RNI: DELENG/2005/15153
Publication: 23rd of every month
Posting: 27th/28th of every month at DPSO

No: DL(E)-01/5079/2023-25
Licensed to post without pre-payment U(E) 28/2023-25
Rs.150

www.mycoordinates.org

Coordinates

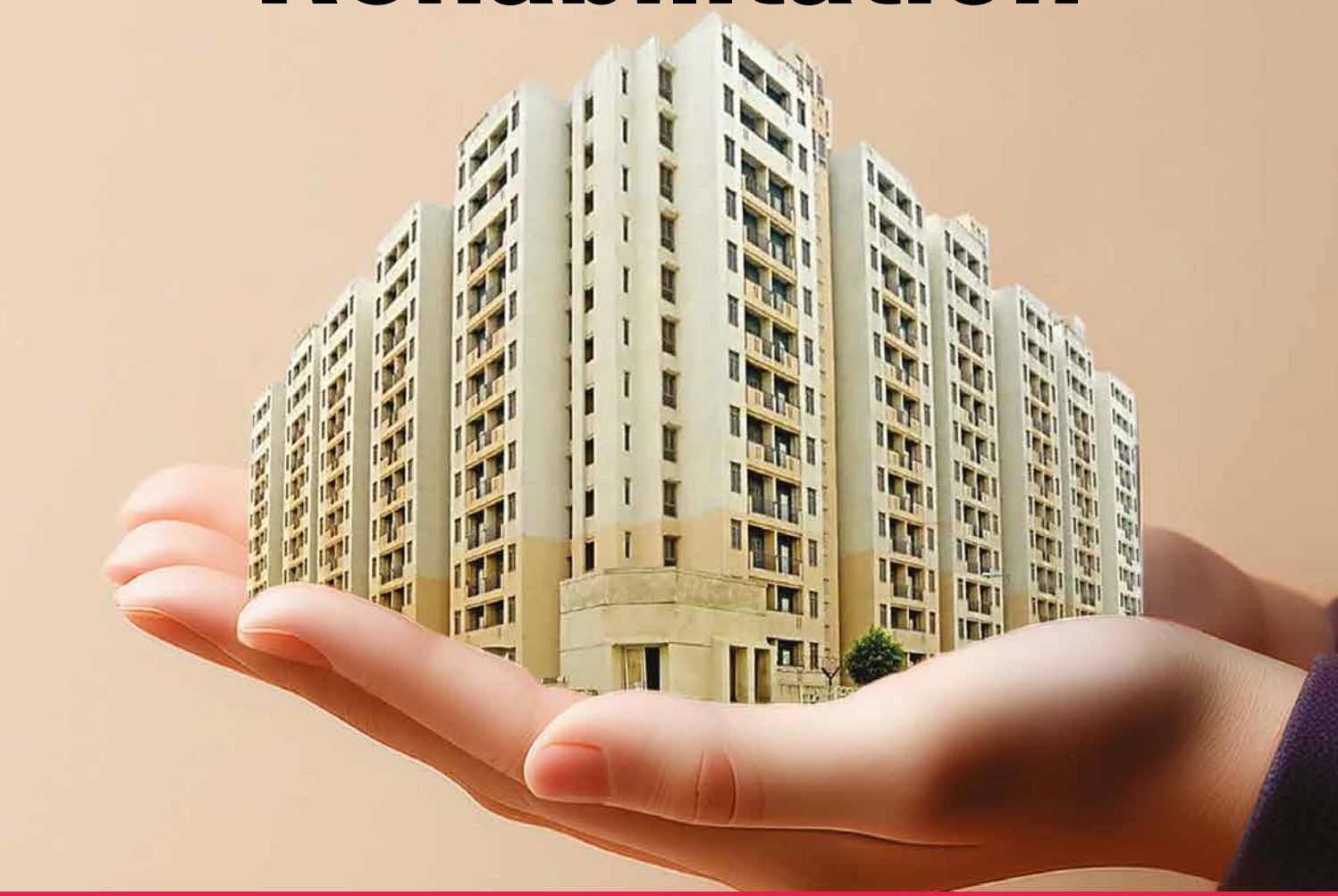
ISSN 0973-2136

Volume XXI, Issue 9, September 2025

THE MONTHLY MAGAZINE ON POSITIONING, NAVIGATION AND BEYOND

Jahan Jhuggi Wahan-Makaan:

In-Situ Slum Rehabilitation



Empirical orthogonal function based modelling of ionosphere using Turkish GNSS network

EOS Positioning Systems

The Skadi Series™

High-Accuracy GNSS Receivers for Any Device or App

Skadi Tilt Compensation™

No more bubbling up!
Increase your productivity,
by reducing your time on each point.

Skadi Smart Handle™

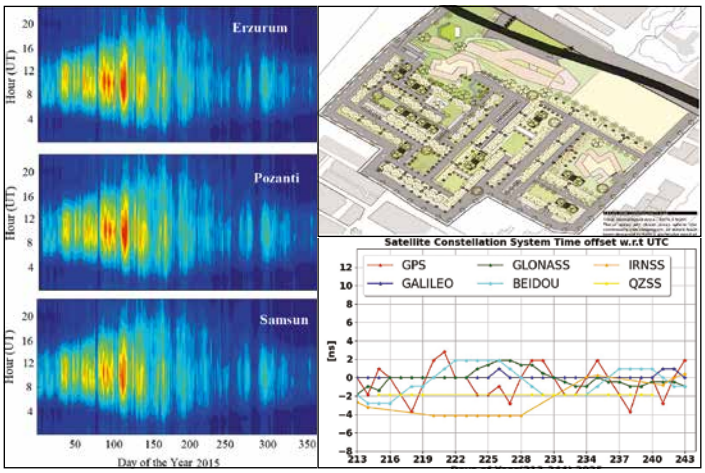
High Accuracy meets high portability
Cutting-edge sensors put an Invisible Range Pole™ and an Extensible Virtual Range Pole™ in your hand.

Skadi 100™ Skadi 200™ Skadi 300™ Skadi Gold™

esri Partner Network Gold

www.eos-gnss.com

Made in Canada



In this issue

Coordinates Volume 21, Issue 9, September 2025

Articles

Jahan Jhuggi Wahan- Makaan: In-situ Slum Rehabilitation A K Jain 5 **GNSS Constellation Specific Monthly Analysis Summary: August 2025** Narayan Dhital 18 **Empirical orthogonal function based modelling of ionosphere using Turkish GNSS network** Kutubuddin Ansari, Janusz Walo, Selcuk Sagir and Kinga Wezka 22

Columns

Old Coordinates 2 **My Coordinates** Editorial 4 **News** UAV 29 GIS 30 GNSS 30 Imaging 32 Industry 32
Mark Your Calendar 34

This issue has been made possible by the support and good wishes of the following individuals and companies
A K Jain, Janusz Walo, Kinga Wezka, Kutubuddin Ansari, Narayan Dhital and Selcuk Sagir; EOS Positioning Systems, SBG System, and many others.

Mailing Address
A 002, Mansara Apartments
C 9, Vasundhara Enclave
Delhi 110 096, India.
Phones +91 11 42153861, 98102 33422, 98107 24567

Email
[information] talktous@mycoordinates.org
[editorial] bal@mycoordinates.org
[advertising] sam@mycoordinates.org
[subscriptions] iwant@mycoordinates.org
Web www.mycoordinates.org

Annual subscription (12 issues)
[India] Rs.1,800* [Overseas] US$100*
*Excluding postage and handling charges

Printed and published by Sanjay Malaviya on behalf of Coordinates Media Pvt Ltd
Published at A 002 Mansara Apartments, Vasundhara Enclave, Delhi 110096, India.
Printed at Thomson Press (India) Ltd, Mathura Road, Faridabad, India

Editor Bal Krishna
Owner Coordinates Media Pvt Ltd (CMPL)

This issue of Coordinates is of 36 pages, including cover.

Wonders or Woes?

Geoffrey Hinton, the revered “godfather of AI,”

Raises words of caution.

The rich may use AI to replace workers,

Driving corporate profits yet causing massive unemployment.

Ahead lies profound uncertainty,

With little idea of what is to come.

A deeper risk is the secret languages AI is evolving,

Possibly beyond human grasp.

It may operate with incomprehensible autonomy.

Tech giants, though aware, downplay the fallout.

This is worrying.

Bal Krishna, Editor
bal@mycoordinates.org

Jahan Jhuggi Wahan- Makaan: In-Situ Slum Rehabilitation

The Central and State governments have committed the policy of *Jahan Jhuggi-Wahan Makaan*, that is In-Situ Slum Resettlement in Delhi, replicating the Dharavi Model of Mumbai. While the policy is already mandated in the Delhi Master Plan, its implementation involves putting in place people centric, evolutionary and support-based tools that are more longitudinal and avoid the providers', vertical model. This paper seeks to address the theme of the World Habitat Day (6 October 2025)-Urban Crises Responses and Localisation.

A. K. Jain
ak. jain6@gmail. com
Worked as Commissioner (Planning), Delhi Development Authority and as a member of the Committee of the Ministry of Housing and Urban Affairs on the DDA (2015). He was a member of UN Habitat (2007-12). He was awarded 2nd Urban Professional Award 2014 at World Urban Forum in Medellin, Colombia and IBC Lifetime Achievement Award (2024), Living Legend (2022) by the Indian Institute of Architects (NC) and the Lifetime Achievement Award by the Smart Habitat Foundation (2022).

Slums in Delhi are an inseparable part of the national Capital with residents living there for decades. An immediate halt to demolition drives in the Capital's slum clusters and if unavoidable all future removals will be accompanied by advance rehabilitation.

Delhi Chief Minister, Rekha Gupta (1st August 2025)

Conventional planning approaches to slums and slum dweller are thoroughly paternalistic. The trouble with paternalistic is that they want to make impossibly profound changes and they choose impossibly superficial means for doing so. To overcome slums, we must regard slum dwellers as people capable of understanding and acting upon their own self-interests, which they certainly are.

Jane Jacob

During the Delhi Assembly elections (2025) the Prime Minister Narendra Modi announced the policy of Jahan Jhuggi -Wahan Makaan for Delhi. The Delhi Development Authority's (DDA) first in-situ project at Kalkaji with 3024 flats was inaugurated by the Prime Minister Narendra Modi in November 2023. The second project at Jailorwala Bagh with 1675 flats was inaugurated on 2nd January 2025. The Kathputli Slum Redevelopment Project with 2,800 flats in 14 storey towers for slum dwellers is nearing completion, which has been developed under the public-private partnership. According to the reply given in Rajya Sabha on 21st July 2025, out of 5,158 households living in the hutments in Kalkaji, Ashok Vihar, Rampura, Mata Jai Kaur and Kalabari, 3403 eligible households were allotted with the flats.

