm (600°C) | 35 | 5 |
| 5 nm (500°C) | 30 | 5 |
| 10 nm (400°C) | 30 | 5 |
| 18 nm (500°C) | 33 | 5 |
| 18 nm (600°C) | 35 | 5 |

after a simple rinsing, as similarly reported by Houmard et al. (2011).

In Figure 2, the water contact angles with surface of the films were represented at the time of removing of the superhydrophilicity property and the contact angles were measured 5° at the times of before.

## AFM analysis

To investigate the effects of heat treatment on surface topography and consequently on the hydrophilicity of the films morphology, AFM was utilized. Figure 3 shows AFM image of the $SiO_2$(5 nm)/$TiO_2$ films (the films with the longest superhydrophilicity) before and after annealing at 500°.

For evaluating the effect of surface roughness on the hydrophilicity of the thin films, the water contact angles measured on surfaces of the $SiO_2$(5 nm)/$TiO_2$ films were compared with the water contact angles modified through Wenzel's equation (Wenzel, 1949) (the contact angles in which the effect of surface roughness was eliminated), as shown in Figure 4. It is seen that although surface roughness could be partially effective in decreasing the measured contact angle especially at annealing temperatures ≥400°C, it was not the main parameter describing the superhydrophilicity of films and its variation. In fact, surface chemical composition can be considered as one of the important parameters in this regard, as discussed in the following.

## XPS analyses

To determine the chemical state and surface stoichiometry of the layers, the samples were analyzed by XPS. The survey scans of the $SiO_2/TiO_2$ thin films (with the $SiO_2$ thicknesses of 1 and 5 nm annealed at 500 and 600°C, respectively) are presented in Figure 5. The survey spectra show the presence of Si, Ti, O, Na, C on surface of the films. In the XPS survey scans, Silicon related to the $SiO_2$ overlayer was obvious clearly. Also, Titanium obtained from the $TiO_2$ underlayer was observed on the surface of the films and therefore can be an expected possibility of the mixed oxide (Ti-O-Si) on the surface of the films. In this case, we will discuss it in

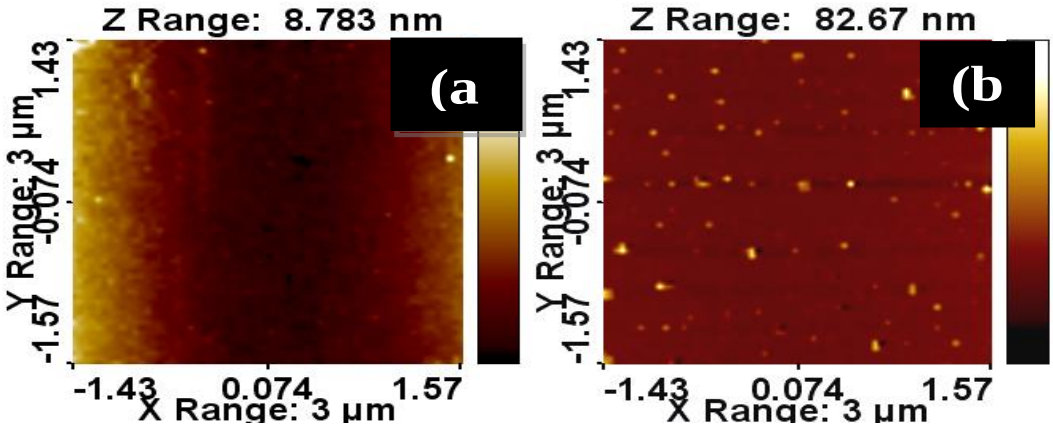


**Figure 3.** 2D AFM images of $SiO_2$(5 nm)/$TiO_2$ films a) before and b) after annealing at 500°C.

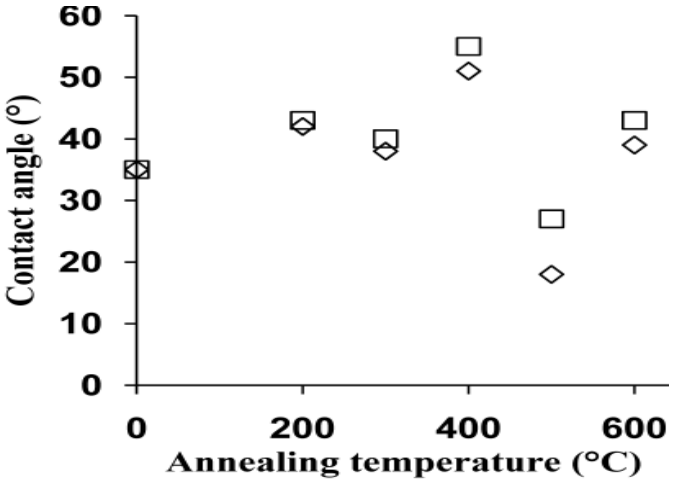


**Figure 4.** □) Measured and ◊) calculated contact angles (based on Wenzel's equation) on surface of the $SiO_2$(5 nm)/$TiO_2$ films annealed at the different temperatures.

the deconvoluted O (1 s) peaks. The existence of Na ion indicates the migration of Na related to the glass on the surface. The carbon peak shows the contamination of the surface on the films.

