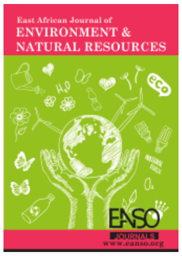

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Original Article

Cement Dust Spread as Influenced by Wind and Its Impacts on Settlement Patterns and the Biophysical Environment

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ABSTRACT

Distance between cement factories and human settlements is key to determining the extent to which neighbourhoods are affected by cement dust. A key influencer of settlement patterns is zoned development and physical planning for healthy living. Wind patterns are also a factor in determining the proximity of settlements, an aspect requiring zoned development. This study focuses on cement factories in Athi River Township, established as early as 1933 when there was barely any settlement. They include East African Portland Cement Company (1933), Bamburi (1951), Athi River Mining (1974) and Mombasa (2007). Zoning development failure and unclear guidelines on the appropriate distance away from cement factories are major threats to human health. This study uses Geographic Information System and Remote Sensing Techniques for proximity analysis of the spatial relations between cement factories and homes. Study results show that residential homes are built on the wind shadow side of factories, thus affected by dust blown by easterly flowing winds. More than 1,888 residential homes in Athi River are within the 3.5 km buffer protection area. 47% of interviewed respondents consider cement factories as the main pollution source. Key Informant Interviews were administered to health officials from the nearby hospital. They reported, from hospital records, that 29.42% (n = 5084) were upper respiratory infections (URI), 17.20% skin infections (n = 2972), 7.72% (n = 1335) eye irritations, 16.32% pneumonia (n = 2821) and 11.49 % (n =1985) asthma, all traced to cement dust. Vegetation mapping using Landsat imagery classification showed a variance in the area under pasture (0.54%) and cropland (4.42%). These impacts point to a need for the implementation of zoned development to safeguard communities against cement dust impacts.

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INTRODUCTION

Human settlement proximity to cement factories is a huge determinant of vulnerability to cement dust and its spread to the surrounding environment. Nkhama et al. (2017) assessed the relationship between exposure, human health, and settlement at Chilanga, Zambia. The study outcomes reported that the most common cement dust-related respiratory problems include coughing, phlegm production, wheezing and nose irritation. Cases related to coughing were the highest reported at 52.5% (cold season) and 75.1% (hot season). Freedom communities were found to suffer from it. A similar study was done in India by Mehraj et al. (2013) illustrated that there was a high particulate and gaseous load in a cement-polluted environment than at a control site. This was noted to be the reason for an increase in the number of local inhabitants who suffered from respiratory health problems. Reported cases included allergic reactions that affect breathing (99%), eye irritations (97%), asthma (49%) and chest pains (49%). Other diseases reported were such as emphysema, chronic bronchitis, wheezing and shortness of breath.

Aribigbola et al. (2012), in their study to assess the environmental and health issues from a cement factory in Ewekoro community residents, Nigeria, noted that cement dust contains silica, which results in diseases such as bronchitis, cancer of the lungs, asthma, and also tuberculosis. In a similar kind of study done by Kakooei et al. (2012), common respiratory problems included coughing (60.7%), wheezing (41.1%), sputum (37.5%), and dyspnea (44.6%) of the total exposed subjects. Different skin and hand infections are also common among workers and people living near cement factories.

Wang et al. (2011) assessed occupational hand dermatitis from cement dust exposure in Taiwan, China. Study results indicated that 65 out of 97 workers showed hand dermatitis. Effects on the skin include itching, scratching, dryness, and erythema, which is the reddening of the skin in patches. García-Pérez et al. (2013) did an ecological study in Spain to analyse cement dust impacts on people living nearby cement factories. Study results indicated that residents living within 3 km of cement factories have a high risk of lung cancer (Bertoldi et al., 2012).

Purwanta et al. (2018) scrutinised dust spread and how fogging method can be used as a mitigation alternative. His study outcomes indicated that trends of dust spread and the direction of the wind affect a wind shadow area and that fogging method is a good method of dealing with this problem since it helps capture very tiny cement particles.

Gupta & Sharma (2013) examined the impacts of heavy metals found in cement dust to plant growth

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and soil. The findings of his study indicated that the direction of the prevailing wind has a huge influence on the distribution and settlement of cement dust. This dust has a high content of heavy metal that is harmful when they combine with the soil and gain contact with plants and also water bodies. High lead concentration was found on plants located 500 m away from cement factories than at 1 to 2 kilometres. Lead concentration at 500 m was as high as 0.699 ppm and 0.511 and 0.427 ppm at 1 and 2 kilometres, respectively. These results were compared to a central pollution standard of 0.1 ppm for various heavy metals. Gupta and Sharma (2013) noted that the direction of the prevailing wind has a major influence on the concentration level of various heavy metals present in cement dust. Soil productivity depends upon soil quality which is directly linked to water quality (Cetin, 2013.)

Communities that suffer the most from health issues because of cement dust are those living nearby cement factories (Zeb et al., 2019). Afolabi et al. (2012) investigated the influence of cement dust emission on residential homes in respect of distance from cement factories. One hundred twenty-five respondents, constituting 72.68% of those interviewed live 2 km away from cement factories and were all affected by dust. Cement dust pollution was also felt 3 km away from cement industries. 19.77% of interviewed respondents suffered from asthma, while others suffered from skin cancer and heart diseases. (Gupta and Sharma 2013) evaluated the levels of exposure to heavy metals contained in cement dust while assessing different cement factories in Nokha, India.

Mehraj et al. (2013) investigated the health issues due to cement dust in neighbourhoods near cement factories in India, with a focus on those living within 2-3 km. Site I was 2 to 3 km away, while site II was a control site, 18 to 20 km away. Study results indicated that there was high particulate and gaseous pollutant load at site I than site II. Nitrogen Oxide had a mean concentration of 117.09 µg/m3 in site I, 19.46 µg/m3 in site II, whereas Sulphur Oxide had a mean concentration of 115.82 µg/m3 in site I and 28.13 µg/m3 in site II. 97% of respondents in this area suffered from irritations of the eye, itching in the nose, allergic reactions, and other irritations of the mucous membrane (Nkhama et al., 2017).

Warrah et al. (2021) investigated the abundance of toxic metals in plants near Sokoto Cement. Research findings showed a decrease in the concentration of different heavy metals as one moves further away from the factory. The concentration of mercury, for example, was 11.12 mg/l at 50 m, 1.92 mg/l at 400 m, and 2.21 mg/l at 1000 m away from the factory. Warrah et al. (2021) also reported that plant growth reduction in terms of height and number of leaves was attributed to cement dust because of toxic metals such as mercury, copper, cadmium, zinc, lead, chromium, and also nickel. Ogunkunle and Fatoba (2013) noted that plants near cement factories are prone to a very high concentration of cement dust, which generally affects growth. This is a result of reduced carotenoid and chlorophyll content due to the destruction of the chloroplast, thus interfering with the photosynthetic process Salama et al., (2011).