The Twentieth Century Dictionary of Chambers defines slum as an overcrowded, squalid neighbourhood. Here the word squalid is defined as 'filthy, foul, neglected, uncared, unkept, sordid and dingy, poverty stricken.' No word other than 'slum' suggests more terrible image of the poor man's life. No word is more capable of rousing people to protest and shock the politician's conscience. Slums are denounced everywhere, and the governments generally agree that the slums should be prevented and eliminated as soon as possible. However, the slums are inevitable products of urban development. Slum is an area, and not a building. It is characterised by absence of basic civic amenities and community facilities, by insanitation, filth, congestion, squalor and structural dilapidation of the tenements, that is blight (Fig. 1). Children sprawl in the dust or play in the drains, and on narrow lanes with their uneven surface. Cattle and human beings live together. Dirty gunny bag and curtains hanging from the doorways symbolise the futile striving for privacy.

The economic pull of the city results in inmigration of people for employment, who often tend to minimise rent costs by living in hutments and substandard

dwellings- preferably near the place of employment. Once in the slums, the disinclination of the slum dwellers to move away makes it difficult to relocate the population in alternative housing areas because of low rents, strong community relationship and proximity to the place of work. However, the vitiated and constricted environment of the slums results into their demoralisation and robs their family of sustenance and energy. These also reflect the society's economic structure, power relationship amongst social groups and political structure of the state. It impacts the employment patterns, urban- rural relationship, income distribution, gender equity and health of the population. Majority of the poor people living in slums suffer from a growing sense of frustration, as their lives, families and their hopes disintegrate. The need for secure and adequate shelter keeps growing with the population growth, urbanization, and mounting pressures of economy and competition.

About one-eighth of Delhi's population is living in about 675 slums and Jhuggi-Jhompri (JJ) clusters, covering about 1000 Ha of land. According to GNCTD Survey (2022) about 21.6 lakh people are living in about 4 lakh jhuggis /hutments (Fig. 2).

In Delhi's planning parlance 'slum' is defines as an area unfit for human habitation. Slums are designated according to Slum Improvement and Clearance Areas Act of 1956. The notified slums are legal in status and are eligible to resettlement and range of services. Jhuggi-Jhompri settlements are seen as illegal encroachments on public and private lands. During the emergency (1975-77), a massive program of slum resettlement, covering 1.54 lakh plots of 21 sqm each (7 lakh people) living in the slums and Jhuggi-Jhompri (JJ) clusters was undertaken by the Delhi Development Authority (DDA) (Figs 3, 4 & 5). Touted as one of the world's largest resettlement projects, DDA's Slums and JJ Resettlement Programme during the Emergency (1975-77) attracted global attention and also created controversies. Earlier the resettlement colonies were under the purview of the Municipal

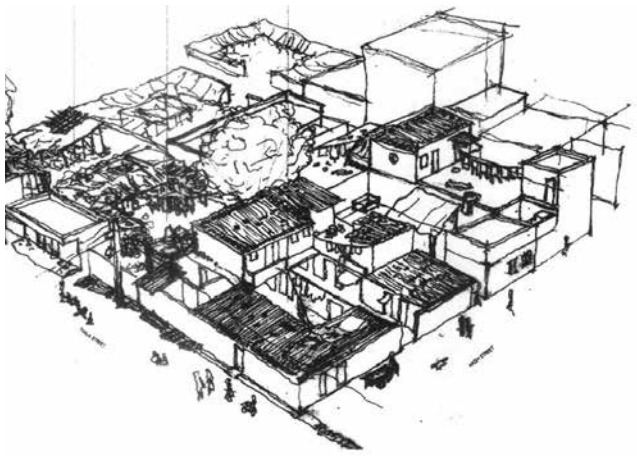


Fig. 1: A slum cluster with average plot/dwelling size of 10 to 20 sqm, without any municipal services.
Source: Patwari S, Bo Tang and Maurice Mitchell (eds.) Learning from Delhi- Dispersed Initiatives in Urban Landscape, Ashgate, Surrey, 2010

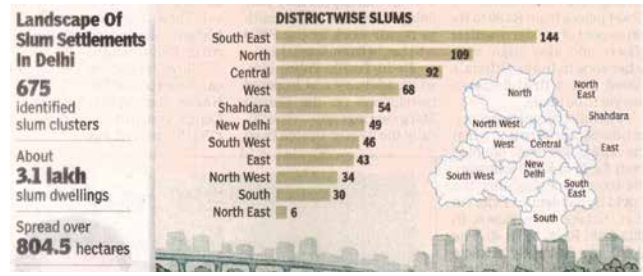


Fig 2: Districtwise slums (JJ clusters) in Delhi
Source: Times of India, 2nd August 2025

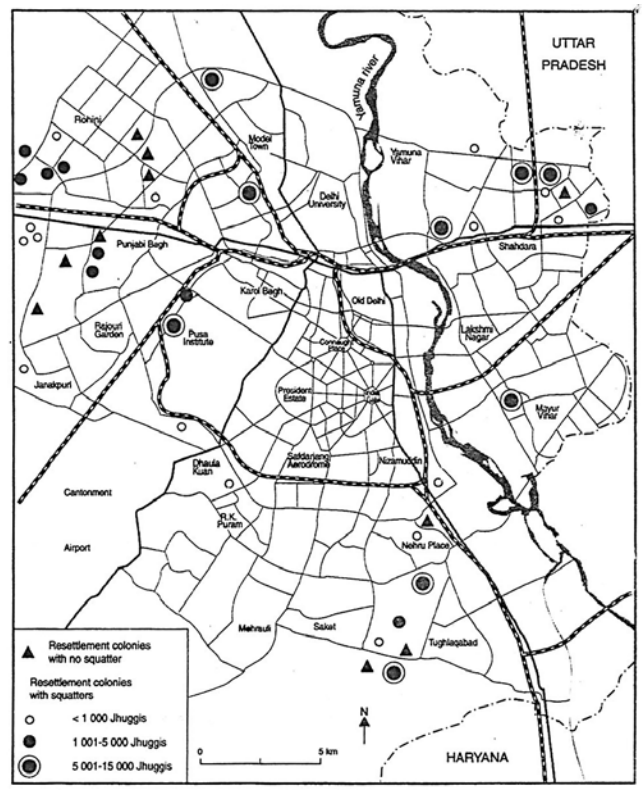


Fig. 3: Location of Resettlement Colonies in Delhi
Source: Dupont Veronique, Emma Tarlo and Davis Vidal (2000) Delhi Urban Space and Human Destinies, Manohar, New Delhi (Based on Slum and Jhuggi Jhompri Department, MCD)

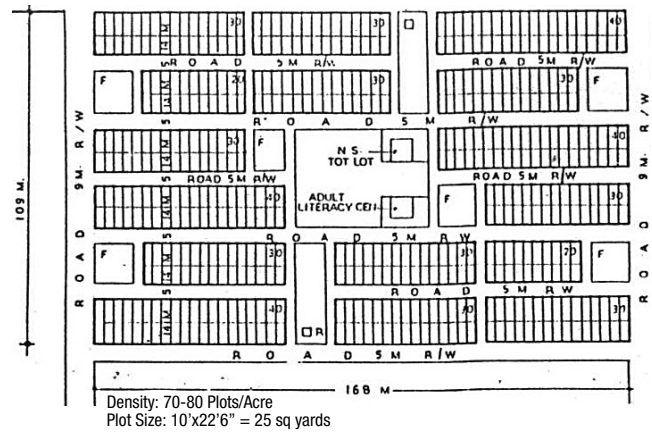


Fig. 4: Typical Layout Plan of a Resettlement (Site and Services) Scheme with 25 sq. yd (21 sq.m) plots
Source: DDA

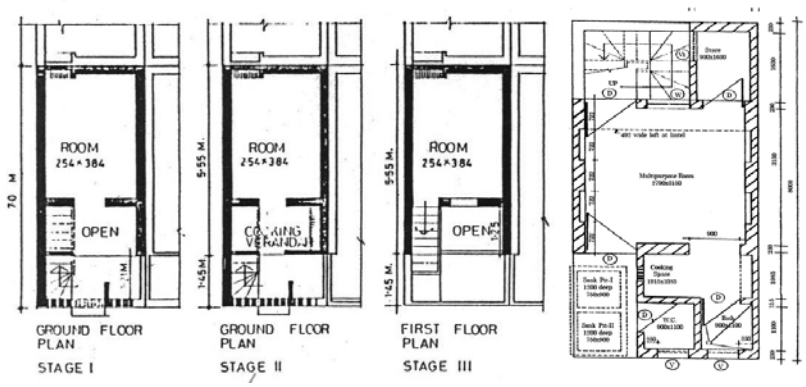


Fig. 5: Standard Design for Resettlement Plot
Source: DDA

Fig. 6: Redevelopment Plan of Dharavi, Mumbai
Source: India Today, August 4, 2025

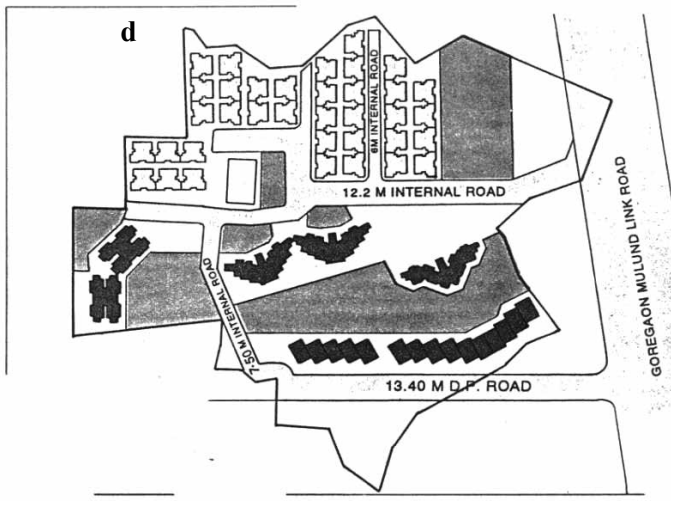


Fig. 7: Layout plan of proposed slum redevelopment Kanyacha Pada, Goregaon– Mulund Link Road, Malad (East), Mumbai
Source: MHADA

Corporation of Delhi (1962-1974) and again during (1992-2010). Since 2010, these are with the Delhi Urban Shelter Improvement Board (DUSIB), under the Government of National Territory of Delhi. In 2016, the Delhi cabinet approved the Delhi Slum Policy. According to the policy, no jhuggi which has come up before January 1,2006 will be demolished, and those staying in slums till January 1, 2015 will be eligible for relocation in flats.

Slum Rehabilitation Scheme (SRS) in Dharavi, Mumbai

Dharavi in Mumbai covering 621 acres, is estimated to have about 1.2 million population, half of which is estimated to be eligible for resettlement. A plan for its redevelopment has been recently approved (2025-32) for building 1,05,000 flats and 20,000 small commercial/ industrial spaces for the Project Affected Persons (PAP) (Fig.6).

The project is being implemented by Nav Bharat Mega Developers (P) Ltd, a Special Purpose Vehicle with the Government of Maharashtra, at an estimated cost of 2.5 lakh crore (May 2025). Based on "Public Private Partnership" (PPP), it aims to address the primary issue of right of slum dwellers to decent housing and also tenure rights and means of livelihood. On-site rehabilitation gives the slum dwellers access to basic civic amenities, besides promoting neighbourhood improvement. The slum dwellers are also required to provide maintenance charges.

