DHARAMPETH M. P. DEO MEMORIAL SCIENCE COLLEGE, NAGPUR

3.3.2 Number of papers published per teacher in the Journals notified on UGC website

LIST OF RESEARCH PAPERS PUBLISHED

Sr. No.	Title of paper	Name of the author/s	Department of the teacher	Name of journal	Year of publication	ISSN number
1.	Ethnobotanical Survey on Trees of Seminary Hills, Nagpur (MS): An Approach towards Plant Conservation	Nikhat Naqvi, Sarika Gurav, **Pitambar Humane**	BOTANY	Current World Environment	2022-2023	0973-4929(p), 2320-8031 (e)
2.	Ethnobotanically Important Herbaceous Flora of Seminary Hills, Nagpur	Nikhat Naqvi, Arvind Mungole and **Pitambar Humane**	BOTANY	Indian Forester	2022-2023	ISSN: 0019-4816; eISSN: 2321-094X
3.	Charge transfer mechanism in KNbO3 dispersed composites of monovalent alkali carbonate, Ferroelectrics	**Prashant Ambekar**, Jasmirkaur Randhawa and Kamal Singh;	PHYSICS	FERROELECTRICS;	2022-2023	0015-0193(p) 1563-5112 €

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Ethnobotanical Survey on Trees of Seminary Hills, Nagpur (M.S.): An Approach Towards Plant Conservation

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Abstract

Seminary Hills (Latitude 21°9'57" North and Longitude 79°3'47" East) play an important role in maintaining ecological and environmental balance of the rapidly- growing Nagpur city. Majority of the area of Seminary Hills lie under protected forest area. Seminary Hills Forest represents the unique vegetation of tropical dry deciduous forest, and shows presence of trees like *Tectona grandis* L.f., *Butea monosperma* (Lam.) Taub., *Azadirachta indica* A. Juss., *Acacia catechu* (L. f.) Willd., *Anogeissus latifolia*(Roxb. ex DC.) Wall. ex Guill. & Perr., characteristics of tropical dry deciduous forest. The survey was conducted to explore the valuable tree species and enrich the knowledge of ethnobotanical plants in the area. Study revealed occurrence of 49 tree species belonging to 19 families in the area. Majority of the trees belong to the family Fabaceae (43%). Survey showed that virtually all the recorded tree species have medicinal and economical value. Stem/Bark (78%) of the plants was most useful part followed by leaves (59%), fruit and seeds (45%), roots (33%), flowers (29%), gum (12%). In 6% of the trees, all the parts were found to be useful. Knowledge gained about the diversity and uses of trees will generate awareness among people regarding importance and conservation of these plant species.

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Introduction

Since ancient times humans have been dependent on various plants for diverse needs *viz*. food, shelter, clean air, medicines. They play key role in regulating air quality, noise pollution, soil erosion, water quality and quantity and reduce the risk of flood, drought and They help in balancing oxygen and carbon dioxide level in atmosphere, regulate earth's temperature and hydrologic cycle. Wood, which provides raw material for domestic and industrial processes, is the chief product of forests. Forests also are a source of medicinal plants that provide primary health care for majority of population in developing countries. Different plant parts such as bark, leaves,

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flowers, fruits, seeds are used to treat diseases viz. dysentery, diarrhoea, fever, cough, cold, bronchitis, diabetes, skin diseases. Natural plant products have been ascertained to be source of many newly synthesized drugs.[1] Miscellaneous products like bamboo, gums, resins, fibers, katha, some oils are also obtained from forests. Environmental practices which protect and restore forests are indispensable for human wellbeing and alleviation of poverty.

Floral diversity of forests encompasses various herbs, shrubs, trees and climbers. The dense coverage of plants helps in mitigating air pollution, balancing oxygen and carbon dioxide levels in atmosphere thus regulating earth's temperature.[2] Trees, a major component of forest flora, form a valuable natural resource from ecological and economical viewpoint. Trees store large amount of carbon and contribute significantly in carbon cycle dynamics in forests. Tree diversity has an impact on forest ecosystem stability and services. They are source of fruits, timber, fuel. They provide shade and act as wind breaks. Trees form an important part for water management, especially in an urban ecosystem.[3] They also have religious importance and are used in many folklores. Ethnobotany has become a critical need of modern times as it deals with traditional and natural relationship between plant wealth and human societies including cultural beliefs, practices and conservation of environment. Ethnobotanical studies help in proper documentation of the age old knowledge of tribal people about the uses of various plants for human welfare.[4]

Nagpur is located in the Vidarbha region of Maharashtra. It has semi-arid climate with an average annual rainfall of about 1161.5 mm. Temperature of Nagpur during summer range from 28 °C (March) to 46 °C (May). Vegetation of Nagpur can be categorized into Hill forest, Savannah and Pond vegetation. Plant diversity of Nagpur includes 1136 plant species comprising of 679 genera & 142 families.[5,6] Due to rapid expansion of the city and increased urbanization, it is witnessing increased air and water pollution, shrinking green areas, temperature extremes, increased flash floods.

Seminary Hills, often called as lungs of the Nagpur, play an important role in maintaining ecological and environmental balance of the city. Major portion of Seminary Hills encompasses closed protected dense forest which has great floristic diversity. Seminary Hills Forest represents the unique vegetation of tropical dry deciduous forest. This study was conducted to explore the valuable tree species in the area. As participation of masses is important, this paper aims to create awareness among people regarding various uses of the trees and the need for their conservation which is an important component of sustainable development.

Materials and Methods

The selected study area Seminary Hills is located with Latitude 21°9'57" North and Longitude 79°3'47" East. Total area of Seminary Hills Reserve Forest is 174.97 Acres (Government Notification No.372-1502 XI of 43. Date 30/3/1944).[7]

To study the trees belonging to different families in Seminary Hills Nagpur, extensive field visits were carried out in the areas like SFS Arboretum, Deer Park, Lourd Mata Temple, Telangkhedi and Childrens' Park during 2021-22.

The plants were observed in their natural habitat and the data was collected. The digital photographs of trees were taken with their unique characteristics that can help in identifying the plants in the natural habitat.

The identification of various tree species has been done using standard literature, floras, research papers and reports.[5,8,9] The earlier published scientific literature sources were referred for corroborating the ethnobotanical uses of the recorded tree species.[10,11,12]

Results and Discussion

Seminary Hills, Nagpur has rich vegetation comprising of diverse trees. Floristic study revealed 49 tree species belonging to 19 families in the area. Present report is a result of exhaustive survey of tree species along with their ethnobotanical importance. Highest representation was found to be of family Fabaceae (43 %) with 16 genera and 22 species (Fig. 1). In Nagpur, Fabaceae is a dominant and widely distributed family in other locations also.[13] (Dulare *et al.* 2021)

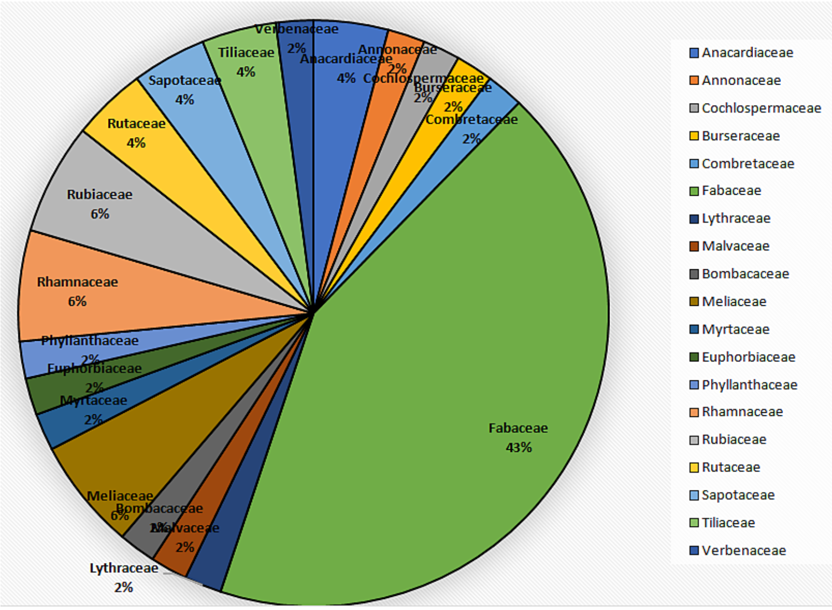

Fig. 1: Percent representation of Trees belonging to different families

Tree species recorded include diverse trees of economic importance like *Azadirachta indica* A. Juss., *Tamarindus indica* L., and *Mangifera indica* L. (Table 1.). All the tree species have medicinal and economic value. Region showed majority of trees like *Tectona grandis* L, *Butea monosperma* (Lam.) Taub. in Engl. & Prantl., *Azadirachta indica* A. Juss., *Acacia catechu*, and *Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr. characteristic of tropical dry deciduous forest.

Table 1: Tree diversity in Seminary Hills, Nagpur along with their ethnobotanical uses.