Chaurasia et al. (2013) discovered that metabolic plant processes are affected when plants come into contact with cement dust due to the presence of heavy metals that reduces chlorophyll content, starch, and protein content. The presence of mercury and cadmium is known to result in stunted growth of plants, as they affect the availability of major macro-nutrients (Farzadkia et al., 2016). The presence of lead is also noted to be very harmful to the ecosystem, especially to vegetation, soil, and human health (Mehraj and Bhat, 2014).

Gupta and Sharma (2013) discovered that heavy metal present in cement dust results in leaf necrosis, reduces the activity of several enzymes thus reducing flowering in plants, interferes with root growth development, and stunted growth in plants. Eugene Lamare and Singh (2020) also noted the formation of a hard crust on soil covered by cement dust. This resulted in a reduction in the population of different plant species due to changes in the soil's chemical composition thus affecting plant growth.

Cement Company Standards and Regulations

As the housing infrastructure in Athi River continues to grow, there is increased concern about whether residential homes are being built at a safe distance away from Cement factories. Despite having some measures in place to limit this dust, cement dust that escapes into the environment

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causes detrimental impacts on the biophysical environment. In order to minimise emissions from cement dust, the cement companies such as Bamburi cement have put in place several measures including regular monitoring of the de-dusting system to ensure cement dust emission is minimised, setting up dust extraction and recycling systems and also regular watering of outdoor surfaces to ensure there is minimal dust spread by wind. They also carry out dust surveys every six months to monitor the amount of cement dust in the air (Mwagwi et al., 2016).

MATERIALS AND METHODS

Health Assessment of Respondents

A random sample of 120 respondents was interviewed using a structured questionnaire to capture data on health, livelihood, occupation and impacts from cement dust. In addition, Key Informants Interviews were administered to health officials at a hospital located 0.5 km away from the Mombasa Cement on the Southeastern side. The hospital health records were also assessed.

According to Machakos County (CIDP) 2022, Athi River is projected to have a population of 203,381 in the year 2022.

The sample size was calculated using a formula by Nassiuma (2000);

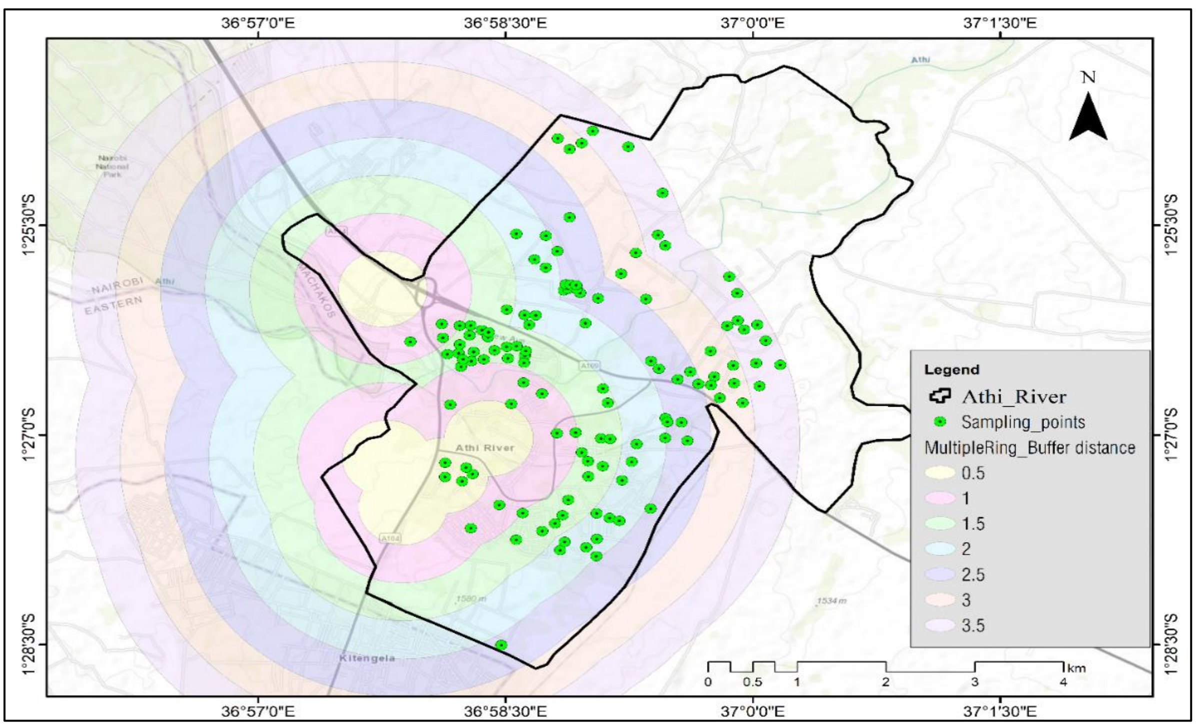
$$n = \frac{NC^2}{C^2 + (N-1)e^2}$$

Where; n = sample size, N = population, C2 = coefficient of variation (take.5), e = margin of error, using 0.05 at a confidence level of 95%

$$n = \frac{203{,}381 * 0.5^2}{0.5^2 + (203{,}381 - 1)0.05^2} = 100\ respondents$$

The distribution of sampled respondents is shown in *Figure 1*

Figure 1: Spatial location of sampled households



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Wind Direction Data

Wind direction data was obtained from Esri's current weather and wind station data layer created from NOAA's hourly METAR station data at an altitude of 30 Hg (10 meters). The data is updated hourly, using the Aggregated Live Feeds methodology. It contains 11 weather variables for each location (arcgis.com), among which is wind speed which was used to ascertain the travel distance of the generated cement dust and flow direction, which was used to show areas most affected.

Proximity Analysis

The proximity toolset was used to help show the proximity relationship between cement factories and residential homes. The buffers were necessary so as to show the areas of influence, in this case, in the cement dust risk zone. By doing this, it was then practicable to determine the number of households found within each multiple-ring buffer by clipping data specific to a specific radius. The location of cement factories and residential homes was determined using geospatial techniques. A GPS was used to store longitude and latitude information. During the ground truth survey, the spatial location of the different utilities was mapped and uploaded to overlay on Google Earth to help assess the structure and environmental profile of the area, including tree cover. ArcMap geoprocessing tools were also used for proximity analysis to determine the distance between cement factories and residential homes. Buffers of 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 kilometres were created in the factories. Based on a study done by Afolabi et al. (2012), in Nigeria, the dust risk zone was mostly found to be at a distance between 0-3 km away from cement factories. With wind flow direction data, it was then possible to assess and determine areas with high cement risk pollution areas.

