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Phone : + 91 712 - 2249748; Fax : + 91 712 - 2249900; E. mail : jese@neeri.res.in
Website : www.neeri.res.in / neerijese.org

Printed & Published by : Dr. Rakesh Kumar, Director, CSIR-NEERI on behalf of CSIR-National Environmental Engineering Research Institute, Nehru Marg, Nagpur – 440 020 (India)
Registered with Registration of Newspapers of India (Reg. No. 6465/59)
Printed at : Mudrashilpa Offset Printers, Bajaj Nagar, Nagpur.

Journal of Environmental Science & Engineering

(http://www.neeri.res.in) ISSN 0367-827 X

Volume 61 No. 3 July 2019

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This issue is published in July 2022

J. Environ. Science & Engg. Vol. 61, No. 3, p. 736- 746, July 2019

Source Apportionment of Coarse and Fine Particulate Matter using Principal Component Analysis in an Urban Environment

JITHIN JOSE[1], B. SRIMURUGANANDAM[1] D AND S.M. SHIVA NAGENDRA[2]

Airborne particulate matter (PM) is a well-known cause of severe acute and chronic health effects. Identifying the sources of PM is thus paramount in controlling and mitigating it. Principal component analysis (PCA) is an eigenvector based statistical dimension reduction method and together with Multiple Linear Regression Analysis (MLRA), it is commonly used in source apportionment of coarse and fine PM. In this study, the PCA-MLRA method is used to quantify the sources of PM at Chennai, a metropolis in Southern India. PM_{10} and $PM_{2.5}$ samples are collected at a point along Sardar Patel road in Chennai city using an Envirotech APM-550 particulate sampler and analysed for 29 elements and ten ions. PCA–MLRA with Varimax and Direct Oblimin rotations are performed. PCA–MLRA with Direct Oblimin brought forth vehicular emissions (38%, 7%), biomass combustion (4%, 1%), marine aerosol (7%, 59%), secondary aerosol (35%, 28%) and the other emissions (16%, 5%) for PM_{10} and $PM_{2.5}$, respectively. While VARIMAX yields vehicular emission (38%, 24%), biomass combustion (18%, 14%), marine aerosol (5%, 17%), secondary aerosol (27%, 42%) and other emissions (12%. 3%). It is conclusive that PCA–MLRA with VARIMAX rotation is a superior choice for source apportionment of PM.

Keywords: *Urban Air Pollution, Airborne Particulate Matter, PM_{10} and $PM_{2.5}$, Source Apportionment, Receptor Model, Principal Component Analysis.*

Introduction

Deteriorating air quality is a predicament that many cities in the developing world must deal in a regular basis (WHO, 2016). Of all the different 'criteria pollutants' as described by the U.S.EPA, the most toxic one is Particulate Matter (PM) (Pope and Dockery, 2006). PM is basically a concoction of different solid and liquid particles with aerodynamic diameter less than 100ìm that are held as a suspension in the atmosphere (Ellison and Waller, 1978). The composition and concentration of PM varies considerably with location and time. This varying heterogeneity makes control of PM a formidable challenge. Unlike other air pollutants, PM has myriad and varied sources (Watson et al., 1994). Therefore, for the effective PM management, it is necessary to identify its source origin (Heal et al., 2012).

The process of identifying PM emission sources is commonly referred to as source apportionment of PM (Viana et al., 2008). Source apportionment has evolved significantly since its inception (Gordon, 1980). Different methods of identifying the sources of PM are grouped into three; emission inventories, source dispersion models and receptor models (Belis et al., 2013). Emission inventories are the earliest form of source apportionment method (Cass and McRae, 1983). Lagrangian, Gaussian and Eulerian models are together called dispersion models or source-oriented models (Holmes and Morawska, 2006). Though they are usually classified together, there are fundamental differences in how they work (Belis et al., 2014). These models calculate the expected pollutant contribution of a source at any receptor by using emissions measured at the source (Doraiswamy et al., 2007). Receptor models are of recent and most used method of source apportionment of PM (Banerjee et al., 2015). In recent past improvements in pre–packaged software and general availability of high-performance computing has increased the use of receptor models. Receptor modelling is a method of source apportionment where the source contribution at a receptor is calculated using the various physical and chemical parameters measured at the receptor itself (Belis et al., 2013).

