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Correspondence

Wood Industry and Engineering Journal
Karadeniz Technical University
Faculty of Forestry, Department of Forest Industry Engineering
Kanuni Campus, 61080, Trabzon / TURKEY

Phone: +90 462 377 1532
Fax: +90 462 325 7499

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Contact

engin_gezer@yahoo.com
iaydin@ktu.edu.tr

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ASSESSMENT OF WOOD WASTE GENERATION AND UTILIZATION: IMPLICATION FOR INDUSTRIAL DEVELOPMENT IN WUKARI, TARABA STATE

Okwuchi Smith Onyekwere [1], Faith Rika Samuel [2], Abel A. Maiguru [2]

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Abstract

The manufacturing industry is a significant element of high-quality economic development with its productivity growth potential higher than that of many other industries. However, one of the factors affecting industrial development is availability of raw materials. There are many timbers related activities in Taraba state which generate high quantity of wood waste and forest residues, which can serve as raw materials for wood-based industries. Hence, there is need to determine the factors responsible for poor wood-based industrial development despite the presence of abundant raw materials and human resources in the study area. A self-administered questionnaire survey method was used for data collection. Descriptive statistics was used to analyze the results. A five-point Likert scale was used to determine the level of utilization. The findings of the study shows that the generated wood wastes were utilized mainly for: energy generation for cooking (38.41 %), animal bedding (29.27%), plant mulching (23.17%) and local building materials (6.71%), while the least uses were for production of engineered wood products (1.83%). The result on the level of utilization of wood waste indicated a low level with Weighted Mean Score (WMS) of 1.9. Lack of awareness (70%) was the most limiting factor of industrial utilization of wood waste followed by lack of technical know-how (23%) and lack of start-up capital (6%). Conclusively, the major problems limiting high-level utilization and industrial application of wood waste is lack of awareness of reuse values of wood wastes and lack of technical-know-how.

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Corresponding Author

Okwuchi Smith Onyekwere
smithonyekwere@gmail.com

[1] Faculty of Engineering, Federal University Wukari, Taraba State, Nigeria
[2] Department of Forestry, Federal University Wukari, Taraba State, Nigeria

ASSESSMENT OF WOOD WASTE GENERATION AND UTILIZATION: IMPLICATION FOR INDUSTRIAL DEVELOPMENT IN WUKARI, TARABA STATE

Okwuchi Smith Onyekwere
smithonyekwere@gmail.com
ORCID : 0000-0003-1907-3616

Faith Rika Samuel
faithsamuelrika@gmail.com
ORCID : 0000-0002-2745-960X

Abel A. Maiguru
ngamuabel@gmail.com
ORCID : 0000-0001-6245-409X

1. Introduction

The manufacturing sector is regarded as one of the pillars for economic expansion and represents the most essential contributory sector in developing countries. Lechuga et al. (2021), stresses the need to identify gaps and provide recommendations to enhance the sector's possibilities for sustained growth. To be relevant, the manufacturing sector must have the ability to harness the various available raw materials, process and transform them into marketable finished or partly finished goods through the use of human capital and other factors of production. The finished goods in turn contribute significantly to the national GDP and create income and employment opportunities for the citizenry of that nation (Sokunle and Harper, 2016). Among the raw materials that are readily available in the study area and can contribute greatly to the manufacturing sector are wood waste and forest residues.

The possible use of wood waste and forest residues are often severely limited by difficulties in handling and segregating them, or by their non-adaptability to the consumer's needs or to his manufacturing processes (Kaushal et al., 2012). Furthermore, wood residues may be of such form, condition, or species that serious technical difficulties preclude their use for regular product with regular equipment (Vassilev *et al*., 2013). However, forest residues and wood waste have found application in some industries which include the energy industries, construction, pulp and paper industries, wood-based panel industries and agricultural industries (Martinez et al., 2018; Sullivan, 2016; Foltz, 2012; Duncker et al., 2012).

In Nigerian wood-based industries includes timber logging, sawmilling, furniture making, match production and the manufacture of several wooden items such as tools handles, sport goods, handicraft equipment and toys (Sekumade and Oluwatayo, 2011). The wood-based industries generate lot of unwanted, or used product (waste) from tree cut-offs, sawdust, tree barks etc. and this waste has become prominent due to the high demand for timber and its derived products (Kizha and Han, 2015; Jørgensen and Pederson, 2018). The produce residues most be utilized or properly disposed-off. Heaps of wood residues are common feature in wood industries throughout the year and these residues are not adequately utilized to satisfy the countries bio-resources and industrial needs (Kaushal et al., 2012). These wood residues, if not properly utilized, have various consequences on the environment and on human health (Dinnes et al., 2002; Owoyemi et al., 2016). On the other hand, proper utilization can lead to reduced deforestation and economic generation (Martinez-Pastur et al., 2020; Allegret et al., 2020). However, the industrial utilization of forest residues and wood waste will depend on the knowledge and technical know-how of timber operators in the area.

Therefore, there is need for study on forest waste utilization in Nigeria in general and in Taraba state in particular in order to access the knowledge and technical know-how of local timber operators on industrial utilization of forest residues and wood waste and factors mitigating against establishment of wood waste-based manufacturing industries.