Vegetation Mapping

Landsat image for the year 2020 that was downloaded from USGS. The downloaded image was uploaded in Arc Map and through an unsupervised classification method, four land covers were generated; built-up area, farmland, shrub/grassland, and also bare land. This information was necessary so as to assess whether existing vegetation cover had an impact on the strength of wind flow. From the attribute table of the LULC layer, the calculated Geometry feature can be used to calculate the area in km^2 of each land cover type. The difference in land area between dry and wet seasons can then be calculated and assessed after which it becomes possible to justify the plausible reasons for these changes.

RESULTS

Health Impacts

Data from a 250-bed capacity hospital nearby indicated that the most common dust-related illnesses are skin infections, eye infections, pneumoconiosis, dermatitis, and other respiratory complications. The result from the administration of the questionnaire is shown in *Figure 2*, where pneumoconiosis reported the highest incidences (35%).

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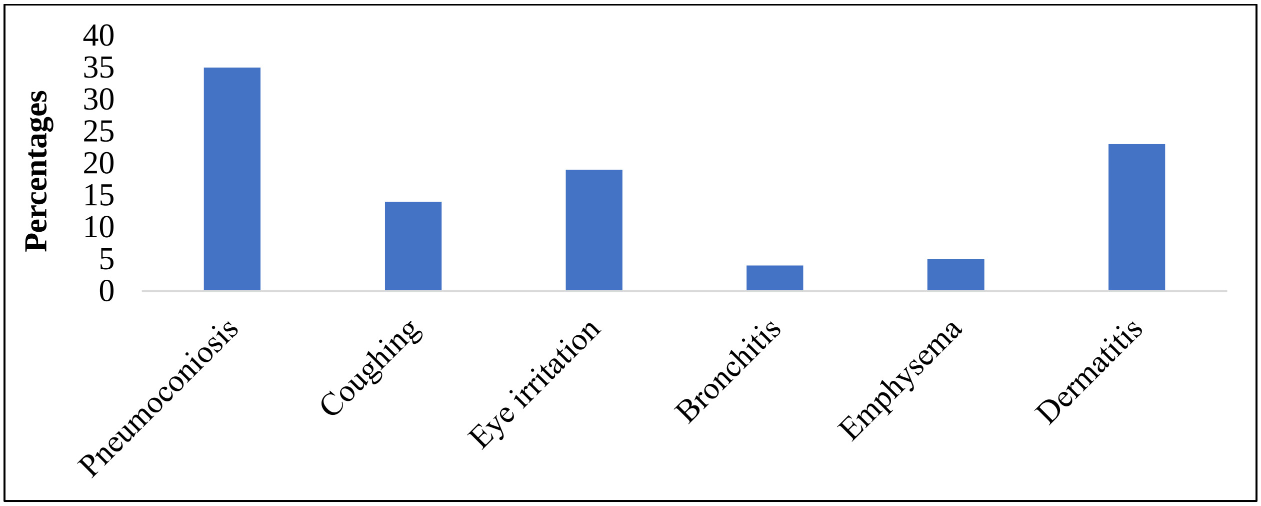
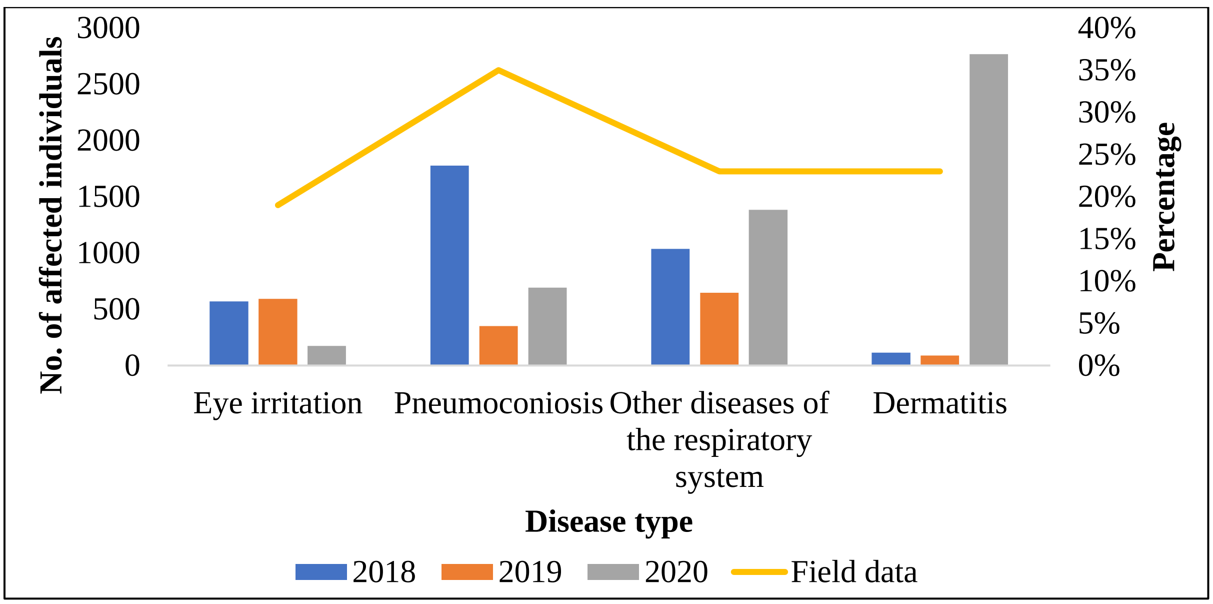
Figure 2: Main respiratory health problems reported



Information in *Figure 2*, when compared with cases reported based on data obtained from health records shows that pneumoconiosis was the highest case reported. Over the three years, 2020 recorded a higher percentage of those suffering from dermatitis. Other diseases reported included bronchitis, emphysema and coughing as shown in *Figure 3*.

Figure 3: Diseases attributed to cement dust



Source of Dust

Interviewed respondents attributed the dust in their neighbourhood to cement dust dispersal from the factories (47%). A noteworthy number of respondents attributed the dust to vehicular movement to-and-from construction sites within the area (Figure 4) without linking that to factory sources.