There are two types of receptor models: chemical mass balance (CMB) and multivariate (MV) models. Although the methods employed by them are functionally different, no receptor model is truly one or the other. Most receptor models fall in a spectrum between the two (Callén et al., 2009). Principal Component Analysis (PCA) is an eigenvector-based receptor model used commonly in source apportionment of environmental matrices. It is a statistical operation that uses orthogonal rotation to reduce several variables into a set of principal components for easy analysis of large data (Karl Pearson, 1901). PCA is a receptor modelling technique which requires a minimum amount of input data with respect to source emission inventories (Cesari et al., 2016). It provides acceptable qualitative information on the source profile at the receptor and its impacts. The theoretical aspects of PCA are relatively

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J. Environ. Science & Engg. Vol. 61, No. 3, p. 747-752, July 2019

Silicosis Among Stone Carvers in Rajasthan-An Urgent Need for Control of Silicosis in India

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Crystalline free silica is released during the stone carving process and the workers get exposed to high level of free silica dust making them prone to silicosis. The study was undertaken to assess the prevalence of silicosis among stone carvers. Medical examination reports including chest radiographs of 135 symptomatic stone carvers from Dausa district, Rajasthan were sent by an NGO for detection of silicosis. Chest x-rays of 88 workers were of good quality and were further evaluated for presence of silicosis opacities during July-August 2014. The chest x-rays were classified into various categories of silicosis in accordance with ILO Classification for Pneumoconiosis, 2000. The occurrence of silicosis was studied in relation to duration of work in stone carving. Out of 88 chest radiographs evaluated, 53 (60.2%) showed radiological evidence of silicosis of which 4 (4.5%) subjects showed large opacities suggestive of progressive massive fibrosis. The prevalence of silicosis increases with increasing duration of work as magnitude of silicosis increased from 41.6% to 60.3% to 72.2% for the duration of ≤10 yrs., 11-20 yrs. and >21 yrs. Respectively and statistically significant (p=<0,001). 10 (11.4%) subjects with silicosis also had associated pulmonary tuberculosis, termed as silico-tuberculosis while 12(13.6%) had an evidence of pulmonary tuberculosis. The present study showed a high prevalence of silicosis, tuberculosis and silico-tuberculosis among stone carvers. This may be just a tip of ice berg as a huge number of workers get occupationally exposed to silica dust without any intervention. Hence, a suitable nation-wide silicosis control programme is urgently needed.

Keywords: *Silicosis, Stone carvers, Silico-tuberculosis, serum CC-16, Early detection.*

Introduction

India has an estimated 46.5 crore labour force of which > 90% are working with different kinds of informal economy or unorganized sectors[1]. Dust related respiratory disease appears to be one of the most prevalent occupational diseases in India, which is neglected to a greater extent and needs immediate attention to improve the occupational health scenario of the country. Disease burden due to silicosis is considerably high contributing significantly to morbidity and mortality.

Stone-carving tradition of India is one of the oldest and richest in the world. Rajasthan is enriched with deposits of rocks like granites, marbles, sandstone, quartzite, slates, and other metamorphic rocks. The fine quality of marble and sandstone extracted from the numerous quarries in the state had given rise to a tradition of stonemasons and sculptors[2].

Dausa district of Rajasthan, is on Jaipur - Agra route and is one of the important hub of stone carvers. Lattice-work, pots, idols of gods, animal figures, lamps, pillars, temple models, fountain and furniture are common stone carved items[3]. Silica varies from 25 to 90% depending on nature of stone[4]. The carvers sculpting various decorative items gets exposed to high amount of silica dust during chiseling, grinding and polishing of the items making them vulnerable to silicosis. Silicosis is an occupational lung disease caused by inhalation of crystalline silica dust and is marked by inflammation with scarring in the form of nodular lesions on the lungs[5]. It is usually misdiagnosed as pulmonary tuberculosis and the persons suffering from silicosis are treated for tuberculosis due to lack of knowledge of local medical practitioners[6]. Silicosis is not a curable but preventable disease. Due to general lack of knowledge and awareness about occupational diseases among the workers, the workers continuously get exposed to silica dust and gradually land up into advanced stages of disease which are irreversible even after stoppage of exposure. A large number of workers are involved in this work and damages their lungs while working and ultimately die prematurely. Many studies have been conducted among stone quarry workers depicting the prevalence of silicosis between 12 to 50% but very limited information is available about stone carvers. The present study was carried out to assess the problem of silicosis and its co-morbidity, silico-tuberculosis among stone carvers in Rajasthan. The study further emphasis to establish national silicosis control programme on urgent basis similar to national tuberculosis