Underutilization of forest Residues and wood waste translates to economic loss as resources are spent on growing of timber and other silvicultural activities. Thus, unutilized forest residues and wood waste translates to loss of economic resource spent on timber plantation. Additionally, purchasers of timbers buy timber in whole - the sawdust and other conversion waste are paid for. Therefore, when there is unutilized waste, the resource used in the purchase and transportation becomes economic loss.

Despite the availability of raw materials - wood waste, there is little industrial presence in the study area to utilize the raw materials. Thus, this research aimed at finding out the factors responsible for poor industrial development despite the presence of abundant raw materials and human resources and make recommendations for effective industrial development. Thus, an assessment of forest residues and wood waste utilization in Wukari local government area of Taraba state was carried out.

2. Materials and Methods

Methods of Data collection and analysis employed in the research are described in this section.

2.1. Description and Location of the Study Area

The study was carried out in Wukari Local Government Areas of Taraba State Nigeria. Wukari Local Government Area is one of the sixteen Local Government Areas of Taraba State. Wukari town is situated in the southern part of Taraba State. It is situated along Latitude $7^0$52’; 17’N to 70 .87’ N and a longitude $9^0$43’ 38’’E to 90 .77’’E at an elevation of 189 meters above sea level. Wukari occupies an area of 4,308km^2 (Taraba State Government Diary, 2016). Figure 1 contains map of Taraba State showing the study area.

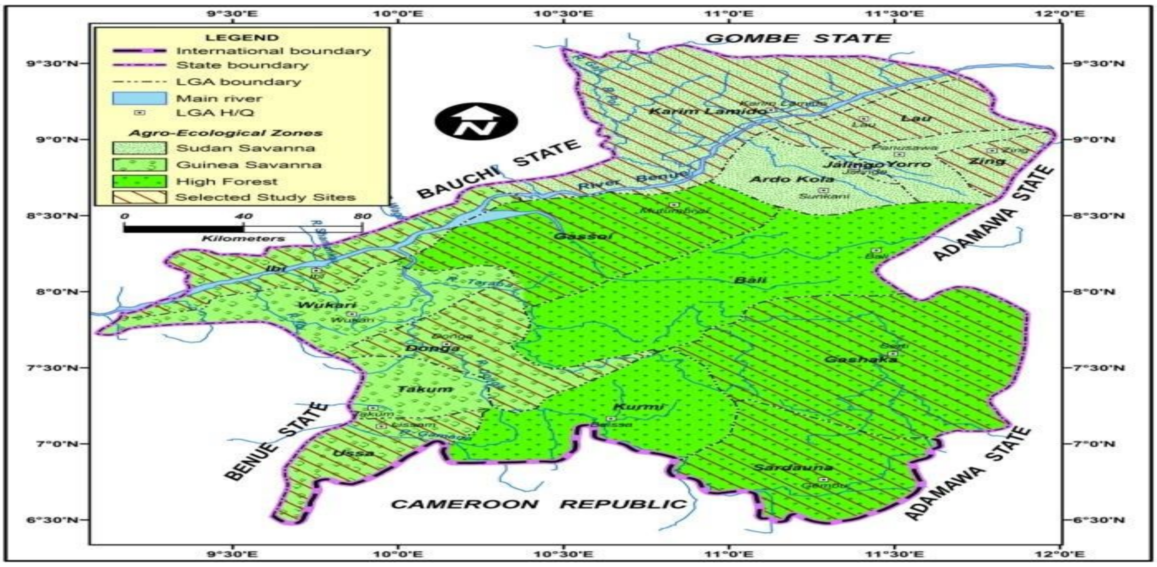

Figure 1: Map of Taraba State showing the study area (Taraba State Government Diary, 2016)

2.2. Method of Data Collection

The data for this research was collected from primary sources. This research adopted a self-administered questionnaire survey method as the strategy for data collection. The use of a self-administered questionnaire instead of a postal or e-mail questionnaire encouraged people to participate fully in the study. The primary data was collected through the administration of semi-structured questionnaires to timber operators. The closed-ended questions were predetermined and gave useful information to support theories and concepts in the literature while the open-ended question was used to explore reasons behind the responses and to obtain more information on the participants knowledge.

2.3. Sampling Procedure

A purposeful sampling strategy was adopted for this study. The purposeful sampling method allowed for the selection of individuals that are information rich and may provide useful information about the central phenomenon. Using 30% sampling intensity, a proposed total of hundred (100) questionnaires was administered in the Local Government Area under study. This number is based on recognizance study on the number of active timber operators in the study areas.

The sampling frame of this study comprises of the timber operators. The unit of analysis required is the individual. The timber operators include sawyers, other sawmill workers, loggers, wood cutters, carpenters/furniture makers and timber marketers.

2.4. Method of Data Analysis

In order to achieve the stated objectives of this research, the methods of data analysis that was used include cross tabulation, frequency distribution and percentage analysis. These types of data analysis were chosen in order to determine the most prevalent wood waste and forest residue in the study area, present most utilization of forest residues and wood waste in the area and knowledge of timber operators on waste and residues industrial utilization among others.