Family	Trees Species	Vernacular Name	Plant Part used	Ethnomedicinal uses	Other uses
Anacar diaceae	*Lannea coromandelica* (Houtt.) Merr.	Mohin	Leaves, bark, stem and gum	Bark is used in ulcers, wounds, ophthalmia, gout, dysentery, diarrhea and mouth sores. The leaves are useful in elephantiasis, inflammations, neuralgia, sprains and bruises.[16]	Used in plywoods
	Mangifera indica L.	Aam, Amba	Bark, leaves, roots, fruits, seeds, and flowers	The roots and bark are useful in leucorrhoea, syphilis, wounds, ulcers, vomiting, The leaves , flowers and seeds are used in burning sensation, haemorrhages, wounds, ulcers, diarrhoea and dysentery. Fruits are used in sunstroke, opthalmia, eruption, intestinal	Shade tree

				disorder, in fertility, night blindness.[17]	
Annon aceae	*Polyalthia longifolia* (Sonn.) Thw.	Ashok	Bark	The bark is used as antipyretic, cutaneous problems, diabetes, hypertension and helminthiasis.[10,18]	Ornamental, Avenue plantation
Coch losper maceae	*Cochlos-. permum* religiosum (L.) Alst	Ganeri, Galgal	Fruits, roots, gum, bark and leaves	The plant has properties like sedative,stimulant and is used in treatment of jaundice, cough, trachoma, etc. Young leaves are used for washing hairs. Gumis used in pharyngitis, dysentery, diarrhea, asthma, eye problems and stomachache.[10,19]	
Burser aceae	*Boswelia serrata* Roxb. ex Colebr.	Salai	Bark, Gum - oleoresin	The bark is used against dysentery, ulcers, skin diseases, and Gum is useful in treatment of fevers, dysentery, bronchitis, asthma, haemorrhoids, cough.[10]	
Combre taceae	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr.	Dhawda	Root, leaf and fruit	The roots are used in abdominal disorders and the bark is used in wounds, ulcers, inflammations, diabetes, dysentery, skin diseases and leprosy. The fruits are useful in treatment of diarrhoea and dysentery.[11]	Fuel, timber, dye
	Terminalia elliptica Willd.	Asan, Ain	Bark	The bark is styptic and cardiotonic. The gum exudates from the stem bark is medicinally useful as a purgative.[20]	Fuel, tool handles
	Terminalia catappa L.	Jangli-badam	Leaves, bark and fruit root	The bark is astringent, diuretic and cardiotonic. Leaves are used in headache, colic and skin ailments viz. scabies, leprosy. Fruit is astringent, aphrodisiac; usedin bronchitis.[11]	Avenue
Fabaceae	*Acacia catechu* (L. f.) Willd.	Khair	Bark, heart wood, flowers	The bark is used in diarrhea either alone or in combination with cinnamon or opium. It is also used in skin ailments, sore throat, bronchitis, digestive problems, ulcers, boils and inflammations.[11,21]	Dye yielding

Acacia leucophloea (Roxb.) Willd.	Himvar,	Bark.	The bark is astringent, styptic, anthelmintic, demulcent, expectorant. It isused in bronchitis, cough, vomiting treatment of wounds, ulcers, dysentery, dental caries, oral ulcers and fevers.[21]	Dyes and tannins
Albizia lebbeck (L.) Benth.	Mothasiras	Seeds, bark, flowers, leaves.	Bark is used in skin diseases, leucoderma, diarrhea, bronchitis and all types of poisoning. Oil from the seeds, is useful in leprosy.[11]	Shade, wood for construction, furniture and veneer
Albizia odoratis sima (L. f.) Benth.	Siris	Bark, leaves.	The bark is useful in skin ailments, diabetes.Leaves are used in cough, bronchitis.[11]	Timber,
Albizia procera (Roxb.) Benth.	Safed siris	Leaves	The leaves are insecticide and are used as dressing inulcers.[11]	Furniture, construction, agricultural implements
Bauhinia racemosa Lam.	Apta,	Gum, leaves.	The root bark is astringent, used in diarrhea and dysentery. Leaves given in diarrhea with onion, also decoction of leaves used in malaria.[11]	Fibre, agricultural implements.
Bauhinia purpurea L.	Kanchan	Bark, root, flowers.	The roots are carminative. The bark is used to releive diarrhea. Flower buds are laxative and anthelmintic.[11]	Tan, dye
Butea monosperma (Lam.) Taub.	Palas,	Gum, leaves, flowers, seeds	The bark is used in diarrhea, dysentery, rectal diseases, etc. leaves are used in diseases of the eye. The gum is used in dysentery, stomatitis, cough, excessive perspiration. the flowers are used in leprosy, gout, skin diseases, thirst, burning sensation.[10]	Timber, plates, resin, fodder and dye.
Cassia fistula L.	Amaltas	Root-bark, flowers, bark, leaves, roots	The bark is used in boils. The leaves and flowers are used in skin problems. The fruits are abortifacient, diuretic, purgative and anti-inflammatory.[11]	Ornamental, timber
Cassia siamea Lam.	Kassod	Bark, Leaves	Aerial parts are useful in ringworm, skin diseases. They are antinociceptive and antiviral, antioxidant	Timber

			and antihypertensive.[22]	
Dalbergia sisso Roxb. ex DC.	Sisam	Bark, roots, leaves, mucilage.	The bark and wood are tonic, abortifacient, aphrodisiac, anthelmintic, antipyretic, expectorant, appetizer, vomiting, burning sensation. It is used in skin ailments, problems of the anus, ulcers, blood ailments, digestive problems. The leaves are used for eye diseases.[10]	Timber
Delonix regia (Boj. Ex Hook.) Raf.	Gulmo har	Bark, Leaves, fruit, seeds	The plants are used as anti-rheumatic and spasmogenic. The bark is used as antiperiodic and febrifuge. The leaves are used in constipation, inflammation and arthritis. Aqueous and ethanol extract of flowers are used against round worms.[23]	Ornamental. Avenue plantation
Gliricidia sepium (Jacq.) Kunth ex Walp.	Undir mari	Leaves, barks, roots	The leaves and bark are used as antimicrobial, antibacterial and anti-inflammatory.[24]	Timber
Hardwickia pinnata Roxb. ex DC.	Anjan	Balsam, roots, leaves, bark, seed, wood	Bark is used in the treatment of diarrhea, worms, indigestion and leprosy. Balsam resin is used in leucorrhoea, chronic cystitis and gonorrhea. Seed used in dysentery. Leave are used, as purgative and in constipation.[25]	Timber
Leucaena leucocephala (Lam.) de Wit.	Safed Babool, Subabul	Leaves, Seeds	The seeds are used as antidiabetics, stomachache reliever, contraceptive, abortifacient and antioxidant.[26]	Timber, Avenue tree
Peltophorum pterocarpum (DC.) Baker ex K. Heyne	Peela gulmohar	Bark, stem, leaves, flowers	The bark is used in dysentery, toothache, eye troubles, muscular pains, sores. Leaves are used in skin disorders. Flowers are used as an astringent, in eye troubles, muscular pains and sores.[27]	Avenue tree
Pithecello bium dulce (Roxb.) Benth.	Jangal Jalebi	Bark, fruits	The root-bark is used as astringent, febrifuge, anti-dysenteric. The seeds are used in inflammation.[28]	Ornamental, shade tree
Pongamia pinnata (L.)	Karanja	Leaves, roots,	The roots are used for ulcers, cleaning teeth,	Oil obtained from seeds

	Pierre		bark and seeds	strengthening gums and gonorrhea. The bark is used in beri-beri, ophthalmology, dermatopathy, and ulcers. Leaves are used in diarrhea, leprosy, dyspepsia and cough. Flowers are used in diabetes. The seeds are used in inflammation, chronic fevers, anaemia and hemorrhoids. The oil is used in opthalmia, leprosy, ulcers, herpes and lumbago.[29]	
	Pterocarpus marsupium Roxb.	Beeja, Vijaysar	Gum	The gum is laxative, anthelmintic, leukoderma, urinary discharges, anal troubles, leprosy, eye troubles and elephantiasis.[10]	Timber
	Samanea saman (Jacq.) Merr.	Rain tree	Root, Bark, leaves	Useful in cold, headache, diarrhoea, stomach-ache intestinal problems.[30]	Timber, shade tree
	Tamarindus indica L	Chincha	Bark, leaves, flowers, fruits, seeds	The bark is used in paralysis, urinary discharges and gonorrhea. The leaves are used in inflammations, tumours, ringworm, blood ailments, smallpox, eye problems, earache, snake bite. The fruits are laxative, used in liver complaints, skin diseases, mouth sores, scorpion-sting.[11]	Shade tree, edible fruits
Lythraceae	*Lagerstroe mia reginae* Roxb.	Jarul	Root, bark, Leaves	Roots are used in mouth ulcers. Bark is used as stimulant, abdominal pains reliever and antipyretic. The leaves are diuretic and decongestant and are used in diabetes mellitus.[31]	Ornamental, Avenue tree
Bombac aceae	*Bombax cieba* L.	Kaate Saanvar	Root, bark, flowers and fruit	Roots are stimulant, demulcent and tonic and are used in dysentery. The flowers are in skin troubles. Fruits are used as stimulant, diuretic, tonic, aphrodisiac, expectorant.[10]	Ornamental
Malva ceae	*Sterculia urens* Roxb.	Kulu, Kondol	Leaves and tender branches	Pulverized bark is given to women to facilitate delivery. Leaves and tender shoots are used for pleuropneumonia in cattle.[10]	Gum