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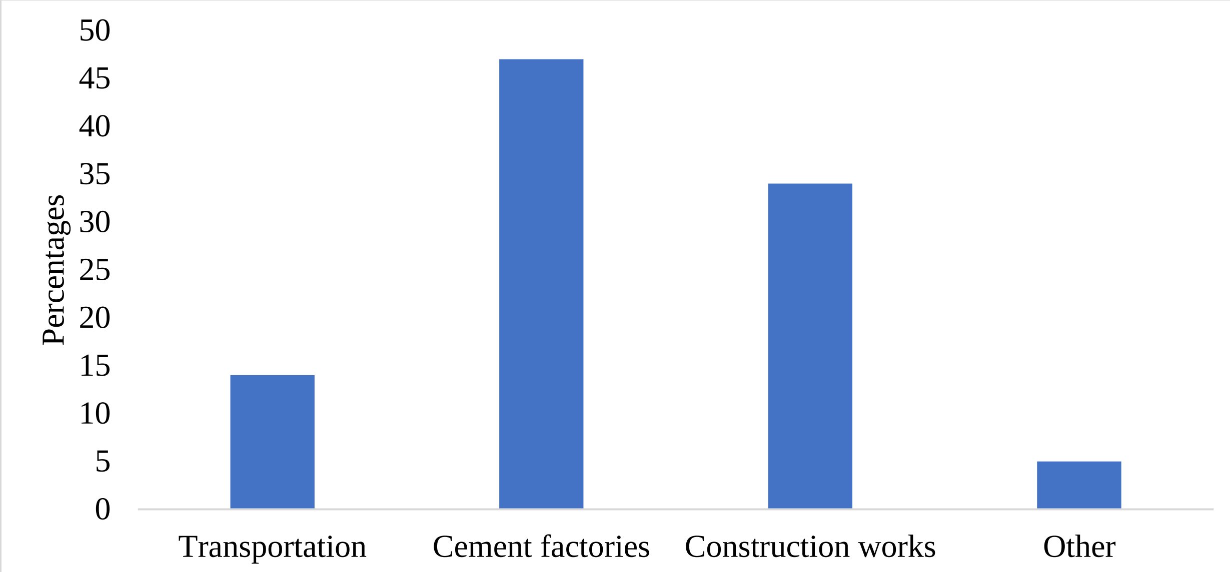
Figure 4: Main source of dust as perceived by the respondents



The data presented below (*Table 1*) shows the common respiratory health problems as per health records obtained from the nearby hospital. Data were recorded for three years consecutively (2018-2020) to be able to show the comparison of the most commonly reported cases based on the totals.

Table 1: respiratory diseases reported from hospital health records

Years	Disease attributed to dust						
	Eye infections	Upper respiratory tract infection	Asthma	Pneumonia	Other diseases of the respiratory system	Diseases of the skin	Cardio-vascular conditions
2018	570	3534	1393	1777	1036	115	20
2019	592	1377	246	352	646	89	0
2020	173	173	346	692	1384	2768	0
TOTALS	1335	5084	1985	2821	3066	2972	20
Percentage	7.72%	29.42%	11.49%	16.32%	17.74%	17.20%	0.12%

Source: Athi River Shalom Community Hospital

In 2018, the most common causes were pneumonia, asthma, and upper respiratory infections with 1777, 1393, and 3534 cases, respectively. Meo et al. (2013) noted that long-term exposure to cement dust over a long period leads to a decrease in pulmonary function, most commonly lung function impairments.

In 2019, there were 1377 cases of infections in the upper respiratory tract and 646 cases related to respiratory illnesses. Skin-related infections were as high as 592, with most cases (72) being reported in January when it is generally dry. This can be attributed to dry, windy weather conditions, which increase vulnerability to individuals residing in dust risk zones.

By 2020, the number of skin infections has risen to 2768 people. Cement dust also results in dermatitis, which causes itchiness and skin inflammation. Oguntoke et al. (2012) noted that infections of the skin are common among residents living near cement factories. Respiratory diseases such as coughing were also on the rise with 1384 cases in

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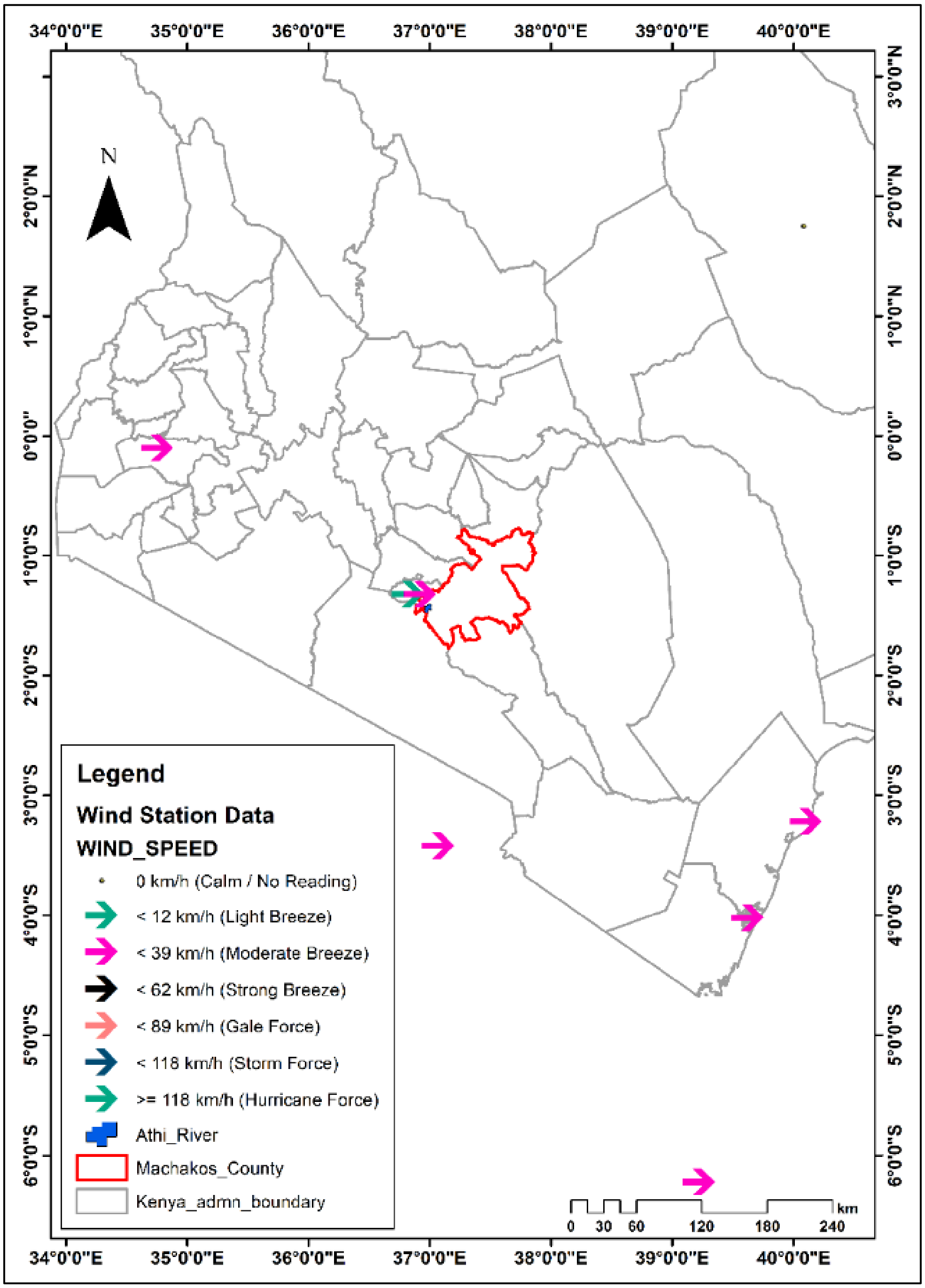
2020. Eye infections, pneumonia, and asthma were still high, which are all caused by inhaling cement dust.