The Ti(2p) peaks of the as-deposited and annealed $SiO_2$(5 nm)/$TiO_2$ thin films are shown in Figure 6. There are two peaks corresponding to the Ti($2p_{3/2}$) and Ti($2p_{1/2}$) components at binding energies of 458.58 and 464.18 eV, respectively. Deconvolutions of the Ti($2p_{3/2}$) peaks indicated that the as-deposited films contained a slight amount of $Ti^{3+}$ chemical state (with $Ti^{3+}$/ $Ti^{4+}$ ratio of 0.003), while after annealing at 500°C, no significant trace relating to the presence of $Ti^{3+}$ was found. The binding energies relating to the $Ti^{3+}$ and $Ti^{4+}$ (as the predominant chemical state of the films) were considered at 456.7 and 458.5 eV, respectively (Kumar et al., 2000).

For studying the chemical state of the Si in thin films, the Si(2p) peaks was recorded and deconvoluted, as shown in Figure 7. Each peak was deconvoluted into two components ($2p_{3/2}$, $2p_{1/2}$) with separation energy of 0.6 eV and area ratio of 2 which is calculated from the splitting theory of 2p levels. Figure 7 shows the Si(2p) spectra of the as-deposited and annealed $SiO_2$(5 nm)/$TiO_2$ films. Taking into consideration the binding energy 103.2 eV for pure $SiO_2$ and in comparison with the binding energy values at our samples, compound structure of $SiO_2$ thin layer was concluded (Netterfield et al., 1989; Babapour et al., 2006). As shown in Figure 7 and Table 2 with increasing of the annealing temperature, the binding energy values of Si(2p) enhanced to the higher energy values. This shift in the Si(2p) binding energy indicates forming of a mixture oxide (Ntterfield et al., 1989; Tachibana, 2000). The results of our XPS analysis for the Ti(2p) and Si(2p) peaks were summarized in Table 2.

The O(1s) spectra of the as-deposited and annealed $SiO_2$(5 nm)/$TiO_2$ bi-layer films are presented in Figure 8. The O(1s) peak of the as-deposited sample was deconvoluted into two components at binding energies of 530.88 and 532.71 eV. The two deconvoluted peaks were assigned to formation of Ti-O-Ti (peak A) and Si-O-Si (peak B). However, another peak (peak C) was found in the deconvoluted O(1s) peak of the film annealed at 500°C at the binding energy of 531.32 eV which was assigned to formation of Ti-O-Si bond in the annealed film, consistent with the previous reports (Permpoon et al., 2006; Yamashita et al., 1998; Lassaletta et al., 1995; Lin et al., 2002; Gallas et al., 2002; Almeida, 1998). Our results demonstrated that the naturally superhydrophilicity of the annealed films in the absence of UV irradiation and the persistence of the superhydrophilicity can be assigned to formation of this bond (Ti-O-Si bond) in the $SiO_2$-$TiO_2$ nanocomposite. Our XPS analysis also showed that the heat treatment resulted in increasing the concentration of Ti on surface of the films (Table 2), and consequently, increasing the