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J. Environ. Science & Engg. Vol. 61, No. 3, p. 753 - 760, July 2019

Solute Transport Modeling to Determine Effects of Pollution in Nag River on Groundwater Quality in Nagpur Urban area using Modflow

UDAY KUMAR DEVALLA* AND YASHWANT BHASKAR KATPATAL

People are majorly depending on surface water resources in Nagpur city, it is required that the groundwater resource must be kept in a safe condition. In the present study, advective contaminate transport modelling of groundwater has been done by taking the Nag River as a pollution source. A two km buffer area around the Nag river is considered for the study. Steady state and transient state groundwater flow models are developed. The transient state model is developed for the period 2014-2018. This model is developed using Visual MODFLOW software. All the supporting files for the MODFLOW software are developed using ArcGIS software. The aquifer model is developed in ROCKWORKS software. Weathered Basalt and Archeans are the major aquifers. The calibrated model is used to track the particles in the Nag river. The year 2014 is taken as initial condition and particles are tracked till 2028 i.e for 15 years. The model results have shown that 1 5ØXÜ5ØZÜ^2 area of New Ramdaspeth and Dhantoli, and approximately and area with in 100m on both sides of the Nag river is affected by polluted water of the Nag river. The particles have travelled through all the four layers of the aquifer system and hence the study concludes that the Nag river is contributing to the pollution in some areas while certain areas in proximity are under the risk of groundwater pollution.

Keywords : *Nag river pollution, Groundwater flow model, Advective solute transport model, Particle tracking.*

1 Introduction

According to Charles Darwin; 'Life originated in the water'. Water is necessary for living things. The abundant quantity of water is available in the oceans, but because of its salinity, human beings cannot use. Hence, the quality of water is very important. Groundwater is the only source available at many places. The quality of groundwater depends on mineral composition of the aquifer and human activities in that area. So, managing its quality has been an important issue because once the aquifer gets polluted, it takes years for natural purification. India is in developing stage and in developing nation, gathering funds for holistic development is a difficult issue. Supplying good quality of water to society is mandatory. This study is related to the groundwater quality in the vicinity of the Nag River in Nagpur city.

MODFLOW was developed by United States geological survey. It is a popular model to solve the groundwater flow equation. It has been using extensively for groundwater modelling. MODFLOW with MODPATH and MT3D packages can be used for particle tracking and fate transport model (Jay et al. 2005). Flow model for semi-arid hard rock aquifer was developed by Varalakshmi et al. (2014). Groundwater level fluctuations were studied for the Osmansagar and Himayathsagar catchments. Lomsoge et al. (2014) suggested a groundwater management plan for the WR-2 watershed in Amaravati district, Maharashtra by using MODFLOW software. Andersen et al. (2014) revised the groundwater flow and transport model after 20 years of its establishment. Nitrate fate and transport model for agricultural watersheds of Blaine aquifer Washington was developed by Almasari and Kaluarachchi (2007). Chitrakar and Sana (2015) developed an unsteady state model and it was used to study seawater intrusion for Eastern Al Batinah Coastal plain, Oman. A numerical groundwater model was developed by Gaaloul N (2014) to study the impact of over exploitation of groundwater on the groundwater quality in El Hicha aquifer, Tunisia. A numerical three dimensional model was developed by He et al. (2009) to determine the area affected by oil pipeline leakage. Their study concluded that the oil plumes were travelling to a depth of 369 m from the leakage point after 20 years. Spatial distribution and concentration of a solute in groundwater can be estimated by developing mass transport models for the aquifers. So the groundwater quality with respect to various quality parameters at different time steps can be predicted using the mass transport models. Attempts of modeling were made by Hudak and Loaiciga (1991), Ghoraba et al. (2013) and Saba et al. (2016). Impact of landfill leachate on the groundwater quality by taking the dumping site as a point source was studied by El-Salam and Abu-Zuidc(2016) and Han et al.(2014). In the present study visual MODFLOW added with MODPATH package is used for particle tracking. Rivers are