Wind Direction

Based on the figure below (*Figure 5*), it is apparent that most structures towards the Eastern side are in the shadow side of the factories and will therefore be affected by the cement dust.

Figure 5: Average wind movement in Athi River



Source: https://www.windfinder.com

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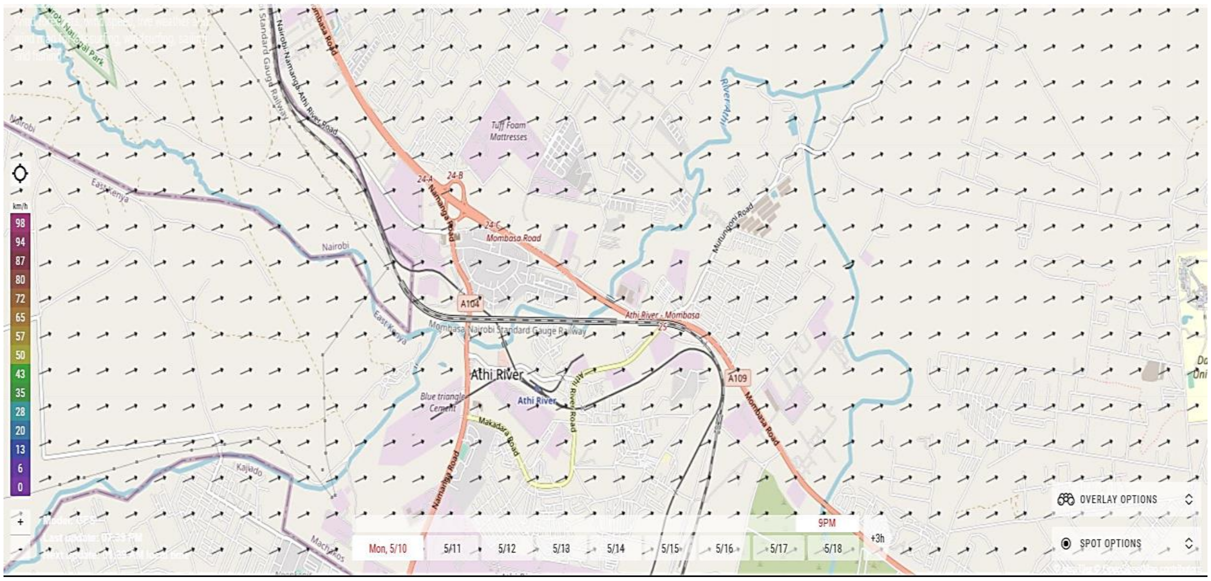
Figure 6 demonstrates wind speed and direction within the Machakos County and Athi River areas. This is based on Esri's current weather and wind station data layer.

Figure 6: Wind speed and direction of Athi River



Source: Esri Current Weather and Wind Station Data layer

Residential Homes and Proximity to Cement Factories Analysis

The table below helps show that most residential homes are found within a buffer of two kilometres to three kilometres. Based on the study done by Afolabi et al. (2012) in Ogun State, Nigeria, this is found to be a dust-prone zone, and based on his study, most people (86.63%) were found to have learned to cope or rather live under these conditions, while a few (3.49%) chose to move to new areas away from cement dust pollution. The rest decided to report to health officials, while others opted for protests against the cement company.

Figure 7 below shows a 3-kilometre buffer of residential homes away from cement factories. From the figure, it is evident that most interviewed respondents live within a buffer of 0.5 to 3 kilometres. Based on the literature reviewed in this paper, this has been identified as a high-risk (dust-prone area). This also indicates that most common dust-related illnesses reported by those interviewed in the field live within this buffer.

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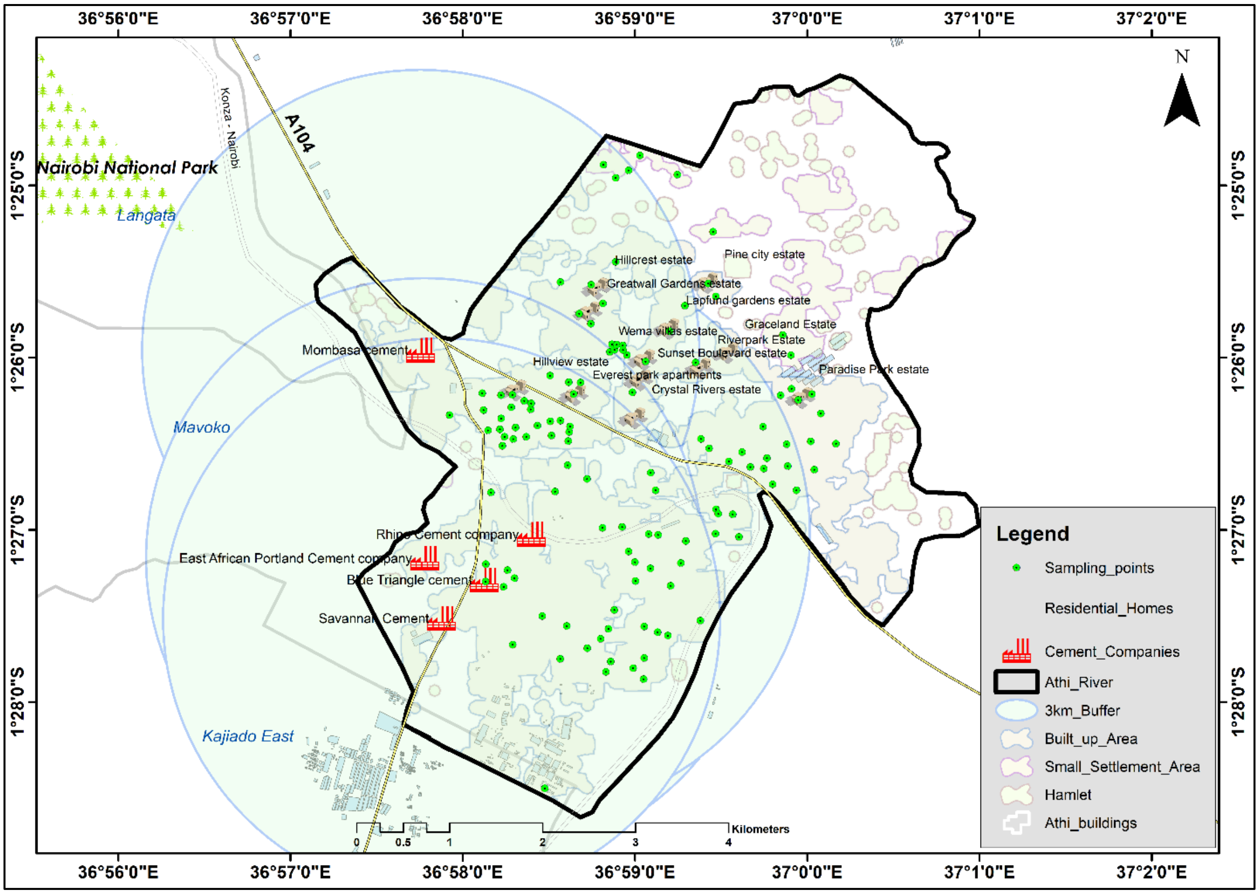
Figure 7: Sampled points within a 3 km buffer