2.5. Determination of Level of Utilization

Five-point Likert scale rating format was used to analyze the level of utilization of wood waste and forest residues in the study area (Dagba et al., 2017). The weighing scale was derived from the following values with respect to the level of wood waste and forest residues utilization; Very High (VH) = 5, High (H) = 4, Moderate (M) = 3, Low (L) = 2, Very Low (VL) =1. The Likert rating Mean Score (MS) of the level of wood waste utilization was expressed as:

$$MS = \frac{\sum f}{n} \qquad (1)$$

Where: Σf = Summation of the five-point rating scale; and n = Number of points

Therefore, for a five-point Likert scale, MS is expressed as:

$$MS = \frac{1+2+3+4+5}{5}; \; MS = 3.0 \qquad (2)$$

The Likert Weighted Mean Score (WMS) of the level of wood waste utilization was expressed as:

$$WMS = \frac{\sum_{i=1}^{n} f_i x_i}{N} \qquad (3)$$

Where: f = frequency of respondent,
x = Likert scale point
N= Total Number of respondents

Using the interval scale of 0.05, the Upper Limit (UL) cut-off is MS+0.05 (3.0+0.05 = 3.05). The Lower Limit (LL) cut-off is MS - 0.05 (3.0-0.05 = 2.95). Based on these two extreme limits any variable with WMS below 2.95 (WMS < 2.95) was considered 'Low'. Variable with MWS between 2.95 and 3.05was considered 'Moderate'. Any variable with MWS greater than 3.05 (MWS > 3.05), was considered 'High'.

3. Results

Results obtained from the research are presented in this section.

3.1. Demographic Characteristic of the Respondents

The result of the demographic characteristics of respondents is presented in Table 1.

Table1: Demographic characteristics of the respondents

Category	Count n=100	Percentage (%)	Variables
Gender	Male	82	82
	Female	18	18
Age Category	15-25Yrs	31	31
	26-35Yrs	46	46
	36-45Yrs	19	19
	46-55Yrs	4	4
Educational Level	Non-Formal	6	6.0
	FSLC	14	14
	SSCE	37	37
	Diploma/NCE	20	20
	Degree	21	21
	Post-Graduate	2	2
Marital Status	Single	40	40
	Married	60	60
	Divorced	7	7
Annual Income in Naira	<100,000	51	51
	101,000-200,000	7	7
	201,000-300,000	9	9
	301,000-400,000	8	8
	401,000-500,000	5	5
	501,000-1,000,000	19	19
	>1,000,000	1	1
Occupation	Sawyer	21	21
	Wood logger	15	15
	Sawmill worker	25	25
	Wood cutter	13	13
	Timber Marketer	25	25
	Others	1	1

The result indicates that the majority of the respondents were male (82%), the age group between 26-35 years were dominant (46%) in the age distribution. About 31% of the woodworkers were aged below 26years of age. While 19% of the respondent were aged 36-45 years. Based on marital status, a greater proportion of the respondents (60%) were married while (40%) were single. In terms of educational level, 37% of the respondents had secondary education, 43% had tertiary education while 14 % and 6% had primary and non-formal education respectively. The income distribution of respondent shows that 19% of the respondents dominated with annual income (in Naira) of 501,000-1,000,000 while the least proportion of the respondents (1%) earned above N1, 000, 000 per annum.

3.2. Types of Wood Wastes and Forest Residues in the Study Area

The types of wood wastes in the study area are presented in Table 2.

Table 2: Types of wood waste and forest residues in the study area

Wood waste	F (n = 202)	Percentage (%)
Bark	15	7.43
Branches	15	7.43
chips	9	4.46
Edging	9	4.46
offcut	30	14.85
Sawdust	80	39.60
Shavings	44	21.78
Total.	202	100

The result indicated that saw dust (39.6%) is the major wood waste generated in the study area. This followed by wood shavings (21.78%) and offcut (14.85%) respectively. The least types of wood and forest residues generated in the study area are barks (7.43%) and branches (7.43%), chips (4.46%) and edgings (4.46%).

3.3. Ways of Wood Wastes and Forest Residue Utilization in the Study Area

Ways of utilization of wood wastes and forest residue in the study area is presented in Table 3.

Table 3: Wood wastes and forest residue utilization in the study area

Usage of wood waste	F (n=164)	Percentage (%)
Animal Bedding	48	29.27
Energy use	63	38.41
Engineered wood product	3	1.83
Local Building Material	11	6.71
Plant Mulching	38	23.17
Traditional Medicine	1	0.61

The highest proportion (38.41 %) of wastes in the study area is used for energy generation, 29.27% for animal bedding, 23.17% for plant mulching, 6.71% as local building materials, while the least uses were for production of engineered wood products (1.83%) and traditional medicine (0.67%).

3.4. Level of Utilization of Wood Wastes in the Study Area

The Likert scale on the level of wood wastes utilization is presented in Table 4. The WMS of 1.9 indicates that the level of utilization of wood wastes is low in the study area.

Table 4: Likert scale result on the level of utilization of wood wastes and forest residues in the study area

N	VH	H	M		L		VL		∑WS	WMS	REMARKS
			f	ws	f	ws	f	ws			
100	-	-	10	30	70	140	20	20	190	1.9	Low

3.5. Knowledge of Timber Operators on General Industrial Uses of Wood Waste and Forest Residues and Factors Limiting the Utilization of Wood Wastes in the Study Area

The knowledge of respondents on industrial application of forest residues and wood waste was assessed and presented in Table 5.

Table 5: Knowledge of respondents on industrial application of forest residues and wood waste

Categories	F (n=110)	Percentage (%)
Briquette	16	14.55
No Idea	68	61.82
Pulp and paper products	4	3.64
Wood based panel products	22	20.00
Total	110	100

The result shows that the majority of the respondents in the study area (61.82 %) has no knowledge of any industrial application of the generated wood waste and forest residues. 20% knows that it can be applied in wood-based panel production, 14.44% knows it can be used for briquette production while 3.64% has the knowledge that it can be used in pulp and paper production.