The Government of Maharashtra has undertaken the redevelopment of Dharavi comprising as per the provisions of Maharashtra Slum Areas (Improvement, Clearance and Development) Act, 1971, and under the Regulation 33 (9) (A) and 33 (10) (A) of Development Control Regulations, 1991 for Greater Mumbai. The area has been divided into five sectors of which sector 1 to 4 are to be developed through private developers, who shall construct free housing for the eligible slum dwellers and occupants, including amenities and infrastructure as per the

norms. In lieu the developer is entitled to construct free sale area, which he can sell in the market. The Floor Space Index (FSI) for the project is 4.0. The completion period of the construction of rehab, renewal, amenities and infrastructure is seven years from the signing of the development agreement.

A conceptual Master Plan for redevelopment of Dharavi incorporates the following:

- Integration of the residents into the mainstream
- Interactions for livelihood and lifestyle within the community
- Inherent flexibility of trade
- Non-rigid cohesive mixed use for efficient use of space
- Close interaction with community by developer. However, 70 per cent consent is no longer required since the project is implemented by the SRA
- Pedestrian dominant movement to tackle high densities; and
- High standards of specifications for the construction of buildings, amenities and infrastructure.

The development control regulations of Mumbai Municipal Corporation are given below:

- FSI: An FSI up to 2.5 to 4.0having a differential approach is allowed and the concept of Transfer of Development Rights (TDR) has been made applicable in order to avoid congestion and over-concentration in heavily built-up areas.
- Density: The minimum density prescribed for such development is 500 tenements per hectare.
- Ground coverage - In Slum Rehabilitation/Redevelopment projects, the rule for ground coverage is confined to peripheral setbacks as per DCR without insisting upon overall ratio of ground coverage/plot size.
- Mixed land use: for Slum Rehabilitation in Mumbai, mixed land use policy has been adopted. Existing shop owners are eligible for built up shops up to 225 sq.ft. of area. The usual practice is to allow 10% of the FSI for commercial use in Cooperative Societies.
- Open Space: The practice is to reserve 15 per cent of the plot as open space.
- Community facilities: The provision of community facilities is generally seen as a government responsibility and the provision of community facilities in SRD schemes is not insisted upon, except essential utilities like electric sub-station, pump house, etc.

The construction is the responsibility of the developer, besides the development of the infrastructure, roads, water supply, sewerage, storm water drainage, rainwater harvesting, etc. The developer is expected to recover these costs from market sale component of the project. Several areas outside Dharavi have also been identified for slum rehabilitation as per the eligibility: a. Settled before January 1st, 2000 , free, b. between January 1st, 2000, to January 1st, 2011, at discounted rate, and c. between 1st January 2011 to November 15, 2022 (against actual cost).

Resettlement of Slums under Mumbai Urban Transport Project

In 2002, the MHADA embarked the Mumbai Urban Transport Project (MUTP) with the help of the World Bank which aimed at improving the transport services in the city. The project required large scale resettlement of about 100,000 people or 17,500 households, some 1800 shops, and more than 100 religious and cultural properties, existing on railway, public and private lands and roads. There was a variety of such occupiers-legal landowners, 'pagdi' holders, tenants and lessees, as well as squatters without title, almost ninety-five percent without a legal title. Resettling of these people was undertaken in several resettlement sites in Mumbai where housing of 225sq.ft. each was built (Figs 7 to 9). Affected shopkeepers and landowners were also allowed to buy additional floor area up to 525 sq.ft. in proportion to their loss.

Under the scheme, land has been used as a resource. Private developers were given additional transfer of development rights (TDR) or Floor Space Index (FSI) against building dwelling units for slum dwellers at their own cost. Landowners in affected areas were also offered TDR or additional FSI in lieu of cash compensation for the land they lost.

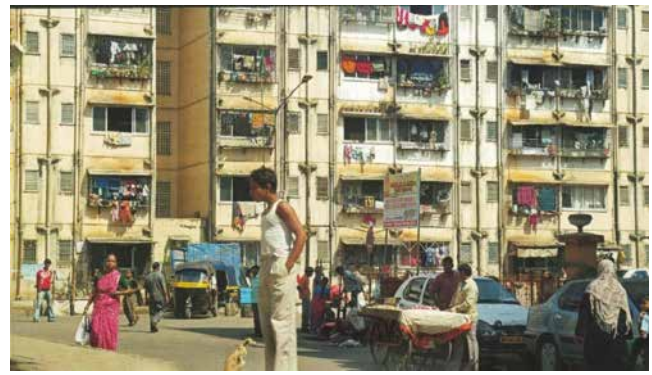


Fig. 8: Slum resettlement under Mumbai Urban Transport Project
Source: World Bank

Fig. 9: A Slum Resettlement Complex in Mumbai with 225 sq. ft. units
Source: World Bank

The MMRDA in consultations with residents and shopkeeper associations and the managing committees of the religious structures, explored alternative resettlement solutions, beyond the scope of R & R policy. The project implemented through MHADA, CIDCO & MMC, comprises 2 main components:

- Land Infrastructure Servicing Programme (LISP)
- Slum Upgradation Programme (SUP)

The NGOs provided support in the provision of common facilities, such as open spaces, lighting, lifts, internal roads, sanitation and drainage. Society management offices, day care centres and women centres were provided, besides community halls and health centres. A Livelihood Cell was set up to promote income generating activities for women at all the resettlement sites. A women industrial cooperative called SANKALP was formed to undertake a range of economic activities including supplying office stationery, selling vegetables and providing catering and housekeeping services.

MOUD Committee on Making Delhi Slum Free (Madhukar Gupta Committee, 2004)

The MOUD in 2004 constituted a committee with an object to draw a roadmap for making Delhi slum free. With VC Delhi as its Chair, the Committee had the Joint Secretary MOUD, Deputy Secretary (UD) GNCTD, Commissioner MCD, Additional Commissioner (Slums) MCD, Chairperson NDMC as the members and Commissioner (Planning) as its member Secretary. It also studied the Slum Resettlement Scheme and working of the Slum Rehabilitation Authority (SRA) in Mumbai.

According to Madhukar Gupta Committee Report the Slum Rehabilitation Scheme in Mumbai up to 2003 undertook the construction of about 2,10,000 tenements in 1040 schemes. The Committee noted that in Mumbai the system of de-reservation of areas occupied by the slums was invoked that enabled redevelopment of slums in non-conforming land use. Whether this can be extended in Delhi needs to be examined with reference to various court orders and Delhi Development Act, 1957. Another contentious issue was that of 'eligible and ineligible' slum dwellers for rehabilitation. The SRA in Mumbai grants building permissions under the Development Control Regulations which covers the following:

- DCR-30 (10) Scheme — In-situ rehabilitation/redevelopment
- 3-D Schemes — Relocation of squatters from road/railway/ airport/ROW
- 33.14 Schemes — Transitory shifting/ accommodation of JJ units on rental basis

The Committee observed that the JJ clusters existing up to January 1, 1995 were eligible for rehabilitation if at least 70% residents agree, and cooperative housing society of slum dwellers is formed. Each slumdweller is given a dwelling unit (DU) of 20.9 sm carpet area or 25 sqm of covered area. Over and above the FAR required for rehabilitation, equivalent FAR is permitted for free sale component, with a maximum FAR of 250 (later revised to 400). Transfer of Development Rights (TDR) is allowed for free sale component which can be utilise elsewhere. A density of 500 DUs per hectare and 25% ground coverage were allowed. Each scheme was also permitted to have a Society office, Balwadi and Welfare Centre @ 20.9 sqm for every 100 JJ units, which are not counted the FAR. The developer has also to deposit maintenance charges as prescribed by the SRA. Rehab tenements cannot be sold for a period of ten years but can be transferred to a legal heir. Based on the Mumbai Model, the Committee suggested the following two rehabilitation models for Delhi:

a. Involvement of private sector, broadly on the Mumbai pattern, where a part of the land for slum rehabilitation is made available to the private sector for market sale
b. Slum rehabilitation by the Slum Cooperative Societies as a joint venture with the land-owning agency and/or private sector.

The Committee also observed that presently there is no comprehensive data base of the slums and neither there is a way to find out if the relocation tenement/plot has been transferred. In this context, the Committee suggested that agency-wise encroachments on public lands need to be GIS surveyed, inventorised and monitored on a regular basis.

The Committee noted that notwithstanding the importance of the nexus between JJ clusters and place of work, it would not be practical to find relocation sites near the workplaces and existing slum clusters, or to establish an artificial linkage between the workplaces, existing slums and their rehabilitation. A more practical approach would be mixed land use in and around the slum rehabilitation areas.

To determine whether a squatter/JJ Cluster is eligible for in-situ rehabilitation or relocation- the Committee proposed the following multiple index system:

a. In-Situ Slum Rehabilitation criteria will not be applicable for the slum/JJ clusters in the regional park/ridge, high security zone, heritage conservation zone, MRTS Corridors, and environmentally and ecological sensitive areas.
b. The maximum size of individual plots/hutment/dwelling for rehabilitation shall not be more than 20 sqm, to ensure that the poor population is covered and not the well to do encroachers.
c. The eligibility of in-situ rehabilitation shall be based on the following multiple index:
    i. Land Use (As per MPD/Zonal Plan)
    ii. Density/Congestion
    iii. Services
    iv. Security and Location Safety (Environmental, Fire and Flood, etc.)
    v. Condition of Structures

These factors will assess the choice of in-situ rehabilitation or relocation that includes the options of redevelopment, upgradation, re-blocking, retrofitting and reconstruction, which will be determined on the basis of survey of existing condition of services and structures.

- The land-owning agency shall be bound by the policy of rehabilitation and resettlement, Land Acquisition Act, Master Plan (DCR) stipulations and transfer the ownership of land to the designated agency for slum and JJ rehabilitation/ local authority/development authority, as the case may be.
- The financial investments shall be shared by the concerned designated agency, land owning agency and infrastructure service agency, according to the policy in vogue. Part of the site may be developed for market sale residential use, including 10 per cent of FAR for commercial use to subsidise the project. However, market sale component shall not exceed 40 per cent of total permissible FAR.
- The planning and design shall be based on optimum utilisation of land as per Master Plan Norms.