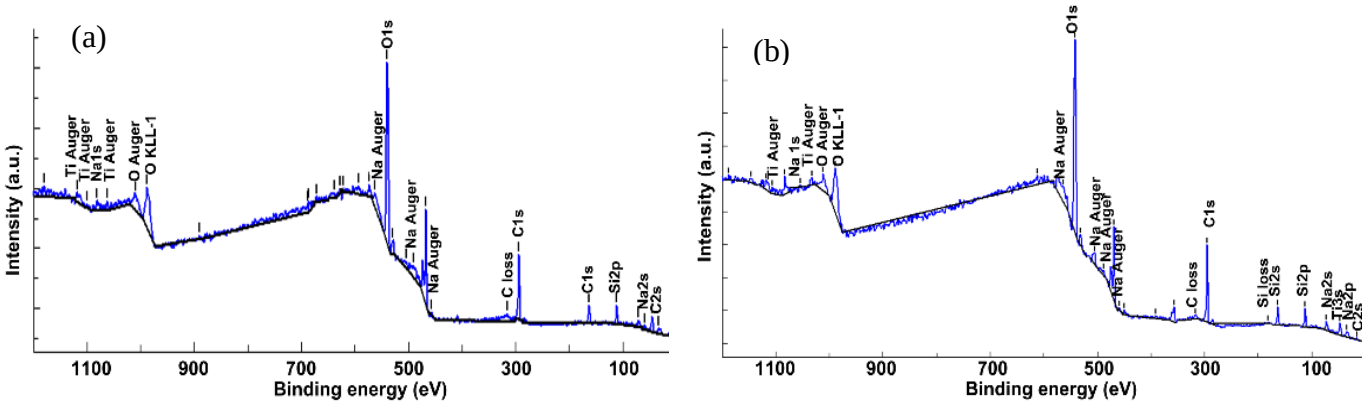


**Figure 5.** XPS survey spectra of a) as-deposited $SiO_2$ (5 nm)/$TiO_2$ and b) $SiO_2$ (5 nm)/$TiO_2$ at 500°C.

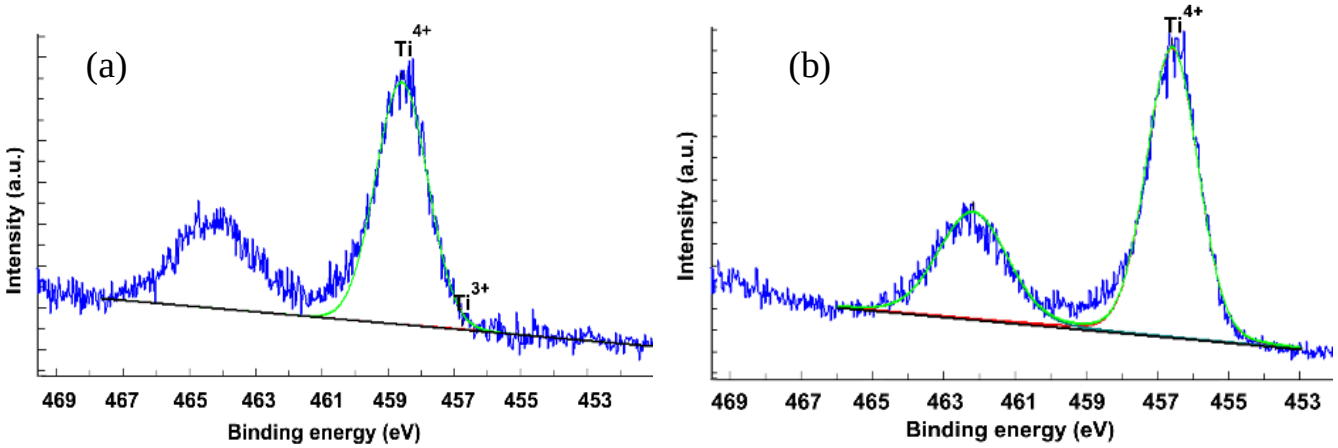


**Figure 6.** Ti(2p) XPS spectra of a) as-deposited $SiO_2$ (5 nm)/$TiO_2$ film and b) $SiO_2$ (5 nm)/$TiO_2$ annealed at 500°C.

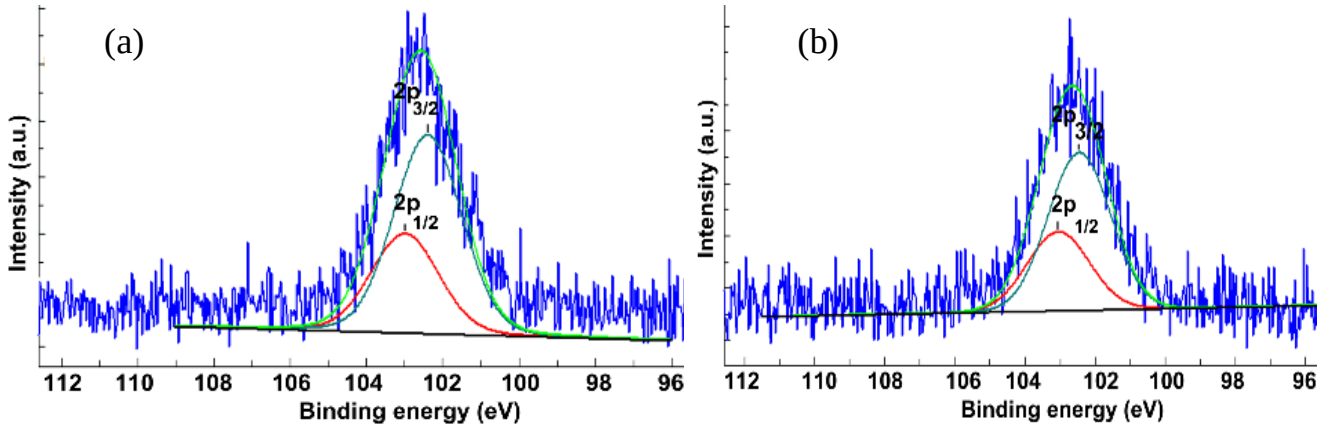


**Figure 7.** Si(2p) XPS spectra of a) as-deposited $SiO_2$ (5 nm)/$TiO_2$ and b) $SiO_2$ (5 nm)/$TiO_2$ annealed at 500°C.

possibility of formation of the Ti-O-Si bond, consistent with some of the previous reports in this regard (for example, Mirshekari et al., 2010).