This study, therefore, proposes that a 3.5 km buffer away from cement factories would be adequate to mitigate cement dust impacts on people's health and livestock and also to reduce impacts on irrigated crops and reduce harvested water contamination.

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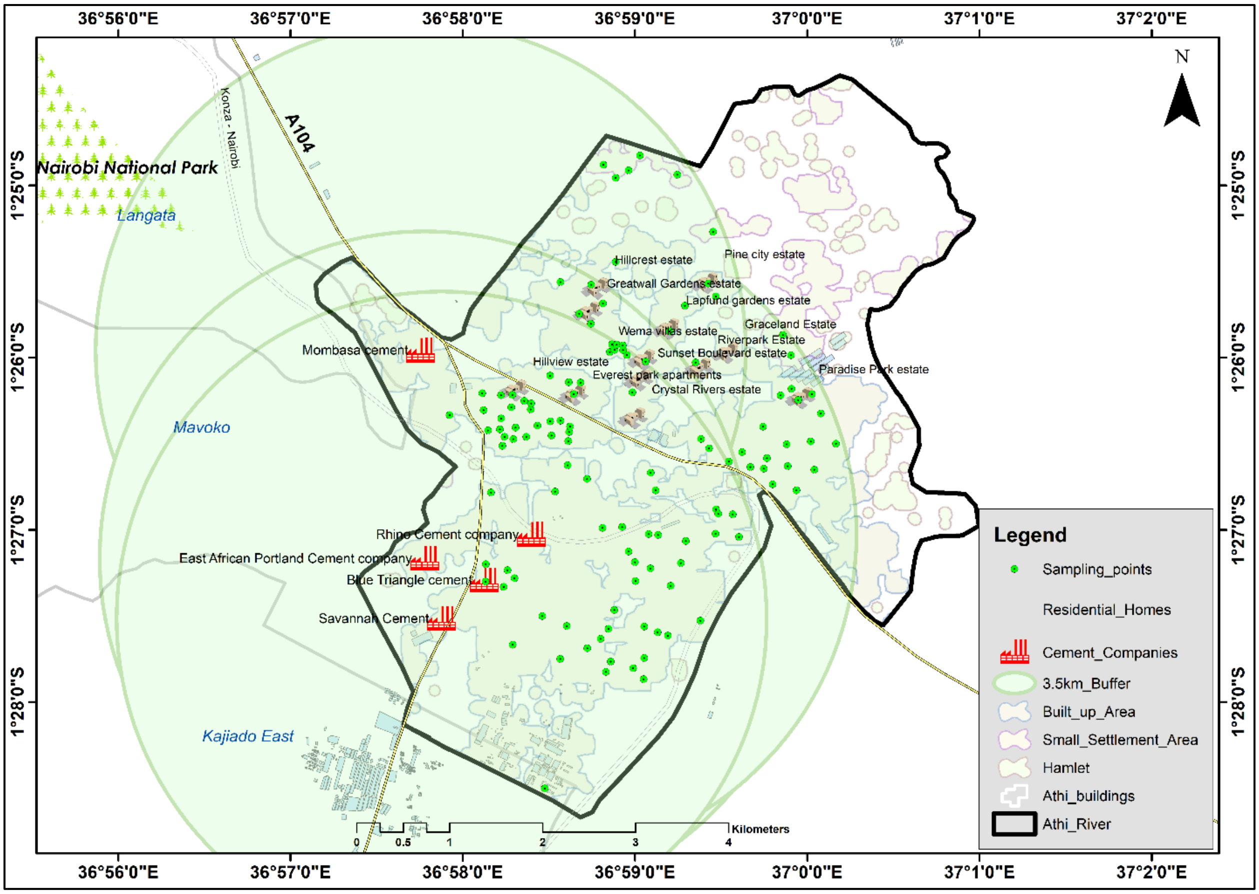
Figure 8: Proposed 3.5 km buffer



Diseases attributed to cement dust among sampled residents include; pneumoconiosis (35%), dermatitis (23%), eye irritations (19%) and coughing (14%). Table 2 shows the household numbers within 0.5 – 3.5 km.

Table 2: Athi River proximity analysis with respect to distance

Proximity Distance (km)	Housing units
0.5	> 5
1.0	> 25
1.5	> 80
2.0	> 329
2.5	> 469
3.0	> 482
3.5	> 498

Development Control Policy and the Responsibility of Factories on Health & Safety

The National Environment Management Authority (NEMA) has also established the Environment Management and Co-Ordination (Air Quality) Regulations, 2014, which aims to abate air pollution by establishing standards for air emission from various sources as defined in the Environmental Management and Coordination Act, 1999. Part II,

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para 7 of the Air quality regulations, 2014, states that no person shall cause the ambient air quality levels to be exceeded (*specified in the First Schedule)*. The First Schedule of this Act specifies the air quality tolerance limits for each pollutant in an industrial, controlled, and residential area (Air quality regulations, 2014).

Despite the release of cement dust into the atmosphere, cement factories try to implement various requirements as required in different regulations. For instance, Bamburi Cement has set up measures to monitor internal processes, especially in clinker production, to ensure that the materials used do not lead to very high levels of cement dust production (Mwagwi et al., 2016). This is a requirement of the Environmental Management and Co-Ordination (Air Quality) Regulations, 2009. In terms of Health and Safety, they have put in place several safety risks in case of incidences such as inhalation of dust and other gases, burns, falls, injuries, and noise. Workers are provided with Personal Protective Equipment to limit inhalation of dust (Hawkes, 2012).

The Occupational Safety and Health Act 2007 is another regulation used which aims at ensuring that practicable measures are taken to ensure that persons employed are protected from inhalation of any dust or fume in the workplace. This is as stipulated under part IV, para 89(1) of the Act (Republic of Kenya, 2007).

Paragraph 13(1) of the Factories and Other Places of Work Act (Cap. 514), Legal Notice No. 31 under Health and Safety emphasises the need for factories to carry out safety audits at least once every year and this is to be done by a registered health officer (RoK, 2004).