The result of factors limiting utilization of wood waste and forest residues are presented in Table 6.

Table 6: Factors limiting utilization of wood waste and forest residues in the study area

Categories	F (n = 100)	Percentage (%)
Inadequate Raw material	1	1.00
Lack of awareness	70	70.00
Lack of capital	6	6.00
Lack of Technical-know how	23	23.00

The result (Table 6) indicated lack of awareness (70%) as the major factor limiting wood wastes utilization, followed by lack of technical-know-how (23%), lack of capital (6%), while inadequate raw material (1%) was recorded the least factor limiting wood waste and forest residues utilization in the study area.

3.6. Environmental Challenges Associated with Forest Residues and Wood Waste in the Study Area

Nonindustrial application and general underutilization of forest residues and wood waste in the study area leads to some environmental challenges (Table 7).

Table 7: Environmental challenges associated with wood waste and forest residues in the study area

Categories	F (n=100)	Percentage (%)
Cause drainage problem	1	1.00
Causes Erosion	1	1.00
Fire Outbreak	8	8.00
Health Challenge (Respiratory)	11	11.00
Increase in Temperature	1	1.00
Loss of topsoil	22	22.00
No Idea	36	36.00
Pollution (Littering the environment)	20	20.00

Among the challenges reported are littering, loss of topsoil, respiratory health problems and fire outbreak. However, some of the timber operators in the area are not aware of any environmental challenges associated with wood waste and forest residues. Converting wood waste and forest residues to industrial products will ameliorate the environmental challenges posed by these waste and residues.

4. Discussion

Wood industries in the study area employ people of different age groups with the male gender dominating the industry. The reason for the male dominance is due to the nature of tediousness of the work which limits women participation. This agree with Rongo and Leon (2005) and Sambe et al.,(2021) who reported that the dominance of the male population and a young workforce in wood industries is due to the tedious operations of the industry which discourage most women from engaging in the enterprise. The fact that majority of the respondents fall within the active age distribution of 26-35 years further justify the above claim. A larger proportion of them were married, which implies that the industry is perhaps a secured livelihood activity in the study area. The relatively larger proportion of literate respondents implies that the industry requires a degree of literacy due to measurements and simple calculations involved in wood processing (Aiyeloja et al., 2013).

Wood wastes found across wood industries include, sawdust, plain shavings, wood offcut, wood backs, wood branches, wood chips and edgings, which are generated during wood processing in sawmills, furniture industries, timber shade, chain sawmill and during wood felling and delimbing. This agrees with Owoyemi et al., (2016) who reported the above wood waste as the common wastes generated in wood industries in Nigeria.

The reason for the highest proportion of wood wastes use as local energy source for cooking, animal bedding and mulching stems from the fact that wood wastes are underutilized and rarely utilized for biofuel production, briquettes, particle boards, and other engineered products. This corroborated the findings of Akhator et al., (2017) who reported that due to lack of technical know-how and investment in the sector, animal bedding and garden mulching are the common ways by which wood wastes are utilized in Nigeria.

The level of wood waste utilization in the study area is very low, the reason is that most of the waste goes to animal bedding, mulching and for firewood which accounts for just a little percentage of the total wastes generated. Ogunwusi (2014) and Akhator et al.,(2017) reported less than 5% utilization of the total wood waste generated in Nigeria, which leaves a huge quantity of wood waste unutilized.

One of the major problems limiting high level utilization of wood waste in the study area is lack of awareness and information, as many timber operators in the study area are not aware that wood waste and forest residues can be used for other things other than what it is being currently used for in the study area. Majority of timber operators in the area lack awareness of industrial application of wood waste and forest residues. Others though are aware of other applications of wood waste and forest residues, lack the knowledge and technical-know-how of converting these waste and residues to other useful products. The very few that has both awareness and technical-know-how lacks the capital to establish wood waste processing industries which will enable them to translate their knowledge to tangible products. This leaves a huge quantity of wood waste unutilized. Wood waste and forest residues handling and processing requires higher capital outlay, considerable development in technology and plant design. The findings by Ogunwusi (2014)corroborates the fact that the lack of incentives for wood waste utilization, inadequate information on economic returns on wood waste utilization, poor enforcement of environmental regulations, absence of policies targeted at wood waste management, lack of technical know-how on wood waste processing and utilization, among others are challenges facing the wood industry.