## Conclusion

$SiO_2$/$TiO_2$ bi-layer films have been grown by RF reactive

**Table 2.** XPS data of the $SiO_2/TiO_2$ thin films for different temperatures.

| Sample characterization | Annealed temperature (°C) | Ti($2p_{3/2}$) (eV) | Si($2p_{3/2}$) (eV) | Ti-O-Ti (eV) | Si-O-Si (eV) | Ti-O-Si (eV) | Ti/Si |
|---|---|---|---|---|---|---|---|
| $SiO_2$ (5 nm)/$TiO_2$ | As deposited | 458.58 | 102.39 | 530.24 | 532.62 | - | 0.84 |
| $SiO_2$ (5 nm)/$TiO_2$ | 500 | 458.59 | 102.45 | 530.24 | 532.62 | 531.88 | 3.80 |

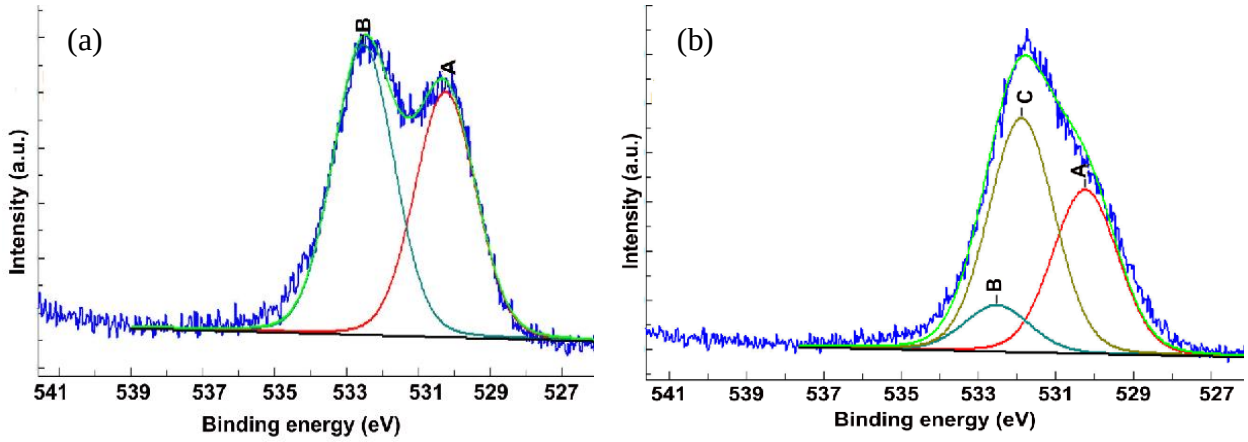


**Figure 8.** O(1s) XPS spectra of a) as-deposited $SiO_2$ (5 nm)/$TiO_2$ film and b) $SiO_2$ (5 nm)/$TiO_2$ film annealed at 500°C.

magnetron sputtering. XPS characterizations indicate that the annealing after deposition yield to the formation of Ti-O-Si bond at the films interfaces. On the other hand, this bond is never observed in deposited films without heat-treatment. The existence of Ti-O-Si bond enhances the surface acidity thus inducing hydrophilicity and it is maintained without UV light radiation. In our research, the best hydrophilic and persistent sample $SiO_2$(5 nm)/$TiO_2$ was evaluated at the annealed temperature 500°C. Finally, regenerable hydrophilic property of this film is observed after water rising operation without the requirement of UV light illumination.

## Conflict of Interest

The authors have not declared any conflict of interest.

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*Full Length Research Paper*

# Researcher vulnerability: An overlooked issue in vulnerability discourses

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**Although widely referred to in research, vulnerability is arguably not well understood by both researchers and research regulators. Authoritative sources including dictionaries, ethics encyclopedia, and esteemed authorities in the field of ethics offer little help; multiple definitional perspectives exist on the subject. Efforts have been made to clarify a component of vulnerability in research – 'participant vulnerability'. There is no closure on this subject of what participant vulnerability is or should be. Researchers, just as the researched may be vulnerable in some instances. This is designated and discussed in this paper as 'researcher vulnerability'. While acknowledging the emphases that regulators place on protecting vulnerable study participants, the paper argues that this should not be interpreted to imply that researchers are immune to vulnerability. The paper articulates the many and varied challenges that researchers confront in research. Such experiences speak to the fact that researcher vulnerability may vary in meaning among contexts, but can be contextually defined and understood as a cross-cutting concept.**

**Key words:** Vulnerability, researcher vulnerability, human subjects research, vulnerable populations, vulnerable researcher.

## INTRODUCTION

This paper examines the concept that the researcher, and not only the researched can be vulnerable. Although the concept of vulnerability with respect to the researched has been widely acknowledged (Quest and Marco, 2003; Slowther, 2007; Kipnis, 2003; Levine et al., 2004; U.S. National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979), this cannot be said of the researcher (Ballamingie and Johnson, 2011; Downey et al., 2007). Downey et al. (2007), lamenting on the neglect of this concept within the research literature, note that overlooking the negative impact that research can potentially have on the researcher may be a mistaken understanding of who the researcher really is. They further state that, the natural

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assumption that power resides within the researcher's domain, and that the research participants are those who are vulnerable and hence need to be protected throughout the research process needs a rethink (Downey et al., 2007). This thinking that it is the research participant and not the researcher, who is vulnerable, is confirmed by the almost overabundance of scholarship and the never-ceasing commentaries on what I refer to as participant vulnerability in this paper (Hill 1995; Quest and Marco, 2003; Slowther, 2007; Kipnis, 2003; U.S. National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979).