Melia ceae	*Azadirachta indica* A. Juss.	Kadun imb	Bark, stems, leaves, fruits, flowers, seeds	Bark is useful in leprosy, cutaneousailments, diabetes, cough and bronchitis. Leaves are used in burning sensation, leprosy, skin diseases, intestinal worms. Flowers are used in dyspepsia and general debility. Fruits are used in skin diseases, tumors, piles, toothache. The oil from seeds is anthelmintic, used in skin diseases.[10,15]	Timber, Firewood Medicinal, Bioin secticide
	Melia azedar ach L.	Mahan imb	Root-bark, leaves, fruit, flowers	The root are astringent, anthelmintic, used in vomiting, skin diseases, belching, blood impurities, ulcers, headache, post-delivery uterine pains, fever,burning sensations, urinary discharges, lung problems.[10]	Agricultural implements, furniture, plywood
	Soymida febrifuga (Roxb.) A. Juss.	Rohani	Bark	The bark is used in fevers, asthma, cough, removes blood impurities, ulcers, leprosy, dysentery, vaginal infections, ulcers.[10]	Timber, tan, dye
Myrtaceae	*Psidium guajava* L.	Peru, Amrood	Leaves, fruit	The extract of the leaves is used for treating diarrhea, coughs, stomachache, toothaches and dysentery. Fruit is laxative, used in thirst, colic and in bleeding gums.[11]	
Euphor biaceae	*Bridelia retusa* (L.) Spreng.	Asana, Kaji	Root, bark	The bark and root are astringents. The bark is useful in urinary concretions and in rheumatic diseases.[12]	Implements for farming
Phyllant haceae	*Cleistanthus collinus* Willd.	Garari	Bark, leaves	The fruit and bark are used in skin ailments. Leaves soaked in water are used to bath the head and upper body parts to relieve headache.[12]	Agricultural implements
Rham naceae	*Ziziphus mauritiana* Lam.	Bor, ber	Root, bark, leaves, fruit	Fruits are used as an antidote to aconite-poisoning and used in nausea and vomiting, abdominal pain in pregnancy.[32]	Tool manufa-cturing, edible fruit
	Zizyphus xylopyrus (Retz.) Willd.		Root, stem, bark, leaves fruits, seeds	Alcoholic extract of the bark has anti-convulsant and anti-inflammatory properties.[33]	
Rubia ceae	*Gardenia resinifera*	Dikam ali		The gum is antimicrobial, anthelmintic; also useful in	Gum

	Roth			skin or cutaneous diseases.[34]	
	Mitragyna parviflora (Roxb.) Korth.	Kaim	Root, Bark, leaves, fruits	The roots and bark are used in colic and fever. Bark is used in muscular pain.[11]	Timber
	Neolam arckia kadamba Roxb	Kadamb	Bark and Leaves.	The bark is tonic, antipyretic, anti-inflammatory, digestive, relieves flatulence, diuretic, used in cough.The leaves are useful in ulcers, wounds, and metorrhea.[35]	Timber
Rutac eae	*Chloroxylon swietenia* DC.	Bhirra	Bark and leaves.	The bark is astringent. Leaves are useful in rheumatism and wounds.[10]	Timber
	Citrus auranti folia (Christm. & Panz.) Swingle	Nimbu	Fruit, leaves	Fruit has anti-cancer, antimicrobial, antioxidant, antiulcer, anti-inflammatory, antityphoid and hepato protective properties. The rind of fruit is anthelmintic, stomachic and carminative. It is used rheumatism, dysentery and diarrhea. Lemon juice is useful in scabies.[10,36]	Edible fruits
Sapota ceae	*Madhuca longifolia* (Koen.) Mac. Bride	Mahua	Young plants, leaves, stems, barks, roots, fruits, flowers, seeds	The flowers are used in tonsillitis, pharyngitis and bronchitis, The bark is used for rheumatism, bronchitis, diabetes mellitus, bleeding and spongy gums, swelling, fractures, snake-bite poisoning. Leaves are used in bronchitis, dermatopathy, rheumatism, cephalgia and hemorrhoids. Fruits are astringent and used in ulcer, tonsillitis and pharyngitis. The seeds are used in skin disease, rheumatism, headache, laxative, piles and galactogogue.[37]	Plates, Oil obtained from seeds
	Mimusops elengi L.	Bakul	Root, bark, leaf, flower, fruit, seeds	The bark, is used as cardiatonic, antihelmentic, astringent and in diseases of gums and teeth. Flowers are used to cure diseases of the blood. The seeds are used to fix loose teeth.[11]	Essential oil
Tiliaceae	*Grewia tilifolia*	Dhamani	Bark and wood.	The bark is useful in burning sensation, cough, wound	Fibre, wood

				healing and diseases of the blood.[10]	
Verbena ceae	*Tectona grandis* L. f.	Sagwan or Sag	Wood	The bark is usefulin bronchitis and skin ailments. The wood is pungent, cooling; laxative; sedative to the gravid uterus; used in digestive issues and piles.[12]	Timber, Dye yielding

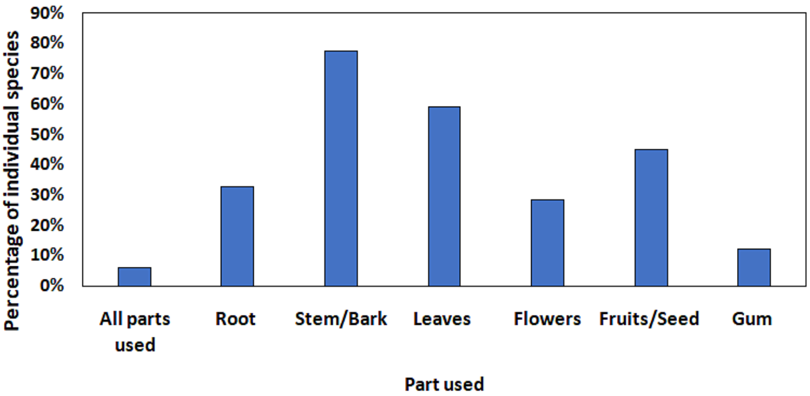

Fig. 2: Distribution of the taxa based on part used

In present study, stem/bark (78%) of the plants were found to be most useful part of ethnobotanical importance followed by leaves (59%), fruits/seeds (45%), roots (33%), flowers (29%) and gum (12%) (Fig 2). Out of total trees enumerated, in 6% of trees all parts were found to be economically important (Fig. 2). Forest and forest products form one of the most important natural resource. One tree species viz. *Sterculia urens* was found to be endemic to Seminary Hill forest. In recent times, natural forest cover is shrinking at an alarming rate owing to accelerated exploitation and misuse, conversion to agriculture fields and industrialization. Denudation of forests pose severe threat to the environment and mankind in terms of loss of biodiversity and many valuable plant species. Hence, there is an urgent need for creation of public awareness.

Trees besides having medicinal importance also have value for beautification, provides shade, cooling effect, source of economically important products like timber, gum, resins, rubber.[14] Presence of cultivated exotic tree species like *Tectona grandis* L. f., which dominates the area at present may change the functional activity and food chain of terrestrial ecosystems in near future. These exotic species may affect the native flora and fauna.

Ethnobotany plays a pivotal role in conserving plant diversity and also in educating people about the significance and role of plants to modern civilized society, which is very important for sustainable use. This indicates theclose relation between human existence and ethnobotany. The plants which are useful in various ways to the mankind are cultivated and conserved for future use. Many trees are cultivated for its ethnomedicinal purposes by local *Vaidus* as well as the people engaged in ayurvedic medicines. Keeping this in view, during floristic investigation, economic importance of different tree species found in the area was conveyed to local people and they were apprised about the importance of conservation of tree species for future sustainable development.[4,15]

The species recorded during this study with special reference to their uses for the mankind will encourage people for management, plantation and conservation of these tree species for future benefits as well as to the researchers in plant sciences. This study will further benefit in research and commercialization of valuable products obtained from them. Documentation of these plants is very much required as information is lost when indigenous knowledge is transferred verbally from one generation to other.

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Conflict of Interest
The authors declare no conflict of interest

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(III)
Ethnobotanically Important Herbaceous Flora of Seminary Hills, Nagpur

Documentation of traditional knowledge on ethnomedicinal use of plants has been considered as a high priority area to support the discovery of drugs benefitting mankind (Cherian and Ramteke, 2010). Ethnomedicinal plants, since times immemorial, have been used in virtually all cultures as a source of medicine. The widespread use of herbal remedies and healthcare preparations, as those described in ancient texts such as *Vedas* and the *Bible*, which were obtained from plants has been traced to the occurrence of natural products with medicinal properties. The plants have been the important source of medicines used by man from prehistoric times for relieving suffering and curing ailments. The need for the integration of local indigenous knowledge for a sustainable management and conservation of natural resources received more and more recognition (Posey, 1992). A medicinal plant is any plant used in order to relieve, prevent or cure a disease or to alter physiological and pathological process or any plant employed as a source of drugs or their precursors (Arias, 1999). '*Health is dearer than wealth*' as quoted by Hamilton (1997); so, the medicinal plants are of great value.

According to an All India Ethnobiological survey carried out by the Ministry of Environment and Forests, Government of India, there are over 8000 species of plants being used by the people of India for different ailments (Archana *et al*., 2011). This indicates that the medicinal plants have been brought in the main stream from folk medicines.