5. Conclusion

Although, the level of wood waste generation is very high in the study area, the level of utilization is very low, because of low presence of wood waste based manufacturing industries, leading to environmental nuisance. Thus, conversion of wood waste and forest residues to other useful products in the study area will result to industrial development, job creation, more economic development and healthier environment. It was found in this study that the major problems of industrial application of wood waste in the study area is lack of awareness of reuse values of wood wastes, lack of technical-know-how and lack of capital for those with technical-know-how. It is therefore recommended that awareness should be created on reuse value of wood waste in the study area. Timber operators and others should be trained and equipped with necessary skills to establish wood waste-based manufacturing industries through the intervention of Government and non-governmental organizations. Capital should also be provided to those with technical-know-how to enable them establish wood waste processing industries.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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SOME PHYSICAL AND BIOLOGICAL PROPERTIES OF *PINUS SYLVESTRIS* WOOD IMPREGNATED WITH NANO-SOLUTIONS

Ayşenur Gürgen [1], Sibel Yıldız [2]

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Corresponding Author

Ayşenur Gürgen
aysenurgurgen@osmaniye.edu.tr

Abstract

In this study, Scots pine (*Pinus sylvestris*) wood samples were impregnated with nano-sized MgO, ZnO, TiO_2 and SiO_2 to determine the effects of nano particles on the some psychical and biological properties of pine sapwood. Water absorption rate (WAR) and fungal decay (*Coniophora puteana*) test were performed after the full-cell impregnation process. Impregnation was carried out with solutions prepared using only water at 1.5% concentration for nano-solutions. The WAR values at the end of test for these samples were ranged between 102.916 % and 120.823% while the 135.143 % for control (not impregnated) samples. Weight losses of wood samples impregnated with nano-solutions were ranged between 1.502% and 2.142%. The results have demonstrated that all four nanoparticles used in the experiment (MgO, ZnO, TiO_2, SiO_2) can be used as impregnation materials in compliance with studied tests. Particularly, SiO_2 has exhibited high performance in increasing the antifungal properties of pine wood.

[1] Department of Industrial Engineering, Faculty of Engineering, Osmaniye Korkut Ata University, Osmaniye, Turkey

[2] Department of Forest Industry Engineering, Faculty of Forestry, Karadeniz Technical University, Trabzon, Turkey

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SOME PHYSICAL AND BIOLOGICAL PROPERTIES OF *PINUS SYLVESTRIS* WOOD IMPREGNATED WITH NANO-SOLUTIONS

Ayşenur Gürgen
aysenurgurgen@osmaniye.edu.tr
ORCID : 0000-0002-2263-7323

Sibel Yıldız
sibelyildiz@ktu.edu.tr
ORCID : 0000-0001-8448-4628

1. Introduction

From the past to the present, wood material has found various uses areas in every country and every culture (Ramirez-Coretti et al., 1998). However, when wood material is left to its natural durability, it tends to deteriorate over the years and lose its economic value. To prevent this loss and extend the lifespan of wood material, it is necessary to impregnation with some chemicals which have resistant against to biological, physical and chemical factors (Chernenko, 2017).

The process of treating wood to enhance its natural resistance, extend its service life, and protect it against various biological factors is called "impregnation." Looking at today's context, the environmental sensitivity of the impregnation materials used has become of great importance (Kjellow and Henriksen, 2009). Particularly, the banning and restriction of the use of impregnation materials containing arsenic in Europe after the United States, Canada, and Japan has made significant contributions to increasing environmental awareness. Following these bans, the impregnation industry and wood preservation companies have aimed to develop environmentally friendly, more natural, next-generation impregnation materials to both prolong the life of the wood and minimize environmental harm (Schultz et al., 2004). Natural preservatives derived from various plants such as tannins, come to mind are the first ones in this field (Pizzi, 2016). These natural products provide resistance against adverse weather conditions such as sunlight and rain, as well as harmful effects from organisms like insects and fungi, but they may not fully fixate onto the wood (Tomak and Gonultas, 2018).

With the advancement of technology, new methods and materials are being discovered in the field of wood impregnation (Kurkowiak et al., 2022; Zelinka et al., 2022). One of these methods is impregnation with nanoscale materials, which has emerged with the development of nanotechnology. Nanotechnology is a branch of science and technology that involves the manipulation of atoms and molecules in the size range of 1-100 nanometers (White et al., 2009). Nanotechnology finds applications in various fields such as chemical engineering, physics, electrical engineering, materials science, chemistry, biology, and more (Stephanopoulos and Reklaitis, 2011; Bayda et al., 2019).

In recent years, the use of nanotechnology has gained significant potential in the forestry sector (Papadopoulos and Taghiyari, 2019). Nanotechnology contributes significantly to improving the use of wood and enhancing the economic value of forest products. Nanotechnology offers various opportunities in the forest products industry, ranging from the production of raw materials to new approaches for wood-based materials and applications in composites and paper products (Chauhan and Chakrabarti, 2012; Jasmani et al., 2020). Nano-scale lignocellulosic surfaces can open new possibilities for functionalizing wood materials, enabling self-cleaning surfaces and more. The use of nano-sized building blocks can make materials lighter and reduce energy requirements. Nanotechnology can also be applied to improve moisture problems in wood-based materials, making them suitable for paper product applications to use outdoor applications (Chauhan and Chakrabarti, 2012).

In a study conducted by Taghiyari (2011), *Populus nigra* samples were impregnated at 2.5 bars inside a chamber, with water-based nano-silver solution at 45°C for 24 hours. Then wood samples were treated with heat treatment at different temperatures and durations. The test results showed a decrease in resistance values. However, it was indicated that the breakdown and pyrolysis processes were not effective and did not penetrate the inner parts of the material. Additionally, heat-treated samples exhibited increases in elastic modulus and compressive strength.