The Belmont Report of 1979 does not define vulnerability. However, its concept of vulnerable populations in research clearly excludes the researcher (U.S. National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979). Literature predating the Belmont Report nevertheless seemed to have given some hints on the concept of researcher vulnerability (Cassell, 1978; May, 1980; Trend, 1980). These are explored later in this paper.

In the mid nineties, Hill (1995) had identified a number of issues and ethical dilemmas that researchers face when researching sensitive topics in marketing (Hill, 1995). Davison's explorations of dilemmas in research questioned the perceived eternality of the researcher's power. To Davison, the relationship between researcher and the research participant is one of "shifting boundaries" (Davison, 2004). In other words, the researcher contrary to the general perceived notion is not always in the dominant role; he is susceptible to changing positions of vulnerability throughout the research process.

Given this background, the paper's central argument is that, "researcher vulnerability" as a concept has been largely neglected within both clinical and nonclinical research literature. To destabilize the naturalness with which researchers relegate the concept, this paper initiates a debate on the utility of acknowledging and publicizing the concept. The paper argues that vulnerability in research be conceived as a multi-sided dynamic phenomenon involving the researcher and many other actors in the research process. It draws on available literature, documentary and oral evidence from experiences of other researchers, personal professional experience amongst others. Overall, the paper aims to expose some challenges in research that confirm the existence or possibility of researcher vulnerability. Researchers need to be abreast of these.

## Conceptualizing participant vulnerability

Definitions of vulnerability vary, and although there are common themes, these turn to confuse both non-experts and experts alike. In their paper titled "To cry or not to cry: analyzing the dimensions of professional vulnerability", Davenport and Hall draw on the Compact Oxford English Dictionary of Current English, the Cambridge Dictionary, and the Merriam-Webster online dictionary to reiterate not just the lexico-semantic differences, or the many interpretations of the term, but also the fact that a clear unambiguous definition of vulnerability remains elusive (Davenport and Hall, 2011). From these authoritative guides, the terms that are considered synonymous with the word vulnerable are susceptible, weak, insecure, defenseless, open, threatened, and compromising. The current conceptualizations identify among others; minors, pregnant women, racial minority populations, the poor, the homeless, and undocumented immigrants as vulnerable in human subjects research.

A careful analysis of the discourse on vulnerability indicates that, it is not just the problem of lexical differences; there is also a lack of consensus on the concept by experts in research ethics. Koffman et al. (2009) argue that vulnerability is a poorly understood concept in research ethics, and lament on the frequent alignment of the concept to autonomy and consent. Arguably, one of the significant contributors to the subject is Kenneth Kipnis. Kipnis, in his recent additions to the vulnerability literature presents a 7-level taxonomic delineation of vulnerability. These are cognitive: the ability to understand information and make decisions; juridic: being under the legal authority of someone such as a prison warden; deferential: customary obedience to medical or other authority; medical: having an illness for which there is no treatment; allocational: poverty, educational deprivation; infrastructure: limits of the research setting to carry out the protocol; and social vulnerability, that is, belonging to a socially undervalued group (Kipnis, 2001). Several authors have noted that most of the attempts to define ''vulnerability'' though vary, have usually referred to individuals with limited cognitive abilities or diminished autonomy (Quest and Marco, 2003; Slowther, 2007; Kipnis, 2001).

Levine et al. (2004) however, argue that the efforts to define "vulnerability" in terms of the status of special groups of research subjects fails to achieve the goal such designation is meant to have - the protection of human subjects. They note that, current definitions are too broad and too narrow at the same time, but did not offer a more suitable definition. Henderson et al. (2004) affirm the critique offered by Levine et al. (2004) citing recent discussions about the disutility of imputing a characteristic for groups in the name of protecting them. Henderson et al. (2004) reechoes Levine et al.' (2004) mantra that, being "too broad," vulnerability stereotypes whole categories of individuals, and everyone might be considered vulnerable; and being "too narrow," vulnerability's focus on group characteristics diverts attention from features of the research project and its environment that might affect subjects. In agreement with DeBruin (2001), Henderson et al. (2004) note in the

concluding arguments of their article that the imposition of a static external label (of vulnerability) to groups, besides being potentially misleading, is highly likely to exacerbate stigma and dependency.

There is no closure on the debates currently raging on the concept of participant vulnerability. An unintended consequence of such preoccupation with participant vulnerability is the lack of visibility of researcher vulnerability. Subsequently, this paper reviews the limited literature on researcher vulnerability, and attempts to conceptualize it.

## Conceptualizing researcher vulnerability

The following is a review of available and accessible literature in support of the thesis that, vulnerability is not only an attribute of the researched, but is also of the researcher.

One argument in support of this thesis relates to the concept of relationality. Henderson et al. (2004) in their paper titled “vulnerability to influence: a two-way street”, note that vulnerability is, by definition, relational, and that one is always vulnerable to something, or someone’s influence. By virtue of being relational, vulnerability to influence is potentially bidirectional in all research relationships, they indicated. The primary relationship in this relationality model is between the researcher and the research participant. Such a model requires the examination of both influences by researchers on subjects and influences by subjects on researchers. Existence of secondary relationships such as researcher-researcher, research-sponsor/funder, researcher-community leaders, research-institution interactions are a reality and their implications on vulnerability are worth interrogating. Henderson et al. (2004) thus conclude that applying vulnerability to only one party contributes to conceptual confusion and undermines constructive application of the term.