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J. Environ. Science & Engg. Vol. 61, No. 3, p. 761-767, July 2019

Chemical Analysis and Source Apportionment of Fine Particulate Matter Surrounding Port in a South Indian Coastal City

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People are majorly depending on surface water resources in Nagpur city, it is required that the groundwater resource must be kept in a safe condition. In the present study, advective contaminate transport modelling of groundwater has been done by taking the Nag River as a pollution source. A two km buffer area around the Nag river is considered for the study. Steady state and transient state groundwater flow models are developed. The transient state model is developed for the period 2014-2018. This model is developed using Visual MODFLOW software. All the supporting files for the MODFLOW software are developed using ArcGIS software. The aquifer model is developed in ROCKWORKS software. Weathered Basalt and Archeans are the major aquifers. The calibrated model is used to track the particles in the Nag river. The year 2014 is taken as initial condition and particles are tracked till 2028 i.e for 15 years. The model results have shown that 1 5ØXÜ5ØZÜ^2 area of New Ramdaspeth and Dhantoli, and approximately and area with in 100m on both sides of the Nag river is affected by polluted water of the Nag river. The particles have travelled through all the four layers of the aquifer system and hence the study concludes that the Nag river is contributing to the pollution in some areas while certain areas in proximity are under the risk of groundwater pollution.

Keywords : *Nag river pollution, Groundwater flow model, Advective solute transport model, Particle tracking.*

Introduction

Coastal cities are the major centers for international trade contributing to the socio-economic development of a nation. Ports and shipping industry has a significant role in sustaining the growth of country's trade and commerce. However, in recent days, Ports and harbor activities in coastal cities have been reported to deteriorate air quality in the surrounding environment and have adverse effect on health and environment. Majority of Ports are in the proximity of urban area for ease in transport of goods, thus leading to deterioration of local and regional air quality (Li et al., 2002). Air pollution at port and harbor region has unique characteristics, as continuously varying metrological factors accompanied with emission from land based harbor activities and ships influences air quality(Lu et al., 2006). A typical port operation includes movement of ships, locomotives, heavy duty vehicles, handling cargo containers, land transport, and construction activities. These operations are commonly identified as the major source of air pollution within the ports (Pey et al., 2013; Cesari et al., 2014). The key pollutants emitted during harbor activities are particulate matter, and oxides of nitrogen and sulfur.

Globally, marine vessels emit about 1.2 to 1.6 MT of particulate matter (PM), 5 to 6.9 MT of NO_x and 4.7 to 6.5 MT of SO_x (Song and Son 2014; Liu et al., 2014). The PM emission from ships is generally dominated by ultrafine particle and respirable particle sizes which are proved to affect the human health. Ship emission do not contribute significantly to PM_{10} concentration (upto 5%) near the port area (Saxe and Larsen, 2004). However, it can contribute to about 14% and 20% of total $PM_{2.5}$ and PM_{10} concentration in coastal air (Mazzei et al., 2008; Pandolfi et al., 2011). Epidemiological studies had shown the association of PM in coastal cities with cardiovascular diseases, respiratory symptoms and mortality (Davidson, Phalen, & Solomon, 2005; Dominici et al., 2007; Liu, Yan, Birch, & Zhu, 2014). Fuel oil combustion are major contributor of V, Ni, SO_4^-, and organic carbon (OC) (Agrawal et al., 2009; Pey et al., 2013). Some other important sources of PM emissions include the road dust emissions by vehicular movement, emissions from construction activities and loading-unloading of bulk materials in uncovered areas (Alastuey et al. 2007; Cesari et al., 2014). The re-suspended dust may contain all the crustal elements and contributions from tire and brake wear elements such as Al, Ca, Fe, Mg, Ti, Mn, Cu, Zn, Sb, Sn and