In another study, Akhtari et al. (2012) impregnated *Paulownia fortunei* wood with silver, copper, and zinc oxide nanoparticles. This study aimed to investigate the effects of impregnating *Paulownia fortunei* with silver, copper, and zinc oxide aqueous nanoparticles ranging in size from 10 to 80 nm on the mechanical properties of the wood, which has a dry density of 0.37 g/cm^3. Mechanical properties are generally considered as crucial characteristics for wooden products in structural applications. Therefore, these properties hold vital importance for the material. For the study, test samples were impregnated with a 400 ppm aqueous nano-silver, nano-copper, and nano-zinc oxide suspension under a pressure of 2.5 bars in a pressure chamber for 20 minutes. The results obtained showed a significant improvement in mechanical properties, with the highest enhancement observed in samples impregnated with nano-copper.

Additionally, it was observed that nano-copper and nano-zinc oxide-impregnated samples formed chemical bonds between the nanoparticles and the wood cell structure.

In a study by Afrouzi et al. (2013) the resistance of poplar wood (*Populus deltoides*) impregnated with nano-zinc oxide to color change was investigated. For this purpose, samples were impregnated with nano-zinc oxide at three concentrations: 0.5%, 0.75%, and 1% using the full-cell method. Subsequently, the samples were exposed to artificial weathering tests for 200, 400, and 600 hours. At the end of each stage, the color change of the samples was measured. Nano-zinc oxide was found to reduce the interaction of UV radiation, especially on the lignin wood surface, by increasing the contact surface area and improving optical properties, thus preventing the formation of free radicals. These results indicate an increase in resistance to color change in wood. Additionally, nano-zinc oxide not only enhances anti-UV properties but also reduces wood's air permeability and increases its hardness. Therefore, it can be said that nano-zinc oxide reduces erosion, graying and surface deterioration occurring in outdoor environments. As a result, it was concluded that nano-zinc oxide can be used as a color change inhibitor in the formulations of materials used for wood protection.

In a study conducted by Habibzade et al. (2016) the effects of ZnO nanoparticles on the fire retardancy, physical, and mechanical properties of polymerized poplar wood were investigated. Poplar samples were impregnated with styrene monomer containing four different nano ZnO contents (0, 0.5%, 1%, and 1.5%) based on the monomer's dry weight. As a result, the presence of zinc oxide nanoparticles significantly improved the physical and mechanical properties of poplar wood impregnated with styrene. It was observed that nano-zinc oxide enhanced some fire-retardant properties of poplar wood.

This study focuses on investigating the potential use of nanoparticles which can penetrate micro-pores and provide more effective protection with smaller quantities, on wood. In accordance with this purpose, water absorption rate and fungal decay performances were investigated of Scots pine wood samples impregnated with some nanoparticles such as MgO, ZnO, TiO_2, and SiO_2.

2. Materials and Methods

Methods of data collection and analysis employed in the research are described in this section.

2.1. Material

2.1.1. Wood Material

In this study, the sapwood of Scots pine (*Pinus sylvestris* L.) trees, naturally grown in Turkey and considered a valuable timber, species was used. The wood raw material was obtained from Yıldız Village in the Torul district of Gümüşhane province. The altitude of the location where the trees were cut is 1300 meters.

2.1.2. Impregnation Solutions

Nano-sized MgO (45 nm), ZnO (25-35 nm), TiO_2 (4-28 nm), SiO_2 (28 nm) were used as impregnation agents. These chemicals were sourced from the Nanografi company (Ankara, Turkey) and were dispersed in water for the study.

2.2. Method

2.2.1. Preparation of Wood Samples

The samples used in the experiment were selected according to TS 345 (2012) criteria, ensuring that they were free from knots, in good condition, and free from decay.

2.2.2. Preparation of Impregnation Solutions

The impregnation solutions were prepared using pure water through weight percentage calculations. To ensure homogenous mixing, the prepared impregnation solutions were stirred on a magnetic shaker at a speed of 1000 rpm for 10 minutes. A concentration of 1.5% of the impregnation agent was prepared. The nano solutions used for impregnation in the laboratory experiment are shown in Figure 1.

Figure 1: Impregnation solutions prepared for experiments

2.2.3. Impregnation Process

The impregnation process was carried out using the full-cell method. According to this method, the wood samples, which were air-dried, were placed inside the impregnation vessel. Initially, a vacuum of was applied for 15 minutes to remove the air from the cell lumens. Following this, the impregnation solution was applied at 7 bars of pressure for 60 minutes.

Retention was calculated as follows Equation 1;

$$R\ (kg/m^3) = (G \times C) / V \times 10 \quad (1)$$

R represents the retention amount in kilograms per cubic meter (kg/m^3).
$G = T_2 - T_1$;
G: The amount of impregnating substance absorbed in grams (gr).
T_1 is the weight of the test sample before impregnation in grams (gr).
T_2 is the weight of the test sample after impregnation in grams (gr).
C represents the solution concentration in percentage (%).
V is referred to as the sample volume in cubic centimeters (cm^3).

2.2.4. Water Absorption Rate

The water absorption rate (WAR) was calculated for samples with dimensions of 6.4 x 25 x 50 mm^3. The impregnated samples were dried at 103±2°C until a constant weight was reached and the weight and dimensions of the completely dry samples were determined. Subsequently, a specific amount of water was placed on them, and they were left with a weight on top. The specimens were soaked in water for 2, 4, 8, 24, 48, 72 hours, and 1 week. At the end of each period, the water on the absorbing samples was wiped off and the dimensions of the test and control samples and the amount of absorbed water were determined. The initial completely dry weight values were used to calculate the WAR (%) for each individual experimental and control sample. The water absorption ratios were calculated according to Equation 2, (Tomak, 2011).

$$WAR\ (\%) = [(W_t - W_0)/W_0] \times 100 \quad (2)$$

In the equations:
W_0: Initial completely dry weight (grams).
W_t: Weight of the sample removed from water at each interval (grams).