Recognized among student researchers, research assistants, study coordinators and even seasoned researchers are a host of potential vulnerability issues worthy of discussion. Kidd and Finlayson (2006) examined issues of emotional intensity that arise when nurse researchers effectively co-construct narratives with interviewees. In a paper titled “dilemmas in research: issues of vulnerability and disempowerment of the social worker/researcher”, Judy Davison explored the ways in which researchers working with vulnerable informants may through empathy experience undue conflict and distress (Davison, 2004). Hill (2004) touched upon the impact of role reversal in collaborative research relationships, during which the researcher may experience powerlessness and abandonment.

Ballamingie and Johnson (2011) draw on their field experiences as doctoral researchers to give elucidation on some of the challenges and issues related to researcher vulnerability among graduate students. Dreyfus and Rabinow’s visitation of Foucault’s multidirectionality concept of power contributes to this discussion (Dreyfus et al., 1983), and so does Tindana et al. (2006) perspectives on power relationships in a rural Ghanaian community. Cassell’s (1978) tale of a researcher trying to live safely in a ghetto educates immensely on the possibility of research vulnerability. The growing dependence of researcher on sponsors/funders and its vulnerability-inducing effects is captured by Trend (1980). Even though, these insights may not be sufficient to theorize the inevitability of researcher vulnerability, they are supportive of the view that the researcher is not immune to vulnerability.

These works are looked at in detail. First, Foucault’s multi-directionality concept of power (which says that power can operate from the top down and also from the bottom up) – re-narrated by Dreyfus and Rabinow (1983) lend support to this paper’s argument. That is, if power play truly shapes the vulnerability dynamics, as is currently perceived, then Tindana et al.’s indication of power fluctuating unpredictably between the researchers and the chiefs in rural Ghana is also supportive of this paper’s arguments. This implies that researchers in the said community can be vulnerable to the chiefs. In other words, the all-powerful researcher at about 7am in his air-conditioned four-wheeled Sport Utility Vehicle could suddenly become vulnerable at 10am at the chief’s palace when presented with the unfamiliar traditions he has to follow in order to be permitted to conduct his research.

Other writers have also talked about the power relationships that create vulnerability in the researcher. Cassell (1978) example of a researcher trying to live safely in a ghetto should be a reminder to researchers that there are times when they are not the powerful players in the field. They may, in fact, have little of the power that matters most in such a setting. May (1980) wrote of researchers being vulnerable to the “sweet talk of outside money”. The ever-unpopular 10/90 gap in global research and development may be a good exemplar in support of research-sponsor/funder power relationship. The 10/90 gap refers to the finding of the Global Forum for Health Research that only 10% of worldwide expenditure on health research and development is devoted to the problems that primarily affect the poorest 90% of the world's population. Thus, while the vast majority of researchers do know the priority research areas, they find themselves helplessly playing to the tunes of the funding agencies. Such helplessness was recognized over three decades ago. Trend (1980) note that when a sponsor is responsible for funding a researcher’s forays into a setting, it is the funding agency that holds power over the researcher.

A further delve into the sociological literature also provided some ideas on this subject. Hamilton et al. (2006) in their paper titled “A sheep in a Wolf’s Clothing:

Exploring Researcher Vulnerability" draw on Berger and Kellner's sociological concept of *"a certain debunking angle of vision"* – a frame of reference, which looks beyond the visible, and the obvious to what is latent, or hidden) (Berger and Kellner, 1981). Drawing on this, the paper argues that both the obvious vulnerability of the researched as well as the obscured vulnerabilities of the researcher should be perceivable. Davison (2004) notes that the potential to feel isolated, vulnerable and distressed (*which is human; the emphasis is mine*) does not magically disappear because researchers assume their role of researchers. Kirsten Crowder Tisdale's discussion of vulnerability as either an a priori description of peoples' positions or a posteriori interpretation of those positions (that is, created within the research process) also demonstrates that power depletion can arise during the research process (Tisdale, 2004). Given these developments, it may not be a significant departure from objective reality to hypothesize the researcher, just as researched can be placed in harm's way during the course of the research process.

Presented below is an exemplar from colonial Ghana that may help elucidate the inherent vulnerability of the clinical researcher – vulnerability due to limitation in knowledge.

*"Hideyo Noguchi was a prominent Japanese bacteriologist who discovered the agent of syphilis as the cause of progressive paralytic disease in 1911. After an illustrious research career in the United States, he travelled in 1928 to Africa in an attempt to prove his findings about yellow fever. While working in Accra, Ghana, he died from yellow fever on May 21, 1928". His last words were: "I don't understand"* (Kantha 1989).