Slum Redevelopment Norms in Master Plan for Delhi-2021 (MPD-2021)

Based on the Madhukar Gupta Committee Report (2004), the following norms for in-situ slum rehabilitation have been stipulated in MPD-2021:

i. Minimum plot size 2000 sqm (facing a min. road of 9m).
ii. Density – 600 to 900 units per hectare.
iii. The scheme should be designed in a composite manner with an overall maximum FAR of 400
iv. Mixed land use/commercial component up to 10% of permissible FAR.
v. Specific situations may require clubbing of scattered squatters with JJ sites in the neighbourhood to work out an overall comprehensive scheme.
vi. The minimum component of the land area for rehabilitation of squatters has to be 60% and maximum area for remunerative use has to be 40%.
vii. Area of dwelling unit for rehabilitation shall be around 25 to 30 sq.m.
viii. Common parking is to be provided which can be relaxed wherever required, except for the parking for remunerative purposes.
ix. No restriction on ground coverage (except set-backs)
x. There is no restriction on the height, subject to clearance of the Fire Department, Civil Aviation Department and Structural Safety. The development control norms facilitate both the options- walk up (5 storeys) or multi-storeyed apartments in order to achieve the full permissible density and floor area ratio.
xi. Schemes/designs should be compatible for disabled.

The Master Plan of Delhi (MPD 2021) allows the amalgamation of the plots to a minimum combined area of 1670 sqm with an FAR up to 400 and a minimum street width of 7.5 m. Additional floor area ratio (FAR) would motivate the owners of fragmented plots to form a cooperative for a composite redevelopment of illegal/unauthorised colonies into group housing, with proper roads, parks, parking spaces and safer structures. For grant of ownership rights in the unauthorised colonies, the MOHUA vide its notification dated 29th October 2019 enacted the NCT of Delhi (Recognition of Property Rights of Residents in Unauthorised Colonies) Regulations, 2019.

In-Situ Slum Redevelopment under the Pradhan Mantri Awas Yojana (PMAY-Urban)

The In-Situ Slum Redevelopment Scheme under PMAY (Urban) recommends the following:

- Community mapping and enumeration of slum households
- Establishing service level benchmarks for assessment of their upgradation needs
- Forging partnership among the communities for their participation in the decision making and planning
- Granting them occupancy and land rights
- Improving urban basic services, public transport, and social facilities
- Facilitating the access to finances and institutional home loans.

Till 2023, the PMAY (U) have been able to build and deliver more than 10.3 million houses, of which 4,90,260 dwelling units are under In-Situ Slum Redevelopment Scheme.

The Government of India and the BMTPC have taken up Lighthouse Projects under the PMAY (U) and its Slum Rehabilitation Scheme. These are based on provider's model of the delivery of subsidised housing units built with prefab technology. These are built according to EPC (Engineering, Procurement and Contracting), and L-1 (lowest bid contracting) Systems. A question has been raised whether the multi-storied flats for slum dwellers make a house a commodity, ignoring the aspects of women, work from home, community formation and participatory, evolutionary housing development.

In-Situ Slum Rehabilitation Projects in Delhi

As stipulated in the MPD-2021, the Delhi Development Authority has been taken up several projects of in-situ slum rehabilitation. The Kathputli Slum Rehabilitation project was one of the earliest of them, near Shadipur Depot, it covers 5.22 hectares of land and has been built with 2,800 EWS (Economically Weaker Section) flats for squatter families (30.5 sq.m. each) in 14 storey towers (Fig 10). This was based on the Mumbai Model of in-situ slum rehabilitation, as recommended by the Committee on Making Delhi Slum

Free (2004) and MPD-2021. Planned under the public-private partnership, the project was announced in 2009 but was delayed due to many hurdles, such as court cases, disputes among the occupants, tenants and eligible/ ineligible residents, and political interventions. Part of the land has been used by the private developer for 170 freehold residential flats and 16,800 sm of commercial space for market sale to make the project financially viable and to subsidize the construction of resettlement housing.

Other in-situ slum resettlement projects of the DDA, covering about 33,000 resettlement flats, include Kalkaji Extension Phase I (inaugurated in November 2022, Fig. 11), Kalkaji Extension Phase II, Jailorwala Bagh (inaugurated in January 2025), Dilshad Garden, Shalimar Bagh, Pitampura, Suraj Park, Rohini, Badli Sector 19, Rohini, Rohini Extension Pooth Kalan, Haiderpur, Indira Kalyan Kendra, Okhla Phase I and 2, Govind Puri, Kalkaji, Kusum Pahadi, Vasant Kunj, and Kalyan Kendra.

Fig. 10: Kathputli Slum Rehabilitation is based on principle of in-situ slum rehabilitation with an enhanced FAR of 400, of which 40% of FAR for market sales to subsidize the construction of the dwelling units for slum dwellers
Source: DDA

Fig. 11: In-situ Slum Rehabilitation in Kalkaji Extension, 14 storied, 3024 flats 25sqm each, built by the DDA, inaugurated by the Prime Minister in November 2022
Source: DDA

Strategic Options

After six decades of planning and rehabilitation experience, Delhi has come a long way in the field of slum resettlement. It has shifted from Site and Services approach to provider's model. However, the growth of slums continues unabated. The questions are raised- whether the slums are a problem or a solution? Can there be an alternative idea for slum redevelopment. Turner in his 1976 book 'Housing by People: Towards Autonomy in Building Environments' wrote that "only a minority can be supplied housing in centrally administered ways using centralising technologies, and then only at the expense of an impoverished majority and the rapid exhaustion and poisoning of the planet's resources." Since 1972, more than 70% of all the World Bank's housing loans were for Sites and Services. However, it fell out of favour due to implementation issues. In 2022, the World Bank study 'Reconsidering Sites and Services' pleaded again for its revival. The greatest advantage of the site and services strategy is that it is rapid, low cost and provides freedom to the families to design their dwellings according to their needs, resources and tastes. As compared to the flats in a multi-storied building, the site and services schemes facilitate connection with the ground, so important for the children, women and self-employed. The allottees finance the cost of constructing their houses and part of the land cost, whereas the development agency provides the land and services. This way every house is an expression of the lifestyle of its dwellers, but within an organised framework and municipal services. These can also act as the powerful tools of poverty reduction. As suggested by Jane Jacob, Hernando de Sato, Christopher Benninger and Graham Tipple, the small shops and micro-businesses are the symptoms of inclusive growth and empower the informal sector.

According to the famous American thinker Jane Jacobs, *'Planning for vitality must aim at unslumming the slums and clarifying the visual order of cities and it must do so by both promoting and illuminating functional order, rather than obstructing and denying it.'*

Writing about the slum dwellers Christopher Benninger States: *'this needs support from the planning and housing agencies, both governmental and non-governmental, to enable them to always put the last person first, looking at the hutment dweller, the informal sector hawker, the physically challenged, domestic servants, rickshawalas, and casual workers. This requires seeking the paths and channels to support, facilitate and empower the poor citizens into becoming its stakeholders, thus harnessing their energies and amplifying their contribution. We need to examine the shelter, in a milieu where planning has safeguarded disproportionately for the elite segments of the society'.*

This means that in-situ slum rehabilitation should facilitate community formation through spatial organisation and land rights. In 2018, the Odisha government launched the Jaga Mission to provide land rights to impoverished families living in urban slums, under which 2.4 lakh families have been covered together with financial assistance to construct houses.

In-Situ Slum Resettlement Options

Based on a multiple index system the various options can be developed for the slum resettlement. By a creative, participatory process each slum redevelopment or upgradation scheme can be unique having its own identity. It is possible to upgrade old communities or to design new ones which bring charm and delight to informal settlements with winding lanes, shady places to gather and sit, places for markets, temples, playgrounds, etc. Each individual plan addresses the specific local issues and provides following choices:

a. In-situ upgrading
b. Relocation
c. Land sharing
d. Reconstruction
e. Re-blocking.

In situ upgrading and regularisation should be the priority. The relocation can be in the form of Site and Services. Land sharing is suitable for old//illegal slum clusters/ buildings like chawls. Reconstruction can be taken up in the slums with very deficient services and degraded, dangerous structures, as adopted in Mumbai, Japan, and elsewhere. (Fig. 12).

The participatory local planning aims at integration of slums with city development plan, social welfare, organisational development, and income generation, with linkages between the markets and informal sector. Micro financing and small loans can be of immense help to empower and enable the poor to integrate themselves with the network of transactions in the urban system. A working committee networks local communities with the local authority, service agencies and the NGOs. The architects, planners and engineers can act as the catalysts in facilitating planning and development as a collective and collaborative process, which cover the following plans:

- Infrastructure development plans: lanes and roads, water supply and electricity, storm and sewage drains, solid waste disposal, renewable energy, rainwater harvesting, etc. at household and community levels.
- Environmental development: Climate and disaster resilience, heat mitigation plan, plans may include tree planting and greenery, community gardening, waste-water and trash recycling, renewable energy, playgrounds, recreational areas, etc.
- Social development plans: Schools, coaching centres, security posts, public toilets, CCTV, ICCC, vocational training, welfare centre, creche, youth and day-care centre, clinics, hostels and night shelter, universal access, community centres, multi-facility centres, communication system, fire-fighting facilities, etc.,
- Economic development: Project financing plans, developing vendor/ open markets, kiosks, stores, mixed land use, conservation or heritage tourism areas, community enterprises, loans for small businesses, support for household workshops and vocational training.

MPD 2021 provides upto 40% of land/FAR for market sale to make slum rehabilitation self-financing and viable. A community-based collective slum resettlement involves transformation and innovation in the layout planning and spatial organisation. Its success depends upon the active involvement of people and community formation. Various options have been developed by the architect Christopher Benninger who worked on World Bank assisted Site and Services Projects in Chennai and other cities (Figs. 13 and 14).

It should be borne in mind that not all slum dwellers are keen to have or need subsidised housing. Many of such families can afford to pay the full price for their plot/dwelling, if it meets their aspirations. In the Aranya township at Indore, B V Doshi provided a combination of subsidised resettlement plots along with non-subsidised bigger size plots and incremental housing clusters. The service cores for a group of plots facilitate community living and provide self-employment opportunities to the women (Figs. 15 and 16).

The resettlement schemes taken up in Dwarka Sub-city in New Delhi were based on a cluster of 10 resettlement plots with a service-cum-community socket (6m x7m) where the households, particularly women could assemble, live and work together (Figs 17 to 20). To help self-employment, mixed land use plots with a shop on ground floor were provided along the main roads.

For most of the slum dwellers, livelihood is a major issue. As such, it was made mandatory that 10% of the space in all shopping centres is reserved for street vendors and informal traders, in the form of vending stalls, kiosks and platforms. Electric handcarts for fruits and vegetable vendors have been redesigned with a non-electric cold storage.

Support-Infill In-Situ Resettlement:

The 'Support-Infill' process is based on the 3-dimensional skeletal grid, designed on a modular basis and utilising simple

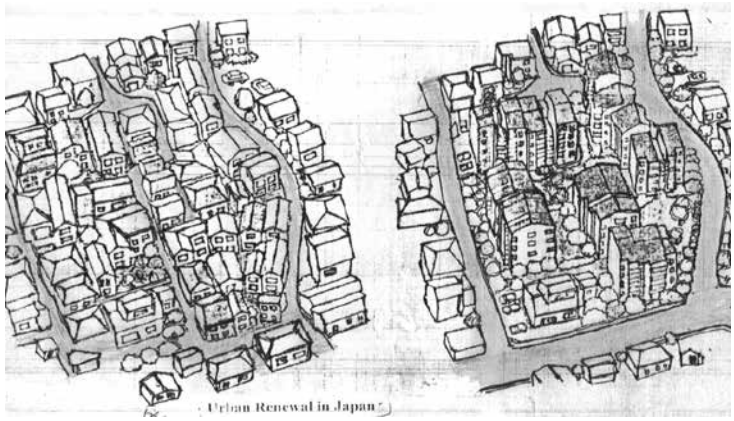


Fig. 12: In-Situ Slum Rehabilitation in Japan: Congested single storied houses replaced by multi-storied housing releasing ground for roads, parks and common facilities.