Study Area-Seminary Hills

The selected study area Seminary Hills is located with latitude 21°9'57"North and Longitude 79°3'47" East. Total area of Seminary Hills Reserve forest is 174.97 Acres, which includes 8.40 Acres of Deforestation area (Government Notification No. 372-1502 XI of 43, Date 30/3/1944).

Extensive and intensive visits were arranged to various regions of study area in different seasons. The plants were observed in their natural habitat and the Ethnomedicinal data was collected and recorded in the field diary. The multiple specimens of plants in flowering and fruiting state were collected, preserved and their herbarium sheets were prepared. The field notes were incorporated with the specimens on the herbarium sheets and stored in Herbarium of Department of Botany, Dharampeth M. P. Deo Memorial Science College, Nagpur. Ethnobotanical information was collected from the local people and Ayurvedic practitioners. The ethnobotanical evidences were searched and recorded from the available literature.

During the study, 67 plant species recorded from the study area were found as ethnobotanically important (Table 1). These species belonged to 25 families (Fig. 1). Herbaceous flora is dominant as compared to the shrubs, climbers and trees. It was observed that the herbaceous flora is more favored in the treatment of various diseases or disorders (Table 1).

Most of the known ethnobotanically important plants species belonged to family Fabaceae, Asteraceae, Acanthaceae and Malvaceae. Medicinal plants are generally used in crude form; this indicates various chemical constituents are present in specific plant. Hence most of the medicinally known plants are found effective against various diseases (Table1, Fig. 3).

In present study, leaves of the plants were found to be most useful part in the disease treatment (Fig. 2). In case of the herbaceous flora, whole plants are useful in the treatment. But in other cases, most frequently useful plant part is leaves, fruits and seeds and followed by

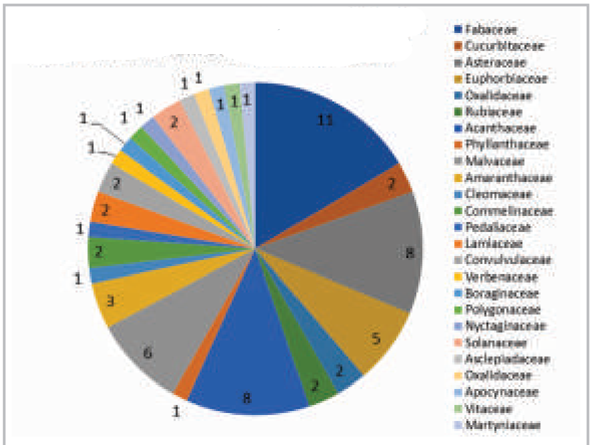

Fig. 1: Representation of different medicinally important taxa from Seminary Hills, Nagpur

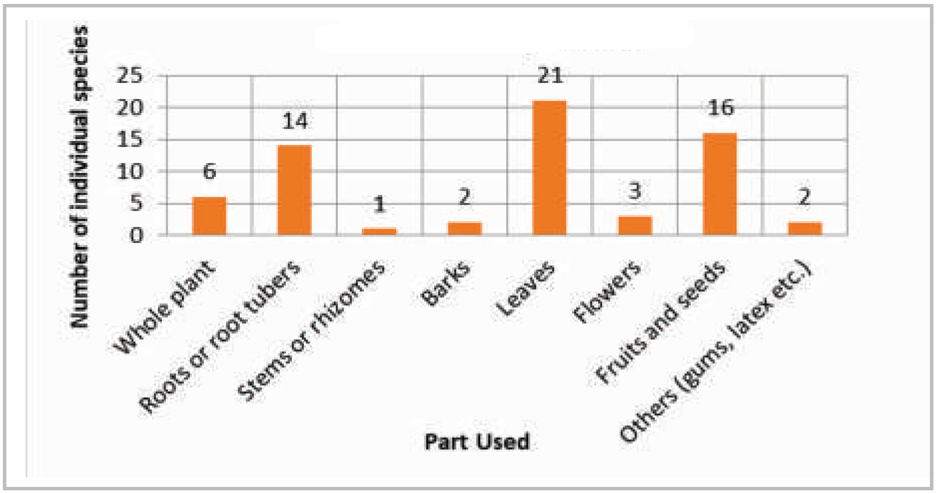

Fig. 2: Distribution of the taxa based on plant part of medicinal importance

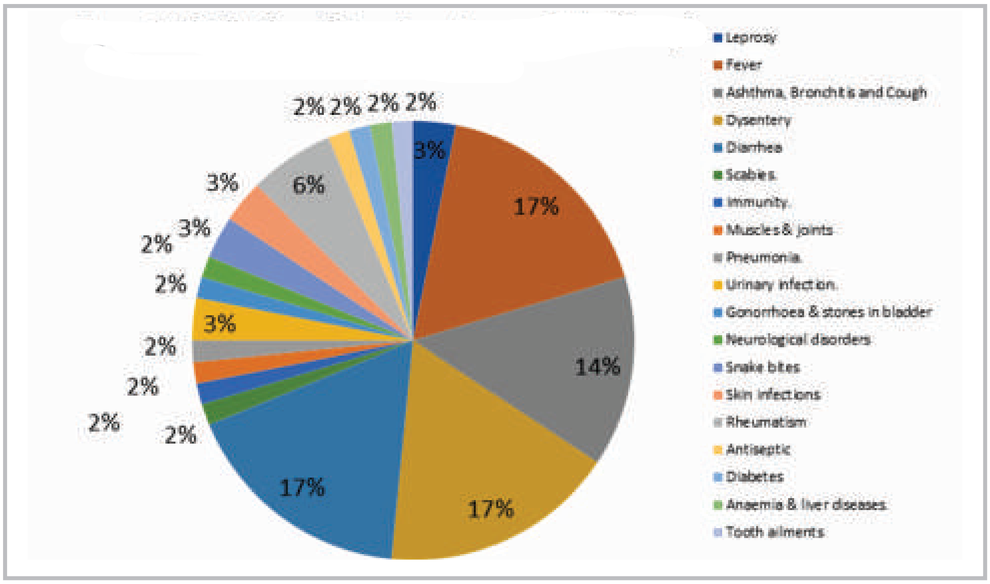

Fig. 3: Distribution of taxa based on medical efficacy in diseases/disorders.

roots or root tubers, flowers, bark, and latex (Fig. 2).

Traditionally, this treasure of knowledge has been passed on orally from generation to generation without any written documentation and is still retained by various indigenous groups around the world (Perumal Samy and Ignacimuthu, 2000; Saranraj *et al*., 2016). Traditional folk medicine uses the knowledge, skills and practices based on the theories, beliefs and experiences of indigenous people to its cultures for maintenance of health. Documenting the indigenous knowledge through ethnobotanical studies is important for the conservation and utilization of biological resources. Ethnobotanical survey has been found to be one of the reliable approaches to drug discovery (Fabricant and Farnsworth, 2001; Kolanjinathan and Saranraj, 2015). The consumption, management and valuation of wild plants are central aspects of the traditional knowledge in many human populations. Thus, plants gathering, the diffusion and conservation of knowledge within the community are traditional practices that have contributed to the subsistence of many cultures. In most of the societies the medical system coexists with several traditional systems. These traditional medical systems are generally based on the uses of natural and local products which are commonly related to the people's perspective on the world and life (Saranraj *et al*., 2016).