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J. Environ. Science & Engg. Vol. 61, No. 3, p. 768-774, July 2019

Assessment of Inhalable Toxic Particulates on the Health of Children in a Tropical Urban Environment

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The short- term exposure to particulate matter (PM) can be harmful to the highly susceptible population, especially children. The personal exposure to $PM_{2.5}$ at urban air pollution hotspots (municipal solid waste dumpsite and school near a busy roadway) in Chennai was studied in the present study. The ambient air quality monitoring and elemental analysis of collected PM samples were carried out at both study sites. The elemental analysis of $PM_{2.5}$ showed that atmosphere in the dumpsite was loaded with heavy metals (Arsenic, cadmium, chromium, copper, lead, nickel, selenium and zinc). The higher concentration of Ca in indoor PM samples of school showed that chalk dust was one of the significant contributors to suspended particulate matter (SPM) in the indoor environment of the school. The probable cancer risks by the inhalation of toxic heavy metals revealed the adverse health implications among children in both the study areas. The inhalation cancer risks of Cr in both indoor SPM (3.78 $x10^{-6}$) and dumpsite PM emissions ($1.04x10^{-5}$) was found to be exceeding the safe limits ($1x10^{-6}$). The present study highlighted that children's exposure to school indoor and dumpsite emissions could cause cancer risks in the long run.

Keywords : *Personal exposure, $PM_{2.5}$, toxic heavy metals, school, dumpsite*

1 Introduction

The fine airborne particles ($PM_{2.5}$) exhibit both spatial and temporal variability which results in the creation of local air pollution hotspots, where the PM concentrations are higher than the other locations of urban areas. $PM_{2.5}$ are well-known risk factors for health effects among vulnerable groups -children, women, and the elderly. It is reported that air pollution is projected to have contributed to 6.67 million deaths in 2019 (HEI, 2020). The population growth, urbanization, and environmental pollution resulted in climate changes which stressed the urban people, especially in a tropical country like India (Revi et al., 2014). Past epidemiological studies have revealed that acute and chronic exposure to $PM_{2.5}$ increases the risk of respiratory and cardiovascular diseases (Dockery, 2009; Guttikunda and Goel,2013).

The assessment of personal exposure to $PM_{2.5}$ mainly depends on ambient exposure, i.e. the pollutant concentration to which people are exposed. Ambient exposure is regularly assessed through pollutant concentrations measured by monitoring stations. The complexity of personal exposure to air pollution is somewhat due to its spatial variations across different locations in a city or urban area. The spatial variation of air pollution depends on the sources that contribute to toxic pollutants and meteorological conditions. There are different sources such as industrial sectors, residential sites, traffic and non-traffic exhausts, and dumpsites that contribute to harmful air pollutants at ground level. The public near these urban air pollution hotspots is often exposed to a higher level of toxic air pollutants. Dumpsites are open lands where municipal solid waste (MSW) is being discarded haphazardly without any precautions. Open dumping and burning of MSW is a common way of disposal. The mismanaged open dumpsites can be considered as one of urban air pollution hotspots as their potential to pollute the ambient air. The heterogeneous activities at MSW dumpsite, such as the movement of heavyweight trucks, unloading, and compaction of wastes, open waste burning emit a large quantity of PM, varying quantities of heavy metals into the atmosphere (Lemieux et al., 2004). The previous studies implied a strong association between exposure to landfill emissions and adverse health effects. The vulnerable population especially women, children living near landfill sites were observed to have a higher risk of health effects ranging from low birth weight, congenital disabilities and some cancers (Johnson, 1997, Klemans et al., 1995, Goldberg, et al.,1995).

The indoor air quality (IAQ) of school buildings are controlled mainly by indoor and outdoor emission sources, climatic conditions, ventilation rate, classroom infrastructures and human activities. The naturally ventilated schools near a busy urban roadway can be impacted by higher PM levels emitted from both exhaust and non-exhaust emissions. The poor IAQ may cause health problems for students and consequently, affect their performance and reduce attendance. Some studies highlighted children's poor performance and absenteeism due to their exposure to low air quality in schools (Shendell et al., 2004; Simons et al., 2010). Most of the scientific studies on the impacts of indoor air pollution on health were conducted in European and North American countries.