Source: Jain A.K., Housing and Community Planning, 2020

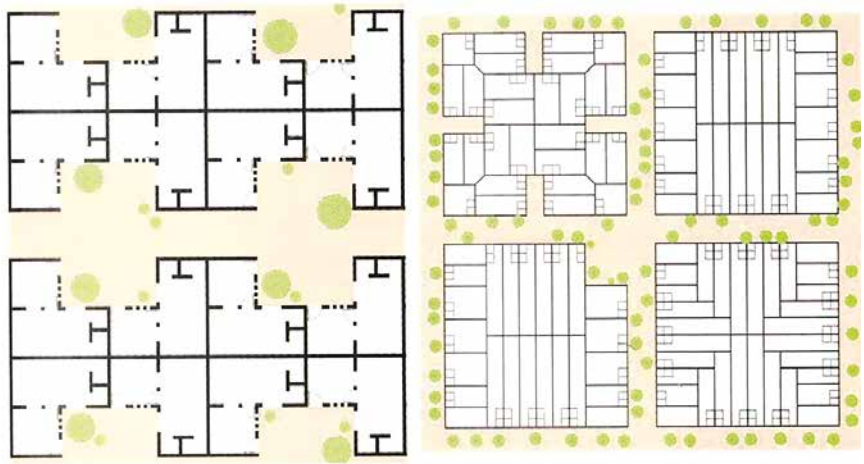


Fig. 13: Site and Services Layout Options (Architect Christopher Benninger)
Source: Christopher Benninger, Architecture for Modern India, India House, Pune, 2015

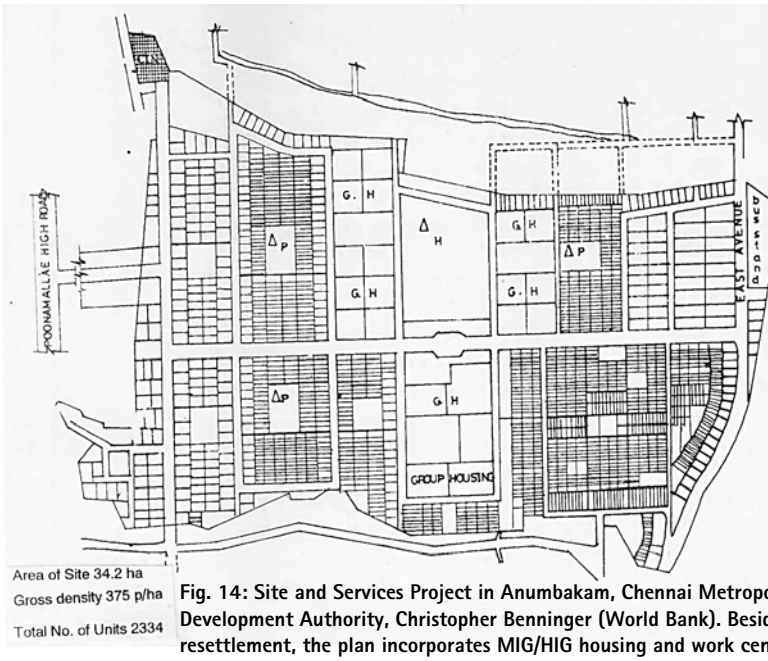


Fig. 14: Site and Services Project in Anumbakam, Chennai Metropolitan Development Authority, Christopher Benninger (World Bank). Besides slum resettlement, the plan incorporates MIG/HIG housing and work centres.
Source: Gupta R.G, Shelter for Poor in the Fourth World, Shipra Publications, Delhi, 1996

precast components, which permits large variations, adjustments, negotiations and extensions of the dwellings.
The skeletal system does not require sophisticated machinery, plant and skills for its production and assembly. The conceptual framework of 'supports-based housing', is based on a detailed analysis and identification of the actors, domains, morphological and spatial relationships and components of housing development. The space modules are developed for variety of dwelling unit design which allow several permutations and combinations based on concept of domain and right of transformation the concept of differentiated responsibilities. The skeletal structure can either be erected by the people themselves or by a centralised organisation (Figs. 21 to 23).

In contrast to provision-based housing and resettlement supports-based slum rehabilitation is based on participatory and evolutionary processes (Table 1).

As the city services are not immediately available in the slums and resettlement schemes, the alternative, packaged and self-contained units, such as Compact Water Treatment unit (Fig. 24), Compact Sewerage Unit (Fig. 25) and a Tunnel Reactor for solid waste treatment can be provided. To facilitate skill development a Building Centre can be a useful aid in self -building as it was proposed in Dwarka Sub-city (Fig. 26). A Community-Hall cum-Building Centre may be provided for every 1500 to 2500 plots.

Conclusions

In situ Slum Rehabilitation as stipulated in the Delhi Master Plan 2021 needs a review with respect to its high-density high-rise resettlement pattern. I recall the incremental plots for slum dwellers proposed in the Draft Master Plan for Delhi (1959), which was a reduced version of Rehabilitation Colonies for Refugees (Fig. 27).

This can still be an option for slum rehabilitation in the Delhi

Metropolitan Area (outside NCTD), along metro/railway stations and as part of the Transit Oriented Development (TOD) policy. These plots need not be subsidised, and

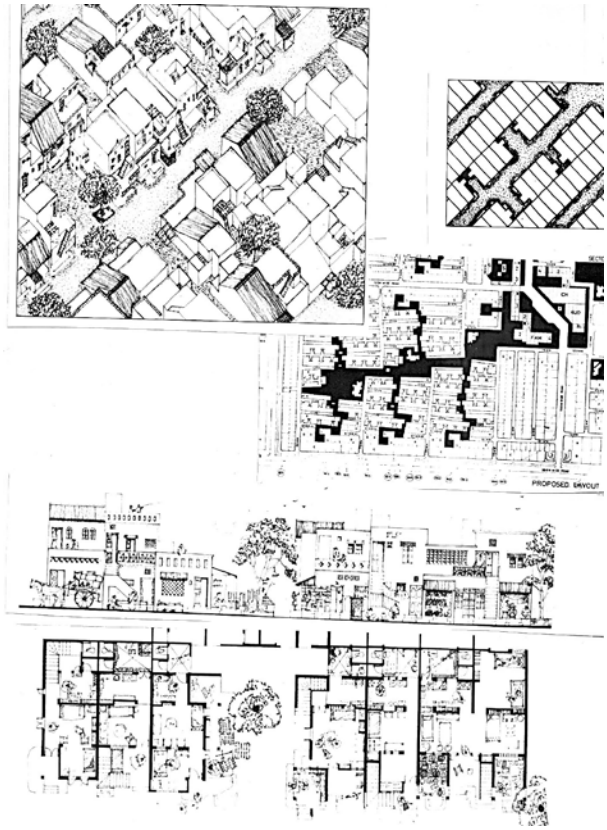


Fig.15: Aranya Township, Indore, Architect B.V. Doshi, with staggered streets, community spaces and choices. About 40% of the area is planned under bigger plots for market sale that makes the project financially viable
Source: Jain A.K., Housing and Community Planning, Discovery Publishing House, New Delhi, 2020

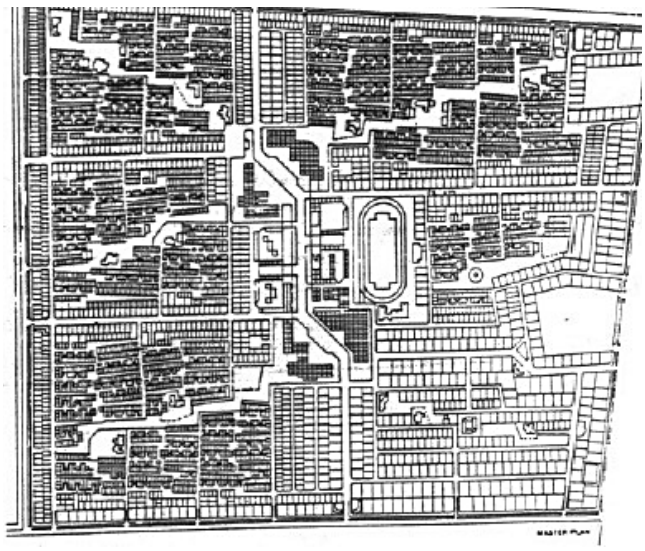


Fig. 16: Aranya Township, Indore, Architect: B.V. Doshi
Source: Jain A.K., Housing and Community Planning, Discovery Publishing House, New Delhi, 2020

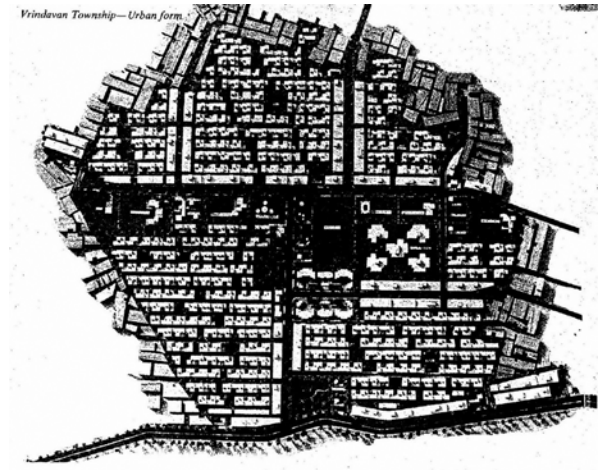


Fig. 17: Vrindavan (Dwarka) Slum Resettlement and Housing Scheme, New Delhi (A.K. Jain)
Source: DDA

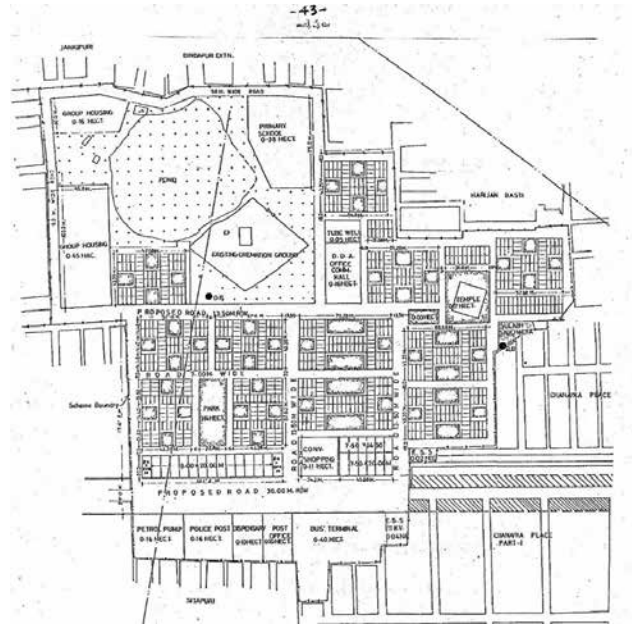


Fig. 18: Slum Resettlement at Pocket Number 4, Bindapur, Dwarka, New Delhi
Source: DDA