Those words – 'I don't understand' is pregnant with meaning as far as researcher vulnerability is concerned. This is one of many examples of the vulnerability of the researcher with respect to limitation in knowledge. Like Hideyo Noguchi, most, if not all of the current day researchers will not perceive themselves to be vulnerable, but can instantaneously become vulnerable during the research process.

Having presented both general and specific arguments in support of researcher vulnerability, the paper presents anecdotes, and instances drawn from personal professional experiences and those of other researchers. These will cover vulnerability in international collaborative research relationships, government-sanctioned research, research assistants, study coordinators, and student researchers.

### *Vulnerability in collaborative research relationships, and government-sanctioned research*

For a variety of reasons, the global research community currently promotes a model of collaborative research that involves researchers from the global north and their counterparts from the global south. South-South collaborative initiatives exist and are equally encouraged. There is no denying the fact that such could help develop a research process that is more ethical, and cost-efficient. This is usually touted as empowering; rather than exploitative, and meets the needs of both the researcher and the researched communities. While a collaborative model may empower, there are arguments currently that this empowerment model does not necessarily benefit researchers from the global south. Some have argued that it relegates local researchers to roles of informants.

It is worthy of note that researchers from the global north can also be vulnerable in these relationships. Researcher vulnerability emerges when at the end of a collaborative research, requests are made by the community leaders or politicians to the researchers not to publish their findings or to delay publication for reasons including such political ones as '*so as not to undermine local initiatives'*. This can situate researchers in a position of unexpected vulnerability. Delay in the publication of the results can cost the researcher dearly.

On another level, after committing enormous time and financial resources, key social actors can deny researchers access to research participants for a variety of reasons. Community access may be limited based on unethical or culturally inappropriate practices of previous researchers. While contractual agreements are binding between the researchers, they may not be to the politicians or community leaders. As such, when such declarations are made by the community leaders, the researcher can be helpless, even within meticulously drafted contractual documents.

What about government-sanctioned research? It is this paper's view that in some instances, researchers implementing government-directed research (security-related or otherwise) can be vulnerable to their 'employers'. Were not some of the Nazi Researchers vulnerable to their government? What about modern day government-sanctioned torture research endeavors? As argued earlier, if power is such an important variable in these relationships, are governments not more powerful than the researchers working for governments?

### *Vulnerability of clinical researchers, research assistants and study coordinators*

Described as professional vulnerability, Davenport and Hall (2011) note that vulnerability is embedded throughout the landscape of clinical, academic, and research environments. Malone (2000) for example, talks about two notions of vulnerability dominating in the nursing literature. Malone's first notion, which can be likened to participant vulnerability, had earlier been

described by Rogers (1997) as a public health model of vulnerability, where vulnerability is equated to susceptibility to particular harmful agents, conditions, or events at particular times. The second view regards vulnerability as the common condition of all sentient beings (Malone, 2000).

Drawing on personal experiences as a research assistant, a graduate researcher, and currently a faculty engaged in research in both the global south and north, it is demonstrated that study coordinators and research assistants could be particularly vulnerable. As a student researcher in a community that was described as the epicenter of Ghana's HIV epidemic, and as such had been over-researched, the community members openly communicated their unwillingness to welcome new researchers during the community entry procedures. After an intervention by Professors from the author's institution and the Resident Physician, the research was allowed. However, when the field work begun both potential study participants and enrolled participants made the researchers feel powerless in a number of ways, including very high non participation, high interview termination rates, and lost to follow up. Davenport and Hall's (2011) work on the many interpretations of the vulnerability identified the following synonymous - susceptible, weak, insecure, defenseless, open, threatened, and compromising. Although the researchers in this case were unquestionably made insecure, powerless, threatened, current discourses on vulnerability do not recognize them as vulnerable.

Another group of vulnerable researchers are study coordinators. Usually but not always nurses, study coordinators have been shown to be very vulnerable in recent times. To illustrate, the case of a 2004 University of Minnesota (The U) Drug Trial death (Elliot, 2010; 2012), and the subsequent sanctions that ensued is cited (Olson, 2012). In this case, only the Study Coordinator of the trial was issued a "corrective action" as a result of errors, which many believe are attributable to the Psychiatrist/Principal Investigator of the trial (Olson, 2012).

According to Hurst, even experienced researchers can find themselves vulnerable when the clinical stories of others are explored in detail (Hurst, 2008). The "other" in this sense is the research participant who may be vulnerable because of health conditions, social status, age, gender, ethnicity, or sexual orientation, any of which can create the disparities of poor health outcomes and marginalization. Dickson-Swift et al. (2007) performed a qualitative study to investigate the professional role experiences of 30 Australian researchers. The study revealed that they experienced vulnerabilities in their professional role as researchers. The quote below from one of the researchers after an emotional interview supports my researcher vulnerability thesis:

*"And all I'm doing is trying really hard to try and hold back the tears myself. I mean I burst into tears when I got out to the car—it was enormously distressing*" (Dickson-Swift et al., 2007).