Vegetation Mapping

Vegetation mapping was done to assess the type of vegetation cover and whether existing vegetation would be enough to offer a barrier against cement dust. From *Figure 9* below, most vegetation covers consist of grass and shrubland. This implies that there is no barrier against the speed of wind and cement dust spread. There is a direct impact of cement dust on pasture land and irrigated crops in terms of growth rate and quality of pasture and crops. This impact would be minimal in cases where trees would have been present since trees act as a barrier against cement dust spread by reducing wind flow speed.

When cement dust comes into contact with soil, the potential of Hydrogen changes due to the presence of sodium, calcium, and potassium oxides (Rawat and Katiyar 2015). This negatively impacts soil as it minimises the absorption rate of minerals in the soil. Alkalinity also interferes with organic matter decomposition, thus influencing ion exchange in the soil.

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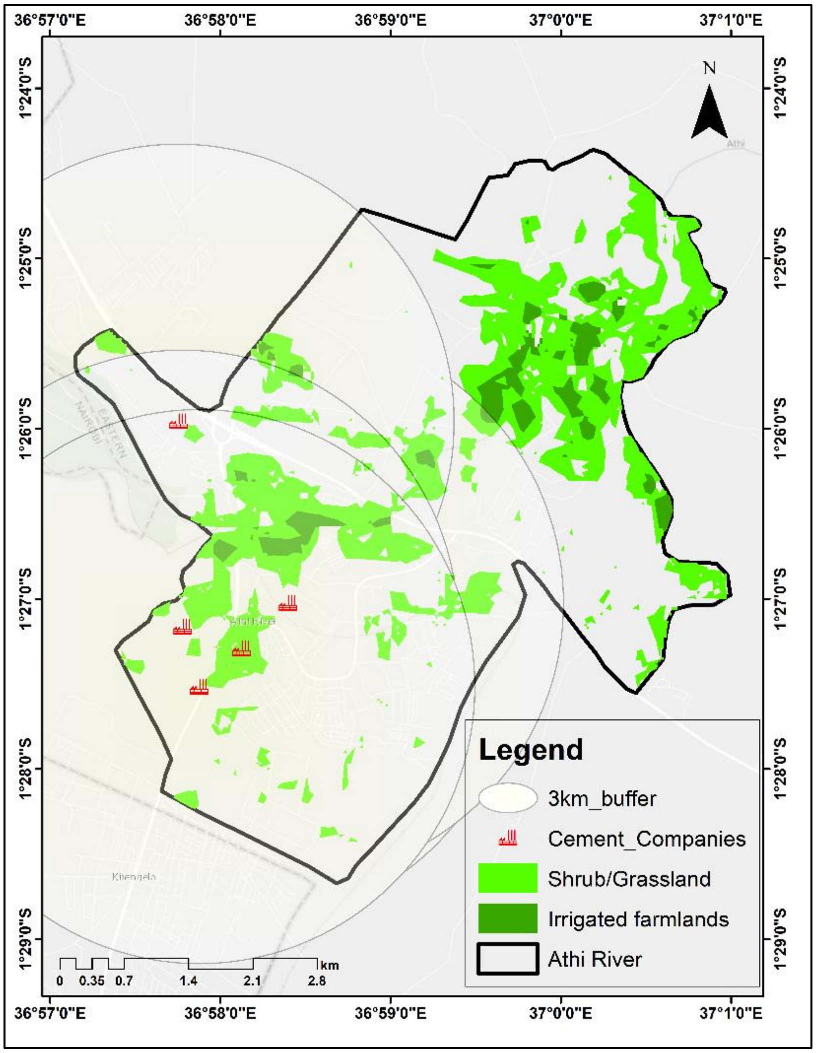
Figure 9: West-East wind movement towards irrigated croplands and grassland



The figure above illustrates the influence of wind on croplands. Land Use and Land Cover of 2020 were used to extract the area under crop cover and grassland. These croplands' experience is characterised by low quality and quantity of farm produce due to cement dust cover on plant leaves and soil. *Table 3* below shows the difference in the area for the four land cover types;

Table 3: Land Use and Land Cover_2020

2020						
Land Use and Land Cover (LULC)	**Dry Season**		**Wet Season**		**Percentage (%)**	
	Area (km^2)	**Hectares (Ha)**	**Area (km^2)**	**Hectares (Ha)**	**Dry Season**	**Wet Season**
Bare Land	2.62	262.0108	2.80	280.0524	8.37%	8.95%
Shrub/Grassland	1.06	106	1.23	123	3.39%	3.93%
Farmland	5.60	560	6.98	698	17.88%	22.30%
Built up Area	22.03	2203.3463	20.29	2029.4502	70.36%	64.83%
Total	31.31	3131.3571	31.31	3130.5026	100.00%	100.00%

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By analysing the change in the four land cover types, it was notable that there was an increase in the percentage of farmland (4.42%) and shrub/grassland area (0.54%) during the wet season. This difference could be due to rainwater washing away most of the dust cover from pasture and croplands, thus making it more visible by satellites. There was also a 0.6% increase in bare land area. The reason for this could be that most of the areas that were pasture or cropland were detected as bare land mostly due to the impact of the dust cover on leaf surfaces, thus interfering with the spectral signature.

Plate 1: Leaf necrosis in Kales – affected vs non-affected

Plate 2: A close-up view of grass covered with dust – Athi River

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DISCUSSION

Health

There is a common relationship between respiratory diseases reported and health data information from the nearby hospital. Pneumoconiosis is a common respiratory illness resulting from workplace exposure through inhalation of dust. Dermatitis is another common disease which results in irritation of the skin when it comes into contact with an unwanted substance. Eye and skin infections are common disease characteristics among residents living near cement factories. When concrete comes into contact with the eyes, it causes irritation and redness. Similarly, when concrete reacts with moisture from the skin, mostly sweat, it hardens and if left untreated, results into swelling, formation of blisters and bleeding.

Settlement

Based on the literature review and analysis done in this paper, it is evident that residential homes should be located at least 3.5 km away from cement factories. The 120 respondents were mostly found to be located within the high-risk area (0.5 – 3 km). This means that most of the health complications that they suffered from could be attributed to cement dust. This would also help reduce the impacts of the dust cover on pasture land and irrigated croplands. Future land acquisition needs to be considerate of the wind direction and location of these cement factories. This will help ensure development control is done in an orderly manner, and that future development patterns address this issue.