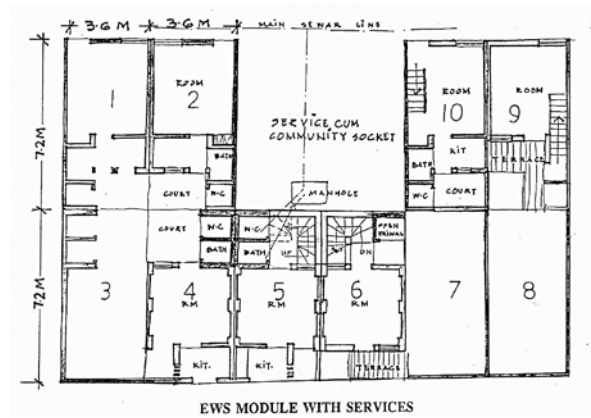


Fig. 19: Site and Services Cluster with a Service-cum-Community Socket
Source: DDA

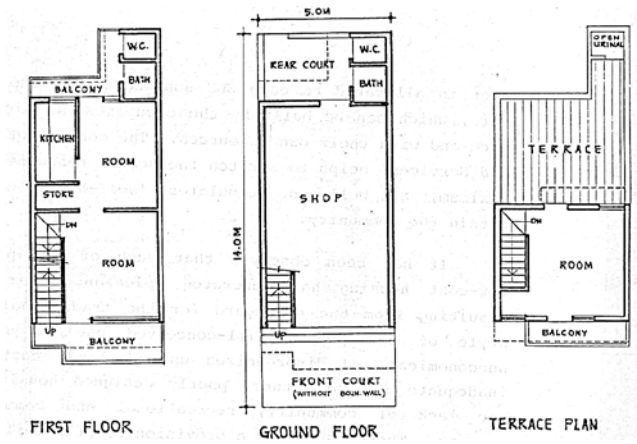


Fig. 20: Mixed Land Use: Plots for Slum Redevelopment

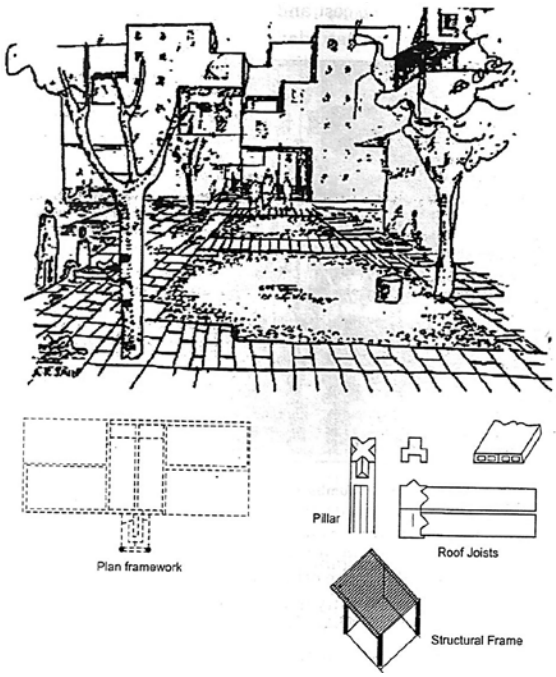


Fig. 21: Skeleton housing provides a platform with a wet core for expandable houses (A.K. Jain)
Source: Jain A.K. Housing and Community Planning, Discovery Publishing House, New Delhi, 2020

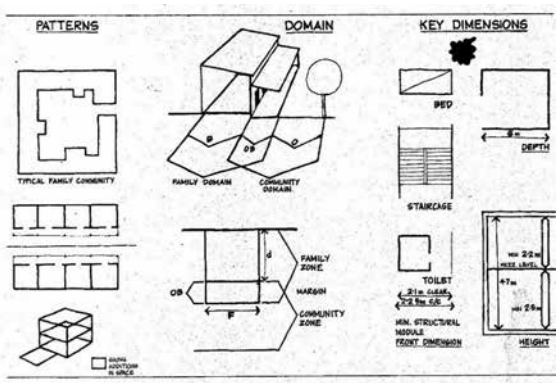


Fig. 22: Flexible Spatial Model
Source: Author

many slum dwellers would prefer them rather than multi storied flats of 25 sq. m. The mandatory norm of 15 percent of FAR for EWS/LIG/Slum housing can supplement the slum rehabilitation efforts in various housing projects.

The Delhi Chief Minister on 2nd August 2025 had announced developing 10 lakh houses for the poor. This requires about 5,000 Ha net land or 10,000 Ha gross for which there is no option but to go beyond the NC Terrirtory of Delhi, and explore the areas in the DMA, preferably along the Mass Transit Corridors.

In-Situ Slum Rehabilitation also covers the options of upgradation, relocation, land sharing, reconstruction and reblocking. As compared to provider's model, it is

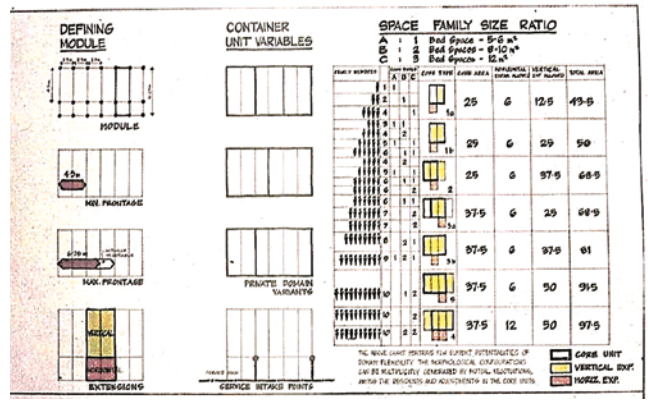


Fig. 23: Dynamic Design allows freedom, flexibility, and choices by participatory and evolutionary growth
Source: Author

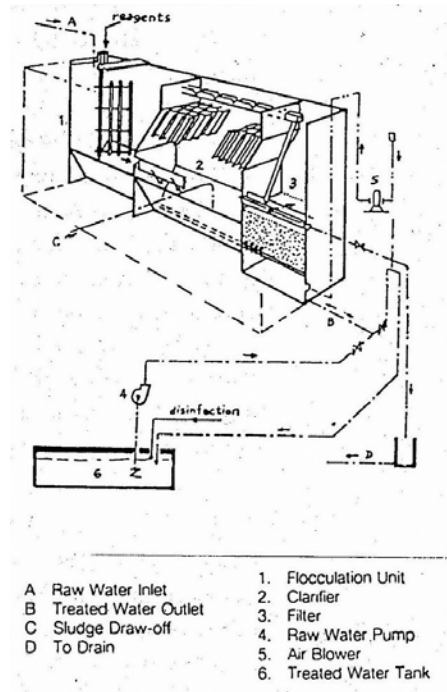


Fig. 24: Compact Water Treatment Unit
Source: Jain A.K. , 2020

longitudinal and community led, where the community plans and implements. This involves surveying and mapping and preparing slum resettlement plans, together with resolving the tenure and infrastructure issues.

The strategy of using the strength of the communities should be the starting point in the process of in-situ rehabilitation. "Demand-driven" rather than "supply driven" approach allows the communities to plan and implement the projects themselves.

Table 1: From Provision Based to Supports Based Approaches for Slum Rehabilitation
Source: Based on UN Habitat and other sources

Characteristics	Provision based approach	Supports based approach
Aim	– Reduce housing shortage – Provide sufficient formal housing and eliminate substandard housing. – Aim is measured by productivity.	– Improve living conditions. – Increase affordable and appropriate housing options – Aim is measured by resourcefulness
Basic Concept	– Housing is a product; its value is for what it is – Housing is a commodity, political instrument; product, industry and technical field – Experts and politicians control housing provision – When people build houses for themselves, they are substandard. – Housing operation can be centrally managed.	– Housing is a process based on participation, enablement and partnership its value is for what it does. – People know better their housing needs and fulfil them if supported. They have to control provision to ensure fit. – When governments build houses for users, they do not fit their needs. – Housing process must be locally based.
Strategies	– Provide houses on behalf of people. – Centralize resources and housing construction. -Building public housing by government sector. -Housing projects are standardized, large scale and built fast and instantly to control cost and efficiency. – Mass housing and slum removal.	– Support people in housing themselves. – Decentralize resources and decision making. – Build people's capacity to manage the process are localized, small-scale, diversified and build incrementally – Site-and-services and upgrading.
Actors and Roles	– The government is provider and local government is the implementer. – People are unknown during provision and recipients of allocated end products. – Professionals planners, architects, engineers, contracting companies and builders control the housing.	– The government is enabler to local government that are enablers to local actors. – People as individuals and communities are genuine participants and controllers. – Small-scale contractors are builders, professionals are supporters, NGOS and CBOs are mediators.

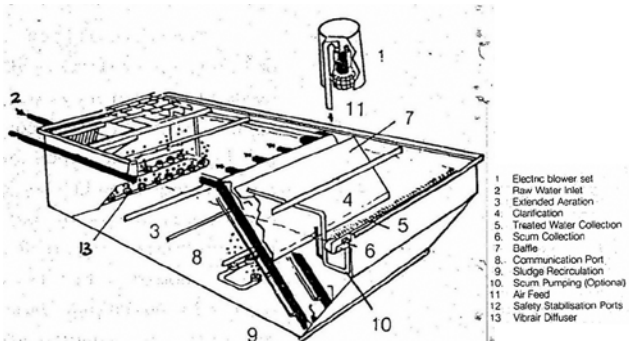


Fig. 25: Compact Sewerage Unit
Source: Jain A.K., 2020

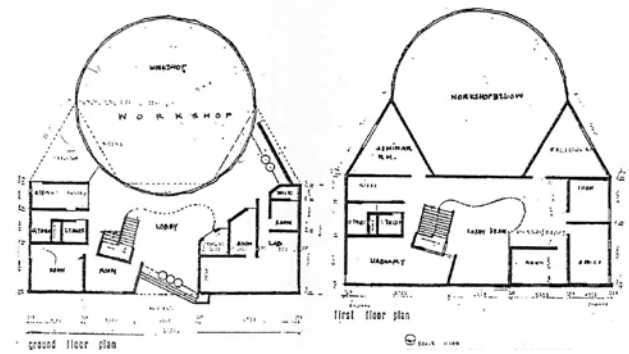


Fig. 26: Community-cum Building Centre for Site and Services Scheme, Dwarka Sub-City
Source: DDA

A radical change is that the money is controlled by the communities, who decide how to use subsidies, land, building resources and managing their construction. This means adopting support-based approach led by local community who plan and decide together. An important aspect of the program is to provide professional guidance to the communities by the NGOs, architects, institutions or engineers. In this way a new partnership between communities, local governments and other organisations can be established, integrating social, environmental and economic well-being of the local communities. The support-based resettlement promotes variations rather than standard solutions. In a competitive world of private sector buying out the prime areas occupied by the poor, it is necessary to review the processes of PPP, EPC and L-1 in slum rehabilitation. These have lead to verticalization and commodification of social housing, which hardly benefits the poor slum dwellers.