In the present study plant species belonging to 25

Table 1: Plant species with respect to ethnobotanical uses

Sr. No.	Botanical name of the plant	Family	Accession No.	Ethnobotanical Uses
1	*Acalypha ciliata* Forssk.	Euphorbiaceae	**PTH/NG/958**	Mashed leaves are applied on sores.
2	*Acalypha indica* L.	Euphorbiaceae	**PTH/NG/1547**	Leaves and latex of the plant are used in treatment of asthma and pneumonia.
3	*Ageratum conyzoides* L.	Asteraceae	**PTH/NG/1460**	Against dysentery, diarrhoea. Juice of flowers is used against scabies.
4	*Alternanthera pungens* Kunth	Amaranthaceae.	**PTH/NG/1033**	Leaves are used in fever and diarrhea.
5	*Alysicarpus heyneanus* Wight & Arn.	Fabaceae	**PTH/NG/1522**	Seeds are use in Inflammation and stomach ache. Roots are chewed in fever.
6	*Alysicarpus vaginalis* (L.) DC.	Fabaceae	**PTH/NG/490**	Seeds are used as anti-inflammatory and as an antidote to snake bite.
7	*Anisomeles indica* (L.) O. Ktze.	Lamiaceae	**PTH/NG/1167**	Leaves juice used in Dyspepsia and fever.
8	*Antigonon leptopus* Hook. &Arn.	Polygonaceae	**PTH/NG/500**	Leaves used in skin problems also in cough, pain and diabetes.
9	*Asystatia gangetica* (L) T. Ander.	Acanthaceae	**PTH/NG/2223**	Flowers used in dry cough and chest discomfort.
10	*Bidens biternata* (Lour.) Merr. &Sherff.	Asteraceae	**PTH/NG/1680**	Fruits are inflammation, leprosy, ulcers and diarrhoea. Also used in malaria.
11	*Biophytum sensitivum* (L.) DC.	Oxalidaceae	**PTH/NG/1050**	Decoction of roots is used to treat gonorrhoea and stones in bladder.
12	*Blepharis repens* (Vahl) Roth	Acanthaceae	**PTH/NG/1112**	Seeds are given to sick goats.
13	*Boerhavia repens* L.	Nyctaginaceae	**PTH/NG/784**	Whole plant is used against anemia and liver diseases.
14	*Calotropis gigantea* (L.) Ait.	Asclepiadaceae	**PTH/NG/1698**	Roots of the plant used against diarrhoea and constipation
15	*Cassia absus* L.	Fabaceae	**PTH/NG/1558**	Leaves are used as an antiseptic.
16	*Cassia tora* L.	Fabaceae	**PTH/NG/2217**	Seeds are used in cough and dysentery.
17	*Cissus woodrowii* (Stapf ex T. Cooke) Sant.	Vitaceae	**PTH/NG/1240**	To treat pain and to repair bone fractures. Also used against allergies, asthma and gout.
18	*Cleome viscosa* L.	Cleomaceae	**PTH/NG/1107**	Decoction of roots is used in fever.
19	*Clitoria ternatea* L.	Fabaceae	**PTH/NG/726**	Leaves are used for natural dyes, treatment of snake bites, eye problems.
20	*Coccinia grandis* (L.) Voigt	Cucurbitaceae	**PTH/NG/843**	Fruit is used to treat leprosy, fever, asthma and bronchitis.
21	*Commelina benghalensis* L.	Commelinaceae	**PTH/NG/663**	Bark is used in dysentery, leprosy etc.
22	*Commelina diffusa* Burm. f. sp.	Commelinaceae	**PTH/NG/1805**	Stem and rhizome used against sore throats, dysentery and rashes.
23	*Corchorus aestuans* L.	Tiliaceae	**PTH/NG/1255**	Leaves are used in demulcent, diuretic and tonic. Also used in gonorrhea and dysuria.
24	*Crossandra infundibuliformis* (L.) Nees.	Acanthaceae	**PTH/NG/2214**	Flowers are used in fever and also in headache.
25	*Crotalaria hirta* Wild. sp.	Fabaceae	**PTH/NG/1432**	Seeds are use in gout, pain, swellings, cuts, wounds and coughing.
26	*Datura inoxia* Mill.	Solanaceae	**PTH/NG/1725**	Leaves are psychoactive
27	*Desmodium triflorum* (L.) DC.	Fabaceae	**PTH/NG/1013**	Leaves are used in dry cough
28	*Digera muricata* (L.) Mart.	Amaranthaceae	**PTH/NG/1313**	Fruits used in cough and dysentery.
29	*Dipteracanthus prostratus* (Poir.) Nees	Acanthaceae	**PTH/NG/1795**	Roots are antidote against snake bites by tribal people.
30	*Emilia sonchifolia* (L.) *DC.*	Asteraceae	**PTH/NG/2157**	Traditionally used in fever, sore throat, diarrhoea, eczema and snakes bites.
31	*Euphorbia heterophylla* L.	Euphorbiaceae	**PTH/NG/2213**	Latex is used against dysentery. Decoction of whole plant is used in bronchial infections and asthma.
32	*Euphorbia hirta* L.	Euphorbiaceae	**PTH/NG/1277**	Leaves and latex is used against dysentery.
33	*Evolvulus alsinoides* (L.) L.	Convolvulaceae	**PTH/NG/1576**	It is used against diarrhoea.
34	*Gomphrena serrata* L.	Amaranthaceae	**PTH/NG/1598**	It is used in bronchial asthma. It is also used in whooping Cough.
35	*Hedyotis corymbosa* (L.) Lam.	Rubiaceae	**PTH/NG/1141**	Leaves are used to treat sores, wounds. Roots are used by Chinese for improved blood circulation.
36	*Hibiscus lobatus* (J. A. Murr.) O. Ktze.	Malvaceae	**PTH/NG/1711**	Roots with turmeric are used to cure dysentery and stomachache. Treats anorexia in cattle.
37	*Hybanthus enneaspermus* (L.) F. v. Muell.	Violaceae	**PTH/NG/1739**	Decoction of whole plant roots is used to treat urinary infection.
38	*Hyptis suaveolens* (L.) Poit.	Lamiaceae	**PTH/NG/2138**	Seeds are used to make refreshing drinks. Seed are also use in beverages.
39	*Indigofera linnaei* Ali	Fabaceae	**PTH/NG/737**	Leaves are used in nervous disorder and asthma. Also as an ointment for curing skin diseases. Roots are use in toothache, syphilis and kidney stones.

40	*Indoneesiella echioides* (L.) Sreem.	Acanthaceae	**PTH/NG/1179**	Leaves and roots are mixed with mustard oil to apply on snake bites. Decoction is used in fever, dysentery and liver disorders.
41	*Ipomoea triloba* L.	Convolvulaceae	**PTH/NG/1390**	Leaves of some species such as *I.batatus* are eaten as vegetable.
42	*Justicia adhatoda* L.	Acanthaceae	**PTH/NG/805**	Whole plant used in Unani, Homoeopathic and Ayurvedic medicines.
43	*Lantana camara* L.	Verbenaceae	**PTH/NG/1338**	Fruits are edible having sweet taste.
44	*Martynia annua* L.	Martyniaceae	**PTH/NG/2107**	In making beads and also in Ayurveda.
45	*Oxalis corniculata* L.	Oxalidaceae	**PTH/NG/1218**	Whole plant is used in treatment of fever.
46	*Parthenium hysterophorus* L.	Asteraceae	**PTH/NG/2127**	In medicines to treat diarrhoea, fever. Leaves are also used in neurological disorders, urinary tract infection etc.
47	*Pentanema indicum* (L.) Ling.	Asteraceae	**PTH/NG/2132**	Leaves of the plants used in treatment of skin infections.
48	*Pergularia daemia* (Forssk.) Choiv.	Asclepiadaceae	**PTH/NG/2214**	Seeds of the plant used in treatment of liver.
49	*Phyllanthus fraternus* Webster	Phyllanthaceae	**PTH/NG/1763**	Seeds of the plant are used in problems of stomach, liver, kidney and spleen.
50	*Physalis minima* L.	Solanaceae	**PTH/NG/1750**	Fruit is nutritious and used in eatables.
51	*Ruellia tuberosa* L.	Acanthaceae	**PTH/NG/1434**	Bark used in treatment of wound and urinary tract infection.
52	*Rungia pectinata* (L.) Nees	Acanthaceae	**PTH/NG/1169**	Leaves of the plant used against inflammation, Diuretic and microbial activities.
53	*Sesamum orientale* L.	Pedaliaceae	**PTH/NG/745**	Seeds are used for medicinal and nutritive value, as they are rich in omega-6.
54	*Sida acuta* Burm. f.	Malvaceae	**PTH/NG/1110**	Roots are used in treatment of urinary diseases and blood disorders. Also in nervous disorders. Used as mild sedative
55	*Sida cordifolia* L.	Malvaceae	**PTH/NG/1756**	Whole plant boosts immunity. It helps heal injuries in sore muscles and joints.
56	*Sida rhombifolia* L.	Malvaceae	**PTH/NG/1675**	Fruits are used to relieve headache. Leaves are used in swelling. Roots used in rheumatism.
57	*Spermacoce articularis* L. f.	Rubiaceae	**PTH/NG/746**	Leaves used in bronchial asthma.
58	*Synedrella nodiflora* (L.) Gaertn.	Asteraceae	**PTH/NG/1397**	Leaf juice used in earache and stomachache.
59	*Tephrosia purpurea* (L.) Pers.	Fabaceae	**PTH/NG/1219**	Decoction of roots is given against intestinal worms, diarrhoea, rheumatism and urinary infection.
60	*Teramnus labialis* (L.f.) Spreng.	Fabaceae	**PTH/NG/1538**	It is used against rheumatism and stomachache.
61	*Trichodesma inaequale* Edgew.	Boraginaceae	**PTH/NG/1227**	Leaves are used against diarrhoea, dysentery and skin diseases.
62	*Trichosanthes cucumerina* L.	Cucurbitaceae	**PTH/NG/1020**	Fruits are good source of vitamins and minerals.
63	*Tridax procumbens* L.	Asteraceae	**PTH/NG/2133**	Whole plant is used in wound healing and as an anticoagulant. It is used in ayurvedic medicines for liver disorders.
64	*Triumfetta rhomboidea* Jacq.	Tiliaceae	**PTH/NG/1083**	Decoctions of roots are used for ulceration. Also use in dysentery, diarrhea and internal hemorrhages.
65	*Urena lobata* L.	Malvaceae	**PTH/NG/1327**	Root decoction used in rheumatism, enteritis and dysentry. Leaves are used in bladder and intestinal infection.
66	*Vernonia cinerea* (L.) Less.	Asteraceae	**PTH/NG/1357**	Leaves are used in malarial fever. Also used to cure diseases caused by ringworms and tapeworms.
67	*Vigna trilobata* (L.) Verdc.	Fabaceae	**PTH/NG/963**	Leaves and seeds applied to treat swelling and skin infections. Leaves are chewed to treat tooth ailments.

families of angiosperms known for different ailments were reported. The present investigation revealed that the medicinal plants found in wild in Seminary Hills have played a vital role in the primary health care of the people. The reported results are encouraging but scientific scrutiny is necessary before being put in practice.