Similarly, Scott's research on ritual abuse illuminated such vulnerability on the part of the researcher (Scott, 1998). In that study, the effects acknowledged were both emotional and physical. Scott states:

*"The sheer quantity of stories in the research process created a high level of stress. I had dreams about dying, and dreams in which I learned that none of my interviewees had told me the truth. Staying in an unfamiliar house after one interview I walked in my sleep for the first time in my life, and during the weeks of transcription I endured stomach cramps and nausea on a regular basis".*

The key point from these examples is that, vulnerability can prevail in the research process, even in the absence of exploitation. The current concept of vulnerability, which overemphasizes 'exploitation', does not recognize these as potentially vulnerability-inducing in research.

### *Vulnerability of student researchers*

Globally, several thousands of undergraduate and graduate students engage in research every year. For many of them, it is a mandatory step towards acquiring a degree and hence future employment. For students, successful and timely completion of such research is often dependent on many factors including adequate funding, and sufficient departmental and faculty support. In settings where the student-professor relationship is nothing less than a master-servant relationship, the student can be extremely vulnerable to the professor. This is in contrast with the perception that those engaging in research are often in positions of privilege. These highly vulnerable students are researchers. Additionally, given that most student researchers tend be younger and for that matter less experienced scholars, they can be prone to most of the vulnerability scenarios so far described in this paper.

Ballamingie narrates her experience in their paper that examined the existential challenges of doctoral student researchers (Ballamingie and Johnson, 2011). Ballamingie indicated facing a challenge when attempting to interview an aboriginal elders, in spite of having adhered closely to the ethical protocols established by her research institution.

*"On meeting in person with the informant, following a verbal introduction, it soon became apparent the interview would not proceed as smoothly as anticipated. According to the interviewees, a researcher from an American university had spent a summer some years*

*back gathering detailed personal narratives, promising to return the original tapes, transcripts, and video footage. He never did. Based on this previous encounter with an academic researcher, I was met understandably with immediate distrust. I felt truly vulnerable"* (Ballamingie and Johnson, 2011).

### Limitations of the paper

This paper has a number of limitations which need to be discussed. First, further research is needed to better refine the concept of researcher vulnerability, as well as exhaustively clarify setting-specific measures to be taken to provide support to vulnerable researchers. It is also important to acknowledge the weaknesses in the methodological approaches employed. While undertaking a systematic review of literature on the subject would have been most appropriate, this was highly challenging, most notably because the subject covers every discipline (medicine, health, social sciences, political sciences, marketing, among others). Another challenge in conducting this literature review was the lack of data on researcher vulnerability. Hence, the literature was expanded to include both published reports and grey literature.

## CONCLUSIONS AND MITIGATING MEASURES

It was not an objective of this paper to bring to closure the somewhat entrenched arguments regarding what vulnerability is or should be, or which study participant qualifies to be tagged vulnerable. The paper has instead tried to challenge some 'taken-for-granted' assumptions that research participants but not researchers can be vulnerable in research. While acknowledging the emphases that regulators and research ethics committees place on protecting vulnerable study participants through time-honored ethical practices, the paper has argued that this should not be interpreted to imply that researchers are immune to vulnerability.

The paper argues further that the concept of vulnerability as currently used in research is too narrow and rigid – overemphasizing only one aspect – participant vulnerability. The paper proposes that vulnerability in research be conceived as a multi-sided dynamic phenomenon involving the researcher and many other actors in the research process.

The paper proposes the following mitigating measures.

1) The first step toward mitigating researcher vulnerability is to acknowledge its existence or possibility. Doing so may motivate the development of counter measures.
2) Given that it is difficult to predict in advance exactly how research will impact on the researcher and what vulnerabilities will be encountered, the issues highlighted in this paper should be considered for every research study, regardless of whether it involves vulnerable or non-vulnerable study participants or whether the researchers perceive themselves to be vulnerable or not.
3) For administrative and supervisory support to student researchers to be meaningful, it should include counseling on researcher vulnerability.
4) To deal with the issues of non-participation, letter of commitment detailing the promise to disseminate findings to the community, and appropriate community entry procedures may be helpful.
5) Researchers intending to engage in a collaborative research should be willing to give significant intellectual contribution to all the major phases of the research process so to be able to qualify as authors.

### Conflict of Interest

The authors have not declared any conflict of interest.

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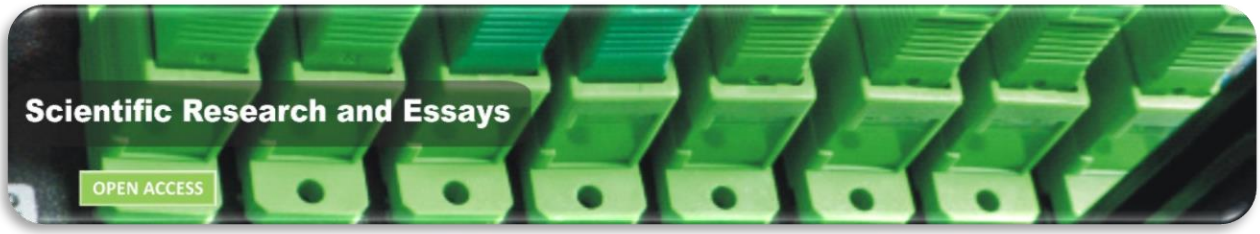


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