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J. Environ. Science & Engg. Vol. 61, No. 3, p. 775-779, July 2019

Assessment of Air Pollution Externalities: Case Study of NagpurCity

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Health risk issues associated with air pollution in India have been rising as a matter of concern for the country. Despite several mitigation measures and policies, achieving the pollutant concentration within safety limit has turned out be strenuous. The current study focuses on analyzing and monetising the health risk associated with air pollution based on secondary data for the period 2011 to 2018 for Nagpur city. Damage due to air pollutants like PM10, SO_2 and NO_2 has been considered with an assumption that effect of individual pollutants on human health is additive for evaluating the damage due to health cost. The attributable number of cases for total mortality, chronic obstructive pulmonary disorder (COPD- morbidity), cardiovascular morbidity (CD) and respiratory disease morbidity (RD) are studied based on breached pollutant concentration, relative risk, and incidence baseline cases. The total monetary damage cost from the year 2011-2018 was estimated to be about 17,427 million INR. A reduction in health damage cost by 64% was observed for the year 2018 as compared to 2011. The reduction in damage due to SO_2 and NO_2 reduction trends. The major pollution is due to local anthropogenic emissions, though a reduction in health damage was observed over the years, the mortality/morbidity damage cost is still high.

Keywords : *Air quality, Health risk assessment, Monetary damage, Mortality/Morbidity, Air Pollution Externalities*

1 Introduction

Business activities in most of the sectors result in harmful emission of particulates and gases pollutants into air leading to air pollution. Pollutants are either emitted directly (primary pollutants) or are formed in atmosphere due to reaction of two or more pollutants (secondary pollutants). Most of the primary and secondary air pollutants create negative impact on human health, visibility, agriculture, tourism etc (Nair et al. 2020; Bherwani et al. 2019)

Emission of primary pollutants and formation of secondary pollutants results in poor air quality ultimately leading to some adverse impacts on human and environment including but not limited to health effects on human due to emission of pollutants leading to respiratory diseases such as bronchitis, asthma, allergy, lung disorder, pulmonary diseases, lung cancer etc; visibility issues as the navigation during the time of transportation is largely affected due to the formation of smog, PM and O_3 are the major contributors to reduced visibility; impacts on flora as reduced air quality within the atmosphere can retard the growth of trees affecting metabolism at the cellular level, also acid rain can also damage trees and acidifies soil reducing the yield and wear and tear of materials due to acidic components formed due to the reaction of pollutants in the atmosphere result in acid rain that has a tendency to corrode the building materials, also PM has discoloring properties reducing aesthetic beauty and quality (Kim et al. 2015; Ghorani-Azam et al. 2016; Maji et al. 2017; Koul et. al., 2019).

Given so many impacts, there is a need to understand the level of impact these pollutants generate and monetizing these impacts/damages is one of the ways by which the scale of impact can be communicated. In order to quantify the impacts in monetary terms, it is essential to understand the mechanism by which the impact happens. The impact pathway reveals, how emitted pollutants lead to different adverse outcomes on human wellbeing and other natural environment. The drivers, outcomes and impacts approach can be used to quantify the impacts (Bherwani et. al. 2020a&b). In case of air pollution, the emission of pollutants is the driver leading to reduced air quality, which is an outcome and finally it generates an impact on health and wellbeing along with others as stated above (Ghorani-Azam et al. 2016). Pollutant such as PM_{10}, NOx, SOx results in various health damages such as respiratory diseases, chronic obstructive pulmonary diseases (COPD), cardiovascular diseases and mortality (Tupin et al., 2016). These pollutants were considered to calculate corresponding health damage cost.

The current paper concentrates on the health impacts associated with air pollution and monetizes the impacts to understand the magnitude of the impact. Very few studies related to monetization of air pollution impacts are carried out in Indian cities which forms the novelty of the paper. Further,

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