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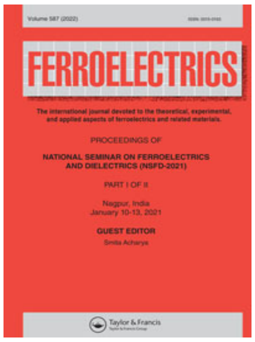

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Charge transfer mechanism in $KNbO_3$ dispersed composites of monovalent alkali carbonate

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Charge transfer mechanism in $KNbO_3$ dispersed composites of monovalent alkali carbonate

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ABSTRACT
The ferroelectric phase $KNbO_3$ dispersed composites of Na_2CO_3 were prepared and studied for its applicability as an electrolyte/sensing electrode in electrochemical sensors. The composites were characterized with *in-situ* impedance measurements under different CO_2 gas partial pressures and transport number measurements. The dispersoid was found modifying the conduction mechanism of ions as revealed from impedance spectroscopy. The electrolyte showed variation in the electrical conductivities in presence of the test gas. Significant improvement in the response time of the electrochemical CO_2 gas sensor was observed while using this composite as an electrolyte cum sensing electrode.

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Impedance spectroscopy; $KNbO_3$-ferroelectric phase; electrochemical CO_2 gas sensors; composite electrolyte; monovalent alkali carbonates

1. Introduction

Overwhelming extent of automation in our routine processes has contrived the need of fast, reliable, sensitive, selective and accurate sensors. IOT functioning will also be effective with them when networked for different devices and processes. The state of art developments in CO_2 gas sensors mainly comprise of the following three types viz.

i. Electrochemical sensors (type II or III potentiometric sensor), which are prepared by using pure carbonate components viz. Li_2CO_3, K_2CO_3, Na_2CO_3 are basically hygroscopic nature, develops cracks on thermal cycling, make poor mechanical interface with electrode materials and give sluggish response on reversibility of the device [1].
ii. Semiconducting Metal Oxides (SMO) Gas Sensors comprises of bulk conductivity/surface conductivity variation on CO_2 gas adsorption [2,3]; which have large number of oxide materials for device fabrication but the sensing mechanism need to be clearly understood. Even though the sensing mechanism in SMO sensors is simple, the details of oxygen adsorption (chemisorption) followed by charge transfer processes are complex and further research is required to gather more knowledge of the interaction of CO_2 with SMOs [4].
iii. Perovskite-based Semiconducting CO_2 Sensors are lagging selectivity as they sense different gases simultaneously [5,6].

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The electrochemical potentiometric sensors are best known for following a theoretical relation Nernst law and are selective in nature, which indeed enable them as a long-term solution in the sensor industry. Use of composite materials as electrolyte and/or sensing electrode has been found helping to overcome the above-mentioned shortcomings [7]. For CO_2 gas sensor development, the composite materials can be engineered by addition of insulating phase, ferroelectric phase, glass or glass ceramics to the carbonate host [8].Composite materials are preferred due to high ionic conductivity at lower temperatures and thermal as well as electrical stability in ionic devices [6]. Inert particle dispersed composites have been reported the enhancement of ionic conductivity due to enhanced defect formation at the grain boundary interface. The idea of dispersing ferroelectric instead of inert phase has been thought of by us having vast experience of the ferroelectrics. In this study, in order to achieve enhanced kinetics of ion migration at the grain boundary due to not only inert phase effect but more so due to localized polarization of charges as the ferroelectric phase has permanent dipole moments within the temperature range of device operation. Therefore, $KNbO_3$ phase has been selected for dispersion. Ferroelectric phase having permanent dipole moments results in enhancement of desired properties for sensor application [7]. Sodium ion-based electrolytes are being developed due to low cost of sodium as compared to that of lithium while its chemistry and intercalation kinetics is similar to that of lithium-based materials [9].

A type three sensors using Li^+ ion conducting Li_3PO_4 thin film electrolytes with Li_2CO_3 + Au as sensing electrode has been reported to operate above 460 °C, giving Nernst's slope of −61 mV/decade for the 250–5000 ppm of CO_2 concentration at relatively higher temperature of 500 °C for film thickness 1.2 micrometer [10]. Here, the sensor *emf* is reported to be getting saturated above 5000 ppm. Moreover, as the sensor is using pure Li_2CO_3 it could be used under hygroscopic conditions. This study has reported the failure of thin films (< 300 nm) in development of Nernstian sensors.

Therefore, in order to develop a fast, reliable, durable sensor having usable range and characteristics, in this study, we are presenting an effort to develop a cheap and reliable CO_2 sensor based on the ferroelectric phase $KNbO_3$ dispersed Sodium Carbonate electrolyte. The electrolyte materials are tested using their electrical characterization by *in-situ* Impedance Spectroscopy in different atmospheric conditions and ionic transport number measurement at different temperatures [11]. The material properties will be discussed to find its use as an electrolyte in an electrochemical CO_2 gas sensor.

2. Experimental

The material preparation is an extremely important part of any sensor related research work. The potentiometric sensors are basically having three components, namely, a solid electrolyte, an open reference electrode and a sensing electrode. The schematic of this sensor is shown in Fig. 1, wherein the solid electrolyte is sandwiched between reference and sensing electrodes by proper interface. Of these materials, the electrolyte should have high ionic transference number and the electrodes should have mixed type of conductions within them. Moreover, the contact between electrolyte-electrodes should be proper and there should not be any leakage of gases from the electrolyte to the

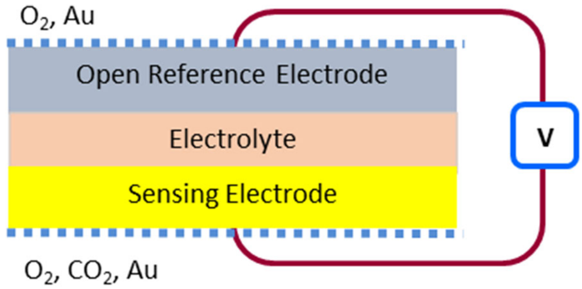

Figure 1. Schematic of electrochemical potentiometric gas sensor.

respective electrodes. Keeping all these factors in mind, materials like $KNbO_3$, composite solid electrolyte and reference electrodes were prepared using conventional melt quenching and/or solid-state sintering techniques. The methods for their preparation are explained below.

2.1. $KNbO_3$ preparation

Well-dried initial ingredients K_2CO_3 and Nb_2O_5 with assay more than 99.5% (procured from Aldrich, USA), were weighed in appropriate mole fraction with an accuracy of 0.01 mg, mixed thoroughly under acetone in an agate mortar for an hour to homogenize the mixture. The mixture was calcified in a platinum crucible over the decomposition temperature 1173 K of the Potassium Carbonate for six hours. The temperature of the mixture was then increased to its melting point 1373 K. The molten material was then quenched in between the revolving twin roller of stainless steel specially made for rapid quenching with a very little gap between them. Thus, obtained material flakes were then pulverized and sieved (400 mesh) to get the fine powder of uniform size for further use.

2.2. Preparation of composite electrolyte

Series of composites of Na_2CO_3 with $>$ 99.5% purity from Aldrich Chemicals, USA having varying weight fraction of $KNbO_3$ (10–80%) were prepared using melt quench technique. The mixture of appropriate weight fractions was treated for melting at about 1125 K for all samples although the melting for few compositions were found far below the said value. The molten mass was soaked in alumina crucible for each composition for about 30 min and then rapidly quenched between clean surfaces of aluminum blocks. The flakes of 1–2 mm thickness were obtained which then crushed-sieved using a 400 mesh for further use. Pellets of diameter 9 mm and thickness ranging from 1–3 mm were formed using a stainless-steel die-punch and a hydraulic press by applying a pressure of 3 tons/cm^2. After sintering them at 823 K for 12 h, the pellets were then used for electrical characterizations applying Pt electrodes at both the surfaces.

2.3. In-situ impedance measurement

All the compositions as discussed in section 2.2 were characterized with impedance measurements in the temperature range from 473 K to 723 K and frequency ranging

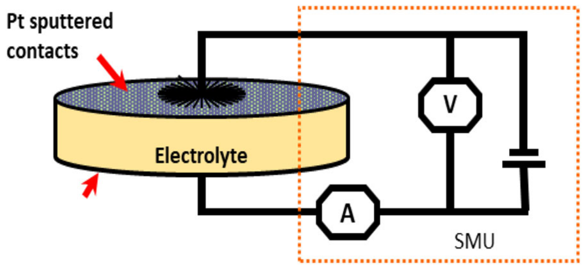

Figure 2. Schematic of experimental arrangement for conducting two probe DC measurements.

from 5 Hz to 13 MHz. The same pellets were then characterized for in-situ impedance measurements under different atmospheric conductions viz. temperatures (473–723 K) and CO_2 concentrations ranging from 0.01 to 100%.The analysis of ac conductivity data has been done manually by plotting impedance plots and Arrhenius plots using MS-Excel and origin software.

2.4. Transport number measurements

The sample composition having maximum ionic conductivity was subjected to transport number measurements using Wagner's dc polarization technique (Fig. 2), for determination of ionic and electronic transport number. The measurements carried out using both blocking electrodes with application of 500 mV for the temperatures ranging from 473 to 773 K in a step of 100 K.