Vegetation

Vegetation is sparsely distributed, mainly composed of grassland and a few acacia trees, for example, Acacia xanthophores. Based on Machakos CIDP, the major land-use type is Agriculture, with 75% of the land being under cultivation. Farm produce is largely relied upon as the predominant food source for the household. From observation, it is easy to notice dust presence on major food crops such as kales. This raises concern over its impact on the kind of impacts on human health. Emissions from cement factories also lead to declined crop productivity and also biodiversity loss (Devi, 2018). Cement dust deposition on leaf surfaces over a long time leads to the formation of a hard crust on leaf surfaces. When water combines with this hard crust, a gelatinous calcium silicate hydrate is formed. It later on crystallises and solidifies forming a hard crust that inhibits light absorption and gaseous exchange since the stomata are blocked (Rawat and Katiyar, 2015).

Wind

The west-east movement of wind allows for cement dust to spread towards residential homes since most cement companies are on the western side. Based on the Beaufort wind force scale, wind speeds of 39 km/hr are capable of influencing swaying in small trees. This, therefore, means that such wind strength is capable of carrying lots of cement dust particles towards pastures and croplands and also affects people in their residential homes. Rauf et al. (2021) assessed community health impacts due to the existence of total suspended particulates near a Cement Plant in Maros Regency in Indonesia. He noted that the total suspended particles in the air are higher when the wind blows to the southeastern side compared to other directions. Stronger wind speed results in further dispersal of pollutants.

CONCLUSION

Health

Results of this study show that there are serious impacts of cement dust on the community living in the dust risk zone. Dust risk zones are a distance of between 0 – 3 kilometres away from cement factories. Settlements in dust risk zones are greatly affected by cement dust spread as a result of the wind flow pattern of the area. Most residents living within the dust risk zones suffered respiratory problems that could be directly linked to cement dust. This is due to the nature of the disease affecting them and their proximity to the cement factories. Health facilities could also take note of patients' location data in order to assess whether there is a correlation in terms of the direction of settlement and exposure to cement dust. Data on the occupation of patients should also be captured as this will help establish whether the majority of the patients work in cement factories or within the area.

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Wind

The west-east movement of wind means that more cement dust is dispersed from the western side, where Mombasa cement is situated to the eastern side, where most settlements are located. There is therefore an urgent need for proper building regulations to be implemented in the area to ensure that there is proper zoning of cement factories away from settlement areas. There should also be an improvement in the establishment of weather stations to be able to capture adequate data on wind patterns within such areas vulnerable to cement dust. This data will be crucial to come up with adequate recommendations against cement dust impacts.

Settlement

Based on the reviewed literature and result findings, it is apparent that certain mitigation measures and efforts by the community, cement factories, and government need to be made effective. This is in terms of ensuring that residential homes are built at a suitable distance away from cement factories. Cement factories also need to ensure certain mitigation measures are taken into consideration such as proper monitoring systems to regularly check on emissions. People living in dust risk zones also need to ensure that they take necessary measures to protect themselves from inhalation of cement dust by wearing personal protective equipment whenever approaching cement factories. Proper zoning will ensure that residents including pastoralists and farmers can live sustainably.

Vegetation

The west-east movement of wind has resulted in health deterioration in the nearby community as most cases reported at the nearby community hospital indicate that there are a lot of complaints of eye and skin irritations, asthma, pneumonia, and other issues of the respiratory system

Farmers are also greatly affected as cement dust has serious impacts on crops. Leaves of crops suffer from necrosis, stunted growth, and poor development of the root system due to poor soil structure and the hard crust formed on leaf surfaces inhibiting photosynthesis.

Recommendations

Human Health

Use respirators such as the N-, P- or R-95 to avoid inhalation of cement dust, especially when one is approaching cement factories. Cement factory personnel also need sufficient training on safe working practices and the need to use protective clothing, respirators, and goggles at work. There is also a need to build awareness of the various respiratory illness that arises from dust inhalation.

People working in cement factories should always put on waterproof knee pads which help prevent contact with wet concrete that would result in skin burns and irritation. Wetting down work areas also helps eliminate the spread of cement dust.

The Extent of Human Settlement

There is a need for proper zoning of residential and industrial areas as this will help ensure that cement companies are located at a safe distance away from residential zones. This study proposes a distance of not less than three and a half kilometres. This would be sufficient enough to reduce the impacts of dust spread towards settlement and farmland areas. This will help reduce cement dust’s impacts on people’s health as well as prevent further spread to the physical environment.

Vegetation

Trees can be used as windbreaks or shelterbelts since they provide a protective zone, therefore, reducing the distance travelled by cement dust. One should consider growing trees that are resistant to drought, are fast-growing, and also have a good crown formation. Bitog & Lee (2013) noted that trees reduce wind velocity by 22 to 93%.

Agroforestry could be adopted by farmers with trees acting as barriers against cement dust. Farmers should also harvest rainwater to be used for irrigation rather than an over-dependence on the river water which has been contaminated by cement dust.

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Cement Factories

Cement factories also need to establish a proper monitoring system that will help monitor the spread of cement dust towards residential homes. This will help achieve environmental sustainability as well as the reduction of greenhouse gases.

The principle of the circular economy could also be adopted in our cement industries which results in the utilisation of cement by-products and secondary aggregates in the cement kilns. Buildings can also be re-used long after their original design has expired. Building elements can also be re-used in a new project. Co-processing is another effective method in which alternative fuels obtained from either cement waste materials, municipal waste, or industrial by-products contribute to a circular economy by preventing emissions that would arise from new raw materials being processed.

Puthussery et al. (2017) researched the interrelation between industrial symbiosis and circular economy in the Aalborg Cement industry. He noted that materials could be recycled through re-introduction into the system as alternative fuels. Wastewater can be used in the cooling process, while excess heat can be re-used in other cement production processes.

Industrial symbiosis is another method that could be adopted by various cement companies, which enables the exchange of waste, by-products, energy, and water. According to Wen & Meng (2015), this process reduces demand for virgin resources, therefore, creating a conducive environment where waste from industry is a resource for another cement industry.

Fogging method is also another alternative method used that captures cement dust, thus limiting its spread. A spray nozzle and high-pressure pump are used here and the tool is made in a way that allows it to trap smooth dust particles. There is a huge deviation between cement dust before and after fogging. Purwanta et al. (2018) noted that a lot of cement dust is captured through fogging at a higher velocity, as 16,592 micrograms of dust were captured at a velocity of 350 ml per minute. The major advantage of using this method is its ability to capture very fine cement dust particles.

Shen et al. (2017) noted that the use of alternative cement would help reduce carbon emissions, as they would be mostly composed of green materials. This together with recycling efforts will also help reduce waste, pollutants, and energy consumption. This can go hand in hand with the concept of green manufacturing, which aims at minimising waste and pollution through the integration of issues related to process and product design (Maruthi and Rashmi, 2015). In the context of circularity, silica fume and brick dust can also be used separately, especially in the mortar as this will help to reduce environmental pollution (Belgin, 2019a). Its amorphous structure and fine grains make it a requirement for much more water to be used in the production of high-quality concrete. Cement factories can therefore channel more wastewater into being used in this production process (Belgin, 2019b)

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