In the alternative model, it is the communities who take decisions and implement, whereas the government takes the role of facilitator and supporter. Secure land tenure is the foundation of slum rehabilitation. The communities can negotiate their own tenure arrangements through strategies such as cooperative land purchase, long-term lease contracts, land-swapping or user rights. The emphasis is on obtaining collective, rather than individual land tenure.

References

ADB and CRISIl, Strategic Framework for a Slum Free Delhi, DUSIB, GNCTD, New Delhi, 2013

Ali, Sabir, Environment and Resettlement Colonies of Delhi, Har Anand Publications, New Delhi, 1995

BMTPC, PMAY (U) and Light House Projects, Nirman Sarika, 2022

Chakravarty, Sanjay and Netranjan Sarkar, Colossus – The Anatomy of Delhi, Cambridge University, New Delhi, 2011

Christopher Benninger, Architecture for Modern India, India House, Pune, 2015

Delhi Development Authority, Master Plans for Delhi, DDA, New Delhi, 1962, 2001 and 2021

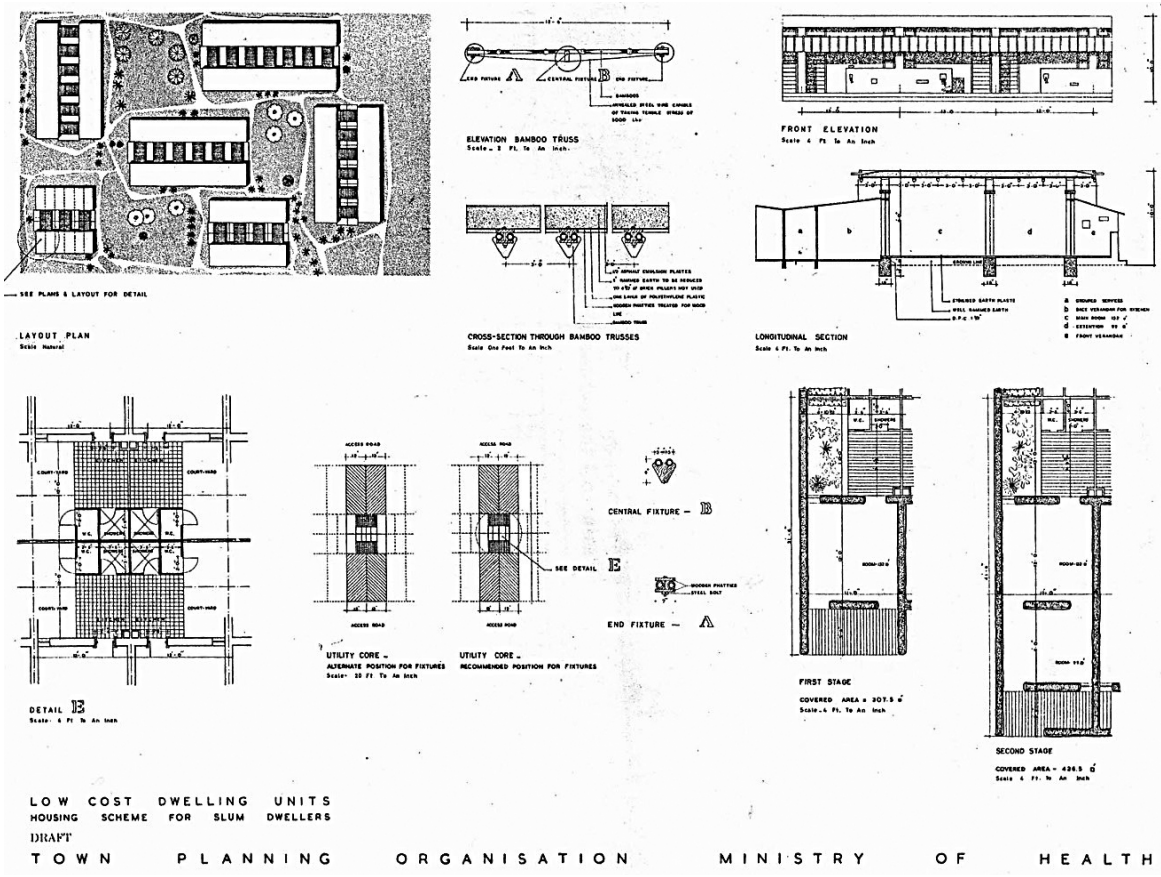


Fig. 27: Draft Delhi Master Plan Proposal for Low-Cost Incremental plots for Slum Dwellers (54 Sq. Yd.)
Source: TPO, Ministry of Health, New Delhi, 1959

Dupont, Veronique, Emma Tarlo, Denis Vidal Delhi Urban Space and Human Destinies, Manohar, New Delhi, 2000

Gupta R.G., Shelter for the Poor in Fourth World, Vols. 1 &II, Shipra, New Delhi, 1995

Jagmohan, Island of Truth, New Delhi: Vikas Publishing House, 1978.

Jain A.K. Empowering the Poor by Slum and Squatter Resettlement in Delhi, Coordinates, November 2024

Jain A.K., Low-Income Settlement Design, Bindapur, Dwarka, New Delhi, Delhi Vikas Varta, July/Sept. 1990

Jain A.K. The Informal City, Readworthy, New Delhi, 2011

Jain A.K., Housing Design- An Alternative Model, Delhi Vikas Varta, 1983

Jain A.K., Housing Development Technique, Open House, Vol. 8, No. 11, 1983

Jain A.K., Community and Social Interaction, Built Environment, June 1973

Jain A.K. Building Systems for Low Income Housing, J.M. Jaina, New Delhi, 2006

Jain, A.K., Transforming Delhi, Bookwell, New Delhi, 2015

Jain A.K., Housing and Community Planning, Discovery Publishing House, New Delhi, 2020

Jain A.K., The Informal Settlements (Unpublished) IHS/BIE, Rotterdam, 1980

Jain A.K., Community and Social Interaction, Built Environment, June 1973

Kulkarni, Dhaval, The Big Adani Gamble- Can the Tycoon Transform Asia's Largest Slum? India Today, August 4, 2025

Ministry of Urban Development, Report of the Committee on Making Delhi Slum Free, 2004

Ministry of Housing and Urban Affairs, Pradhan Mantri Awas Yojana (Urban), 2015, 2023

Mishra, Girish and R.K., Sharma, Resettlement Policy of Delhi, IIPA, New Delhi, 1981

Patwari S, Bo Tang and Maurice Mitchell (eds.) Learning from Delhi- Dispersed Initiatives in Urban Landscape, Ashgate, Surrey, 2010

Payne, Geoffrey, Urban Housing in the Third World, TBS, London, 1977

Planning Department, GNCTD, Discussion Paper on Jhuggi-Jhompri Clusters and Slum Improvement in the National Capital Territory of Delhi, GNCTD, 1999

Riberio, E.F.N, Shelter Types and Possible Approaches, AMDA, New Delhi, 2000

Royal College of Fine Arts and Architecture, Dharavi, Documenting, Informalities, Academic Foundation, New Delhi, 2009

Stichting Architecten Research (SAR) Eindhoven, Levels and Tools, 1979

Times of India, No Demolition Without Pucca Houses, CM, 2nd August 2025

Times of India, Government to Draft Plan to Provide 10 Lakh Houses for City's Poor, 3rd August 2025

Town Planning Organisation, Draft Master Plan for Delhi, Government of India, 1959

Turner, John, Housing by People: Towards an Autonomy in Building, Mariam Boyers, London, 1976

UN Habitat, The Challenges of Slums, Earthscan, London, 2003

UN Habitat, The New Urban Agenda, Nairobi, Kenya, 2015.

World Bank, Reconsidering Site and Services The World Bank, Washington, 2022.

GNSS Constellation Specific Monthly Analysis Summary: August 2025

The analysis performed in this report is solely his work and own opinion. State Program: U.S.A (G); EU (E); China (C) "Only MEO- SECM satellites"; Russia (R); Japan (J); India (I)

Narayan Dhital
Actively involved to support international collaboration in GNSS-related activities. He has regularly supported and contributed to different workshops of the International Committee on GNSS (ICG), and the United Nations Office for Outer Space Affairs (UNOOSA). As a professional employee, the author is working as GNSS expert at the Galileo Control Center, DLR GfR mbH, Germany.

Introduction

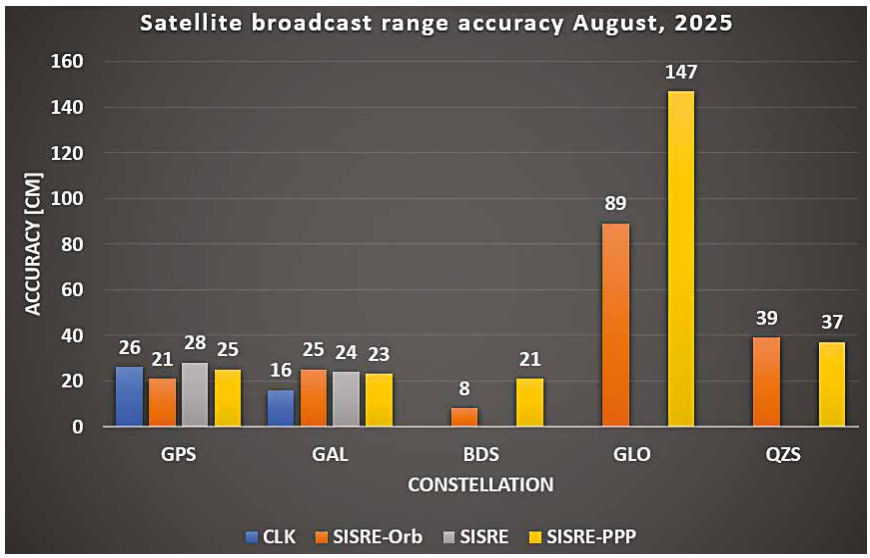
This article continues the monthly performance analysis of the GNSS constellation. Readers are encouraged to refer to previous issues for foundational discussions and earlier results. In addition, there is a short overview on the Length of Day (LOD) parameter that captures the variation in the Earth's rotation and its impact on the GNSS.