2.4. Sensing characteristics

In order to check the validity of sensing the CO_2 gas in presence of catalyst, same pellets were studied for in-situ electrical conductivity measurements in different CO_2 gas partial pressures in embedded air at elevated temperatures. Also, potentiometric plate type sensor with maximum conducting composite as an electrolyte as well as sensing electrode was fabricated with following cell configuration: Au, O_2, CO_2, Ar/Na_2CO_3 + $KNbO_3$/Na_2SnO_3+SnO_2/Au, O_2, CO_2, Ar. This sensor was tested for response time measurement at 673 K. This sensor being electrochemical potentiometric type, the potential developed at the sensing electrode after test gas adsorption is read by comparing a standard potential of an open reference electrode having same ion for migration. The open reference electrode is made using a bi-phase mixture of Alkali oxide of Rare earths with rare earth oxide in order to achieve the cell reaction as- $SnO_2 + 2Na^+ + 2e^- + 1/2\ O_2 \longleftrightarrow Na_2SnO_3$.

3. Result and discussion

The $KNbO_3$ and its composite with carbonate material were prepared using standardize procedure set-up by one of the authors. The structural characterization confirming the formation of ferroelectric phase and composite nature by structural characterization tools has been discussed in earlier reporting elsewhere [12,13].

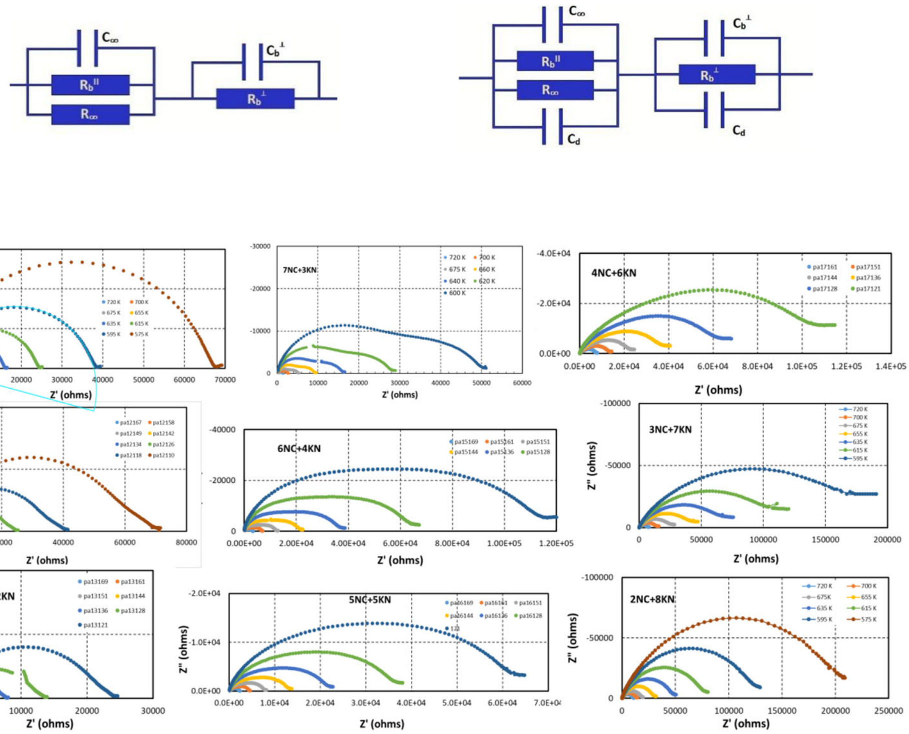

Figure 3. Impedance plots for the binary compositions ranging from 0–80% $KNbO_3$ into Na_2CO_3 at different temperatures.

Figure 3(a) shows the impedance plots for all compositions of the composite electrolyte, depicting two discernible semicircular arcs. The presence of two discernible depressed semicircular arcs is the manifestation of two different conduction regimes within the material [14].The high frequency semicircle corresponds to migration of ions through the bulk of Na_2CO_3 grains as well as parallel to the grain boundaries, whereas the low frequency semicircle suggests migration of ions perpendicular to grain boundaries. These two relaxations are shown by the equivalent circuits in Fig. 3(b). The low frequency semicircle is seen increasing in size with increase in dispersoid $KNbO_3$ concentration.

Complex impedance plots are analyzed by fitting the complex impedance data as per the equation,

$$Z(\alpha) = R_o + \frac{R_{B1}}{1 + (j\omega\tau_1^*)^{a1}} + \frac{R_{B2}}{1 + (j\omega\tau_2^*)^{a2}} \quad (1)$$

Where, R_{B1} and R_{B2} are the bulk resistances related to first and second semicircles (charge transfer mechanisms) respectively; τ^*_1 and τ^*_2 are the mean relaxation times for them [12]. α, an empirical measure of the departure of the charge as learned from the ideal Debye model, is related to the angle of depression ($\theta = \alpha\pi$) of semicircular arc in complex impedance plane. The value of bulk resistance R_B is obtained by taking real axis intercept of the semicircular impedance curve. Bulk resistance was found decreasing with increase in temperature and showed typical composite effect with maximum

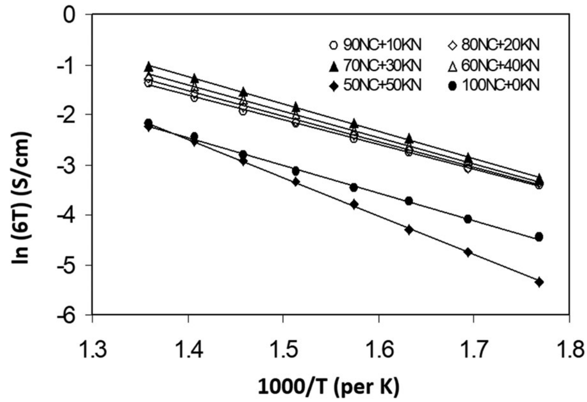

Figure 4. Arrhenius plots for binary electrolyte system (50–100)Na_2CO_3+(50–0)$KNbO_3$.

conductivity at optimum content of inert phase (here $KNbO_3$) in the host [8]. The addition of dispersoid was found modifying the hosts with formation of more than one channels for ionic conduction as revealed from impedance spectroscopy.

Increase in conductivity with higher dispersoid concentration suggest that a greater number of conducting pathways perpendicular to grain boundaries are enabled with increase in dispersoid concentration. Maximum conductivity is observed for the composition $70Na_2CO_3 + 30KNbO_3$, suggesting optimum distribution of dispersoid resulting into connected conduction pathways for ions, which is the typical behavior reported for all inert particle dispersed composites. The equivalent circuit for compositions containing higher dispersoid concentrations is modified with addition of a capacitor C_d in parallel in the low frequency branch [15].

From the Arrhenius plots shown in Figure 4, about one order of magnitude enhancement in conductivity is observed for all compositions having $KNbO_3$ content less than 50 mole%. All compositions have comparable values of activation enthalpy. Though all the four compositions with $KNbO_3$ mole fraction from 10 to 40% gave comparable values of conductivity, the maximum conducting composition $70Na_2CO_3 + 30KNbO_3$ is very clearly identified. Enhancement in conductivity is seen insensitive to composition in low temperature region. For composition $50\,Na_2CO_3 + 50\ KNbO_3$ conductivity is seen decreased for all temperatures with significant drop in at lower temperatures. This decrease in conductivity is also accompanied with increase in activation enthalpy $E_{a.}$

Figure 5 shows the plots of relaxation frequencies with temperature for pure Na_2CO_3 and $70Na_2CO_3 + 30KNbO_3$ composite. Activation enthalpy, E_a for the composite electrolyte obtained from the peak frequency values of high frequency semicircles is found comparable with E_a for the pure Na_2CO_3, validating the equivalent circuit. The low frequency data also gives E_a value comparable with pure Na_2CO_3 indicates that the defects created at the interface of Na_2CO_3 crystallite with $KNbO_3$ crystallite are of similar type as that existing in pure $Na_2CO_{3.}$

Impedance plots of composite electrolyte $70Na_2CO_3 + 30KNbO_3$ for different CO_2 gas partial pressures at 573 K are seen Fig. 6. Slight decrease in ionic conductivity of the composite electrolyte $70Na_2CO_3 + 30KNbO_3$ is observed with increase in CO_2 gas partial pressure ranging from 0.01 to 10%. This decrease is understood in terms of reduction in Na^+ ions at the electrolyte surface due to its equilibration with CO_3^{2-} molecule

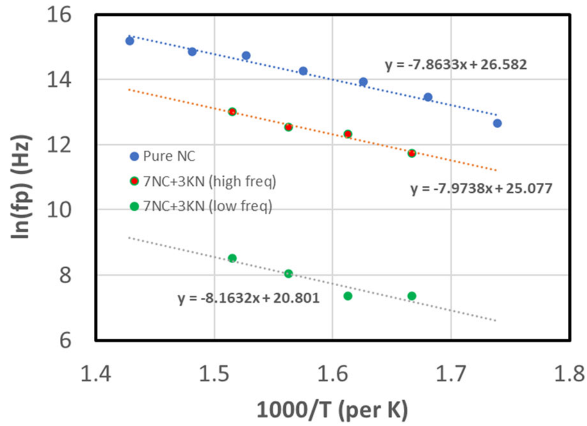

Figure 5. Variation of relaxation frequencies with temperature for pure $Na_2CO_3$and $70Na_2CO_3+$ $30KNbO_3$composite.