2.2.5. Fungal Decay Test

The fungal decay test was conducted according to the European Union Standard (EN-113, 1996) with modifications. The impregnated samples (0.5x1.5x2.5 cm) were sterilized in an autoclave at 121°C for 20 minutes.

For the fungal culture medium, a malt-agar mixture was prepared. To achieve this, 140 grams of malt extract and 20 grams of agar were mixed in 1 liter of distilled water. Each culture bottle was filled with 60 ml of the prepared mixture. The bottles were sealed and sterilized in an autoclave. Once sterilization was completed, the culture bottles were placed in a UV cabinet and left for one day. After one day, fungal mycelia were inoculated into each culture bottle, and the bottles were kept in a climate chamber under conditions of 70% ± 5 relative humidity and 22 ± 2°C until the mycelia completely colonized the culture medium.

In culture bottles where fungal colonization of *Coniophora puteana* was completed, one control and one impregnated wood sample were placed. The samples were kept in the climate chamber under conditions of 70% ± 5 relative humidity and 22 ± 2°C for 14 weeks. At the end of this period, the samples were kept in an oven at 103 ± 2°C until a constant weight was reached, and their completely dry weights were calculated. After removing fungal mycelia residues from the sample surfaces, the dry weights (Ms) were recorded, and weight loss was measured using Equation 3.

$$W_L\ (\%)=[(W_t-W_0)/W_0]x100 \qquad (3)$$

In this equation:
W_L: Weight Loss (%)
W_0: Initial weight before the experiment (grams)
W_t: Weight after the experiment (grams)

According to the standard, for the test to be considered valid, the weight loss in the control (non-impregnated) samples should be at least 20%. To deem an impregnation material successful, the weight loss in the impregnated (test) wood samples should be a maximum of 5%, or according to the new European standards, 3% (EN 113, 1996).

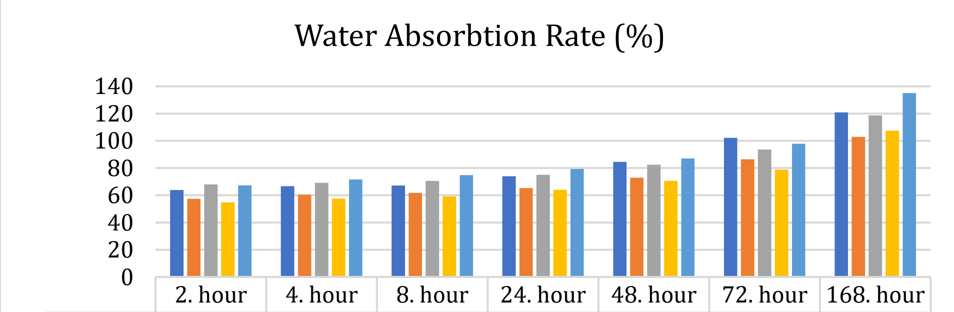
3. Results

Retention values of impregnated wood samples were given in Table 1.

Table 1: Retention values of impregnated wood samples

Retention (kg/m³)		
	Average	**Standard deviation**
MgO	12.237	3.036
ZnO	13.218	1.640
TiO_2	10.261	1.068
SiO_2	10.766	2.021

The water absorption rate of impregnated wood samples is shown in Figure 2.



	2. hour	4. hour	8. hour	24. hour	48. hour	72. hour	168. hour
MgO	63,914	66,72	67,12	73,933	84,554	102,188	120,823
ZnO	57,375	60,45	61,795	65,254	72,94	86,391	102,916
TiO2	67,983	69,156	70,525	75,023	82,454	93,601	118,632
SiO2	54,842	57,54	59,201	63,975	70,617	78,803	107,452
Control	67,275	71,666	74,86	79,252	87,037	97,816	135,143

MgO ZnO TiO2 SiO2 Control

Figure 2: Water absorption rate of impregnated wood samples

Weight losses of wood samples after fungal decay test were given in Table 2.

Table 2: Weight losses of wood samples after fungal decay test

Weight losses (%)		
Impregnation solution	**Average**	**Standard deviation**
MgO	2.136	0.375
ZnO	2.142	0.456
TiO_2	1.989	0.135
SiO_2	1.502	0.103
Control	38.560	6.345

4. Discussion

The retention rate of the wood samples impregnated with nano-MgO, ZnO, TiO_2 and SiO_2 were determined 12.237±3.036, 13.218±1.640, 10.261±1.068, 10.766±2.021 kg/m^3, respectively. Muhcu (2015) impregnated Scots pine wood samples with impregnation solutions prepared at a concentration of 1.0% for nano-ZnO using ethanol as a solvent and for nano-CuO, nano-TiO_2, and nano-CeO_2 using ammonia as a solvent. They reported retention values for nano-ZnO, nano-CuO, nano-TiO_2, and nano-CeO_2 as 4.906±0.728, 5.886±0.364, 5.530±0.738, and 3.780±0.354 kg/m^3, respectively. The reason for the higher retention values compared to the results in this study can be attributed to the use of impregnation solutions at a higher concentration, despite the similar nanochemicals being used.