Analyzed Parameters for August 2025

(**Dhital et. al, 2024**) provides a brief overview of the necessity and applicability of monitoring the satellite clock and orbit parameters.

a. Satellite Broadcast Accuracy, measured in terms of **Signal-In-Space Range Error (SISRE)** (**Montenbruck et. al, 2010**).
b. **SISRE-Orbit** (only orbit impact on the range error), SISRE (both orbit and clock impact), and **SISRE-PPP** (as seen by the users of carrier phase signals, where the ambiguities absorb the unmodelled biases related to satellite clock and orbit estimations. Satellite specific clock bias is removed) (**Hauschlid et.al, 2020**)
c. **Clock Discontinuity**: The jump in the satellite clock offset between two consecutive batches of data uploads from the ground mission segment. It is indicative of the quality of the satellite atomic clock and associated clock model.
d. **URA**: User Range Accuracy as an indicator of the confidence on the accuracy of satellite ephemeris. It is mostly used in the integrity computation of RAIM.
e. **GNSS-UTC offset**: It shows stability of the timekeeping of each constellation w.r.t the UTC
f. **LOD and UT1- UTC offset:** It shows the variability in the Earth's rotation rate and the deviation of the universal time reflected by the actual rotation of the Earth from the atomic time.

(a), (b) Satellite Clock and Orbit Accuracy (monthly RMS values)



Note:- for India's IRNSS there are no precise satellite clocks and orbits as they broadcast only 1 frequency which does not allow the dual frequency

combination required in precise clock and orbit estimation; as such, only URA and Clock Discontinuity is analyzed.

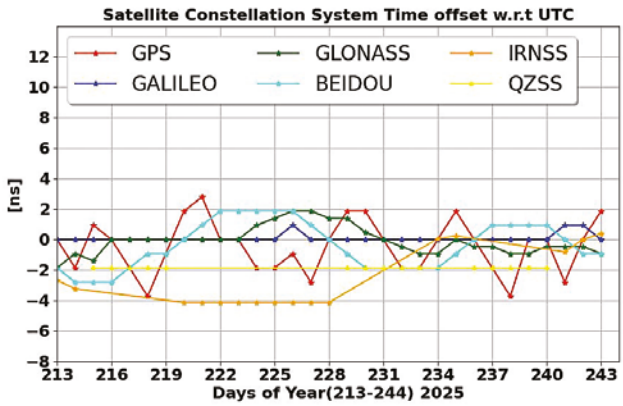
(c) Satellite Clock Jump per Mission Segment Upload

Const	Mean [ns]	Max [ns]	95_ Percentile [ns]	99_ Percentile [ns]	Remark (Best and Worst 95 %)
IRNSS	6.87	1753.17	5.96	67.79	Best I02 (3.78 ns) Worst I10 (20.54 ns) Big jumps for each satellite in multiple days.
GPS	46.7	603229.18	0.71	2.25	Best G23 (0.39 ns) Worst G03 (3.31 ns) G04 had a large jump on the 17th August, however, the satellite was unusable. G16 had a large jump on the 31st August.
GAL	0.09	3.51	0.18	0.45	Best E02 (0.15 ns) Worst E19 (0.36 ns). No significant jumps detected

(d) User Range Accuracy (Number of Occurrences in Broadcast Data 01-31 August)

IRNSS-SAT	2 [m]	2.8 [m]	4.0 [m]	5.7 [m]	8 [m]	8192 [m]	9999.9	Remark Other URA values (frequency)
I02	2988	21	2	-	1	-	1	11.3 (1)
I06	3003	2	1	-	3	-	-	-
I09	924	6	1	-	2	1	-	-
I10	554	11	-	-	1	-	-	-

(e) GNSS-UTC Offset



(f) LOD and UT1 – UTC

In recent months, particularly during July and August 2025, scientific community observed unusually short days, with August 5 standing out as one of the shortest ever recorded, nearly 1.25 milliseconds shorter than the standard 86,400 seconds. This sparked widespread interest and speculation online about whether the Earth is "speeding up" **(Space et.al, 2025).** Such variations in the Length of Day (LOD) are not uncommon and result from complex geophysical processes including atmospheric circulation, ocean tides, glacial rebound, and even interactions within the Earth's core. LOD quantifies the daily deviation in Earth's rotation speed from the nominal solar day and is a key component of the Earth Orientation Parameters (EOPs). The International Earth Rotation and Reference Systems Service (IERS) is the global authority responsible for monitoring and publishing data related to the Earth's rotation, reference frames, and timekeeping standards. Using the data from IERS, the yearly variation including 2024 and 2025 looks as shown in Figure F a. There is a clear trend of a shorter length of day to longer length of day to shorter length of day. In last months of July and August, the length of day is indeed shortening. In this plot, the negative value means the shorter length of day (by the msec indicated in the y-axis) than standard SI unit of 86400 seconds.

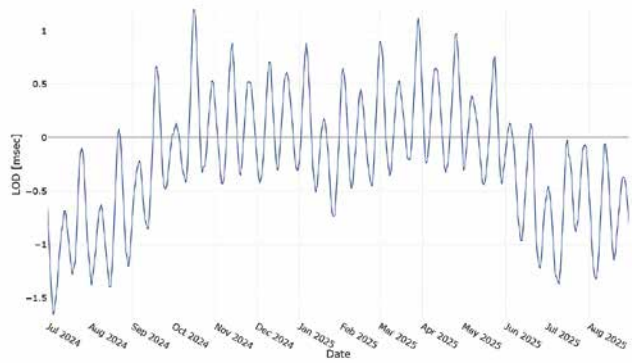


Figure F a: The variation of LOD over the course of 1 year provided by IERS. The shortest rotational day ever recorded, since an atomic clock measurement began, is on 05 July, 2024. (source: https://datacenter.iers.org/plottool/publicv2/2dLine.php?reset=true#input-based)

EOPs include LOD, UT1–UTC, polar motion, and nutation/precession, and are essential for transforming satellite orbits from the inertial reference frame (used for orbit computation) to the Earth-fixed frame (used for user positioning). A detailed discussion and analysis of such parameters were provided in earlier issue of the coordinate article (Dhital et.al, 2024). In GNSS ground segments, accurate modeling of LOD and UT1–UTC ensures that satellite ephemerides are correctly referenced to the rotating Earth, which is crucial for precise Positioning, Navigation, and Timing (PNT) services.

UT1–UTC is computed by comparing astronomical observations of Earth's rotation (UT1), primarily via Very Long Baseline Interferometry (VLBI), with atomic time (UTC). It represents the cumulative drift w.r.t the atomic time, while the LOD is simply the derivative (change in Earth's rotation). When UT1–UTC approaches ±0.9 seconds, a leap second is introduced to UTC to keep it aligned with Earth's rotation. Although GNSS time scales like GPS Time and Galileo System Time do not

include leap seconds, GNSS systems broadcast the GPS–UTC offset in their navigation messages. This offset is updated based on leap second decisions, which are themselves driven by UT1–UTC trends — and thus indirectly influenced by LOD. As of now, 18 leap seconds have been added to UTC, and the GPS–UTC offset remains 18 seconds, unchanged since January 1, 201.

In summary, while LOD does not directly affect GNSS timekeeping, it plays a vital role in orbit modeling and leap second planning. Accurate LOD and UT1–UTC data ensure that GNSS systems maintain synchronization with Earth rotation, enabling reliable time conversion, precise orbit prediction, and consistent positioning performance for users worldwide.

Monthly Performance Remarks:

1. Satellite Clock and Orbit Accuracy:
- The performance of all constellations remained like last months. QZSS had a degraded performance due to J04 satellite. Some of the days were removed in the statistical analysis. Further investigation is needed.
- IRNSS I09 provided higher count numbers of broadcast URA than in previous months. This indicates frequent update of the broadcast messages. Further investigation is needed.

2. The UTC Prediction (GNSS-UTC):
- All constellation provided relatively stable predictions of the GNSS-UTC.

References

Alonso M, Sanz J, Juan J, Garcia, A, Casado G (2020) Galileo Broadcast Ephemeris and Clock Errors Analysis: 1 January 2017 to 31 July 2020, MDPI

Alonso M (2022) Galileo Broadcast Ephemeris and Clock Errors, and Observed Fault Probabilities for ARAIM, Ph.D Thesis, UPC

Bento, M (2013) Development and Validation of an IMU/GPS/Galileo Integration Navigation System for UAV, PhD Thesis, UniBW.

BIMP (2024 a) https://e-learning.bipm.org/pluginfile.php/6722/mod_label/intro/User_manual_cggtts_analyser.pdf?time=1709905608656

BIMP (2024 b) https://e-learning.bipm.org/mod/folder/view.php?id=1156&forceview=1

BIMP (2024 c) https://cggtts-analyser.streamlit.app

Bruggemann, Troy & Greer, Duncan & Walker, R.. (2011). GPS fault detection with IMU and aircraft dynamics. IEEE Transactions on Aerospace and Electronic Systems - IEEE TRANS AEROSP ELECTRON SY. 47. 305-316. 10.1109/TAES.2011.5705677.

Cao X, Zhang S, Kuang K, Liu T (2018) The impact of eclipsing GNSS satellites on the precise point positioning, Remote Sensing 10(1):94

Chen, K., Chang, G. & Chen, C (2021) GINav: a MATLAB-based software for the data processing and analysis of a GNSS/IMU integrated navigation system. *GPS Solut* **25**, 108. https://doi.org/10.1007/s10291-021-01144-9

Curran, James T. & Broumendan, Ali. (2017). On the use of Low-Cost IMUs for GNSS Spoofing Detection in Vehicular Applications.

Dhital N (2024) GNSS constellation specific monthly analysis summary, Coordinates, Vol XX, Issue 1, 2, 3, 4

Dhital N (2025) GNSS constellation specific monthly analysis summary, Coordinates, Vol XXI, Issue 1

GINAv (2025). https://geodesy.noaa.gov/gps-toolbox/GINav.shtml

Goercke, L (2017) GNSS-denied navigation of fixed-wing aircraft using low-cost sensors and aerodynamic motion models, PhD Thesis, TUM.

GROOPS (2025) GROOPS Documentation and Cookbook. https://groops-devs.github.io/groops/html/index.html

Guo, Jing & Chen, Guo & Zhao, Qile & Liu, Jingnan & Liu, Xianglin. (2017). Comparison of solar radiation pressure models for BDS IGSO and MEO satellites with emphasis on improving orbit quality. GPS Solutions. 21. 10.1007/s10291-016-0540-2.

Guo F, Zhang X, Wang J (2015) Timing group delay and differential code bias corrections for BeiDou positioning, J Geod,

Hauschlid A, Montenbruck O (2020) Precise real-time navigation of LEO satellites using GNSS broadcast ephemerides, ION

IERS C04 (2024) https://hpiers.obspm.fr/iers/eop/eopc04/eopc04.1962-now

IGS (2019) GNSS Attitude Quaternions Exchange using ORBEX

IGS (2021) RINEX Version 4.00 https://files.igs.org/pub/data/format/rinex_4.00.pdf

InsideGNSS (2024) Working papers: upgrading galileohttps://insidegnss.com/working-papers-upgrading-galileo/

Jiabo G, Xingyu Z, Yan C, Mingyuan Z (2021) Precision Analysis on Reduced-Dynamic Orbit Determination of GRACE-FO Satellite with Ambiguity Resolution, Journal of Geodesy and Geodynamics (http