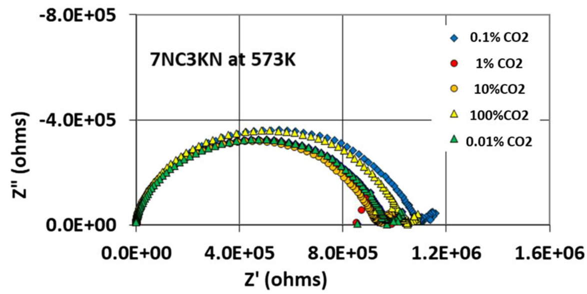

Figure 6. Impedance plots for $70Na_2CO_3+$ $30KNbO_3$ binary electrolyte with CO_2 gas partial pressure at 573 K.

creating temporary phase of Na_2CO_3 as $2Na^+ + \frac{1}{2} O_2 + CO_2 + 2e \leftrightarrow Na_2CO_3$. The ionic conduction is found increased for 100% CO_2 gas atmosphere, which is an obvious effect as CO_3^{2-} ions will not be formed in absence of O_2. This is an important parametric effect that needs to be considered in analyzing the sensor characteristics. As per Nernst equation the *emf* of potentiometric CO_2 gas sensor is independent of electrolyte conductivity, but it has been observed that sensors with different electrolyte materials produces different emfs and also their t_{90} response time differs significantly with the electrolytes used.

Comparison of the Arrhenius plots for pure Na_2CO_3 with that of for composite electrolyte can be seen in Fig. 7(A,B). At lower temperatures, the ionic conductivity for pure Na_2CO_3 is found to be significantly affected by CO_2 gas partial pressure variation, the change is being of two orders of magnitudes. At high temperatures the effect of CO_2 atmospheric condition on conductivity is found decreasing (Fig. 7). At high temperature this effect is not significant seen due to increased number of charge carriers giving ionic conductivity.

Arrhenius plots for composite electrolyte of $70Na_2CO_3+30KNbO_3$ shows that the significant variation in conductivity with CO_2 gas partial pressure at low temperatures seen in pure Na_2CO_3 is obviated for its composite with $KNbO_3$. This is due to increased

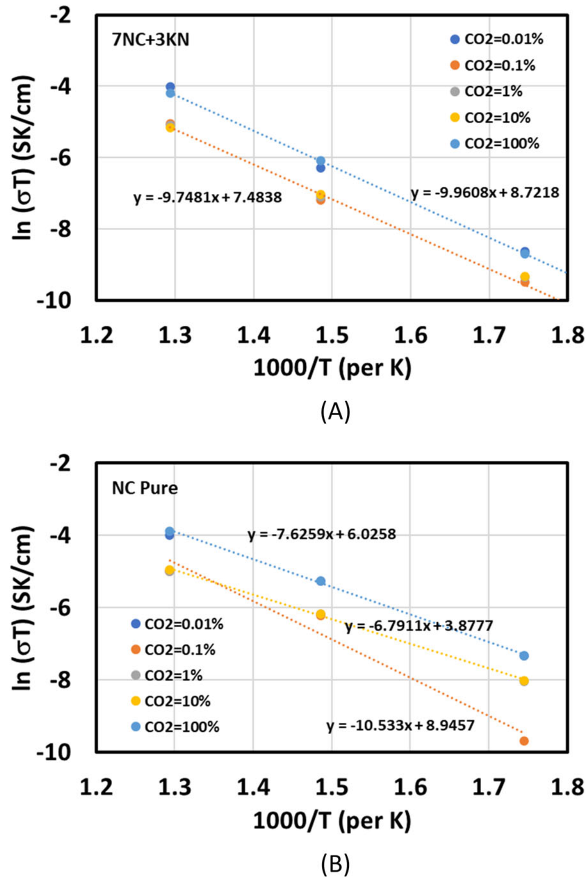

Figure 7. Arrhenius plots for (A) pure Na_2CO_3 and (B) composite electrolyte, $70Na_2CO_3+30KNbO_3$ for different CO_2 gas partial pressures.

number of free ions/defects at the grain boundary interface due to surface interactions typically seen in most of the composites [16].

Transport number measurement studies revealed majorly ionic character of the composite $70Na_2CO_3+30KNbO_3$, as the sample was getting polarized very fast (< 5 s) with the application of small DC potential through reversible electrodes over a wide temperature range (Fig. 8). A comparison of total conductivity (zero time) σ_0 and electronic conductivity (infinite time) σ_{in} in Fig. 9 shows that the increase in ionic conductivity with temperature contributes to increase in total conductivity, as electronic conductivity is found remaining almost constant. From the values of these conductivities, the ionic and electronic transport numbers are found to be $\boldsymbol{t_i}$ =0.99924 and t_e = 0.00076 at 773 K.

Response of the sensor for toggling CO_2 gas partial pressures between two values 260 and 2600 ppm at 673 K is shown in Fig. 10. The sensor response was found stabilized after 70 min of warm up time. Significant improvement in the sensor response time as well as recovery time of the electrochemical CO_2 gas sensor (i.e. $\boldsymbol{t_{90}}$< 10 s) was found with this composite simultaneously serving as an electrolyte and sensing electrode. CO_2

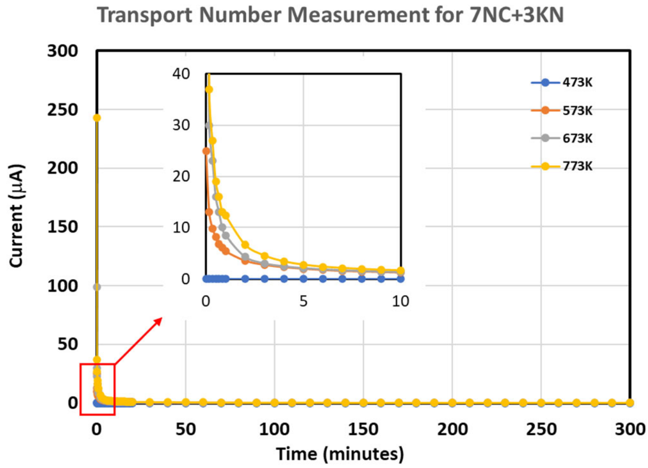

Figure 8. Transport number measurement studies revealed majorly ionic character of the composite $70Na_2CO_3+30KNbO_3$.

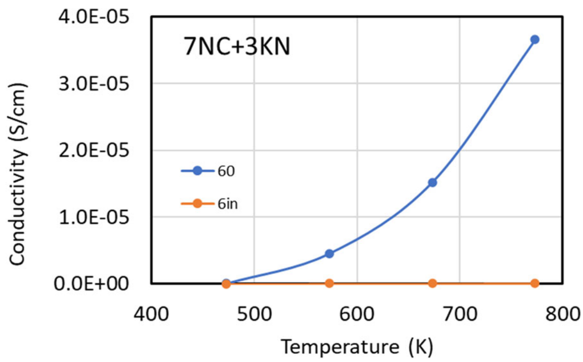

Figure 9. A comparison of total conductivity (zero time) σ_0 and electronic conductivity (infinite time) σ_{in}.

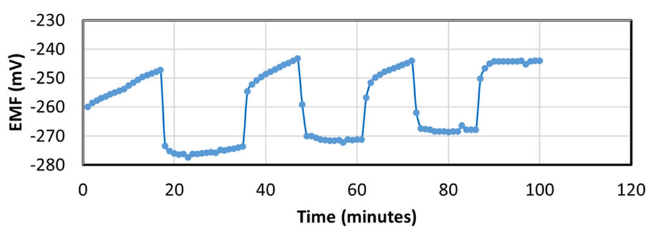

Figure 10. Sensor response for $(Na_2SnO_3)/(70Na_2CO_3+30KNbO_3)$ system while CO_2 gas partial pressure toggled between 1 decade of change.

being polar molecule, its adsorption on the sensing surface is facilitated by the charge topography resulting due to presence of ferroelectric phase in the surface. This has resulted in to significant decrease in sensor response time. Enhanced conductivity due to grain boundary effect has provided highly conducting pathways for ion as well as electronic charges. Sensitivity of the sensor was found matching with theoretical value of 28 mV/decade change of P_{CO2} for gas partial pressures range < 785 ppm (Fig. 11).

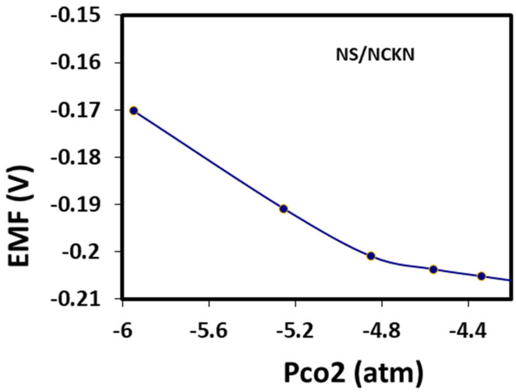

Figure 11. Sensor response for pCO_2 Vs emf developed between sensing ($70Na_2CO_3+30KNbO_3$) and reference electrodes (Na_2SnO_3) while ($70Na_2CO_3+30KNbO_3$) as an electrolyte.

4. Conclusion

The dispersion of hard ferroelectrics into the monovalent carbonates Na_2CO_3 enhances the ion transport perpendicular to the grain boundary as an additional mechanism to that of conduction through the bulk and along the grain boundary. The ferroelectric phase enhances the ionic transport and provides thermal, chemical and mechanical stability to the device. Fast ion migration results in reduced response and recovery times (t_{90}~10 s) of the sensor which is fastest among all composite as well as binary electrolytes.

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