In the study, impregnation was carried out with solutions prepared using only water at 1.5% concentration for MgO, ZnO, TiO_2, SiO_2 and control samples. The WAR values for these samples were found to be 120.823±13.45, 102.916±12.56, 118.632±13.41, 107.452±12.59 and 135.143±14.91%, respectively. When examining the WAR values of Scots pine wood samples impregnated with the four chemicals at a concentration of 1.5% (based on 336 hours), it is observed that the highest WAR is in the control (non-impregnated) sample, while the lowest water absorption rate is in the samples impregnated with ZnO. In a previous study, Scots pine wood samples were impregnated with impregnation solutions prepared at a concentration of 1.0%, using ethanol as a solvent for nano-ZnO and ammonia for nano-CuO, nano-TiO_2, and nano-CeO_2. According to measurements taken at 24 hours, the WAR for the control sample and nano-ZnO, nano-CuO, nano-TiO_2, and nano-CeO_2 impregnated samples were reported as 71.35±4.10, 61.78±5.70, 66.72±7.16, 67.26±2.67, and 62.54±4.36%, respectively (Muhcu,2015). It can be said that the difference between the results of the mentioned study and this study is due to the difference in the solvents of the impregnation solutions. In both studies, the samples impregnated with ZnO and the control samples were the ones that absorbed the least and most water, respectively.

In another study, conducted by Kızılırmak and Aydemir (2019), the effects of impregnating thermally treated Beech (*Fagus orientalis*) and Oak (*Quercus robur*) wood with nano-sized titanium dioxide and boron nitride on wood properties were investigated. According to the results obtained from the applied method and experiments, impregnating wood with nanoparticles and the thermal treatment of wood generally reduced the wood-water relationships. It was determined that thermal treatment is a significant factor in reducing wood's water absorption and dimensional stability. It was observed that the impregnation of wood with TiO_2 nanoparticles reduced water absorption more than the impregnation with nanoboron nitride.

The fungal decay test has been successful. This is because the weight loss in the control samples was observed to be 38.560% because of the experiment. Considering the obtained results, it can be said that all four nanoparticles used in the experiment, MgO, ZnO, TiO2, and SiO2, can be used as impregnation materials in compliance with European standards. Specifically, in the MgO-impregnated sample, a weight loss of 2.136% was observed; in the ZnO-impregnated sample, a weight loss of 2.142% was observed; in the TiO2-impregnated sample, a weight loss of 1.989% was observed, and in the SiO_2-impregnated sample, a weight loss of 1.502% was observed.

In a previous study, Scots pine wood samples were impregnated with impregnation solutions prepared at a concentration of 1.0%. Ethanol was used as the solvent for nano-ZnO, and ammonia was used for nano-CuO, nano-TiO_2, and nano-CeO_2. In the decay test results against *Tramates versicolor* fungus, the weight loss for the control sample and the samples impregnated with nano-ZnO, nano-CuO, nano-TiO2, and nano-CeO_2 solutions was reported as 20.62±4.14, 8.78±4.24, 1.69±0.62, 1.60±0.53, and 7.13±4.28%, respectively (Muhcu,2015).

De Filpo et al. (2013) conducted antibacterial and antifungal tests on eight different types of wood commonly used in cultural heritage sites to measure the performance of nano-TiO_2 particles. The research results revealed that nano-TiO2 particles inhibited the growth of both *Hypocrea lixii* (white rot) and *Mucor circinelloides* (brown rot) fungi, regardless of the wood type.

Akhtari and Arefkhani and Arefkhani (2013) investigated the resistance of *Paulownia fortunei* wood treated with silver, copper, and zinc oxide nanoparticles to white rot fungus. The tree samples were pressure-impregnated with a 400 ppm aqueous suspension. The samples were inoculated with the fungus and incubated in nano-zinc oxide for sixteen weeks following the EN113 (1996) standard. According to Scanning Electron Microscopy (SEM) examinations, the average weight loss of Paulownia wood treated with nano-silver, nano-copper, and nano-zinc oxide particles was 2, 2, and 2% respectively after 16 weeks. It was found that the mass loss due to decay was higher in the control Paulownia wood (28.13%). Additionally, the formation of intercellular voids between cellulose microfibrils was observed. No noticeable differences were observed in SEM images between decayed wood treated with nanoparticles and undecayed wood.

Clausen et al. (2010) investigated the effects of zinc oxide (ZnO) nanoparticles with a diameter of 30-70 nm on the termite resistance and retention properties of pine wood. According to the obtained results, the ZnO treatment did not cause a significant change in termite resistance and peeling. It was found that only a 5% ZnO treatment reduced wood material degradation by 4%.

5. Conclusion

In the study, it was proved that all four nanoparticles (MgO, ZnO, TiO_2, SiO_2) can be used as impregnation materials. Especially, SiO_2 (Silicon dioxide) has been observed to provide high efficiency in increasing the antifungal properties of pine wood. As known, SiO_2 is naturally found on Earth in water, plants, animals and especially rocks and nanotechnology exists that allows the production of this product at the particle level. For this reason, it is estimated that SiO_2 nanoparticle will be used more widely as an effective and economical impregnation agent in the wood protection industry soon. In addition, leaching test should be performed before the fungal decay test to obtain information about its usability in the outdoor. Finally, it is also recommended to investigate the effects of nano-solutions used in this study on mechanical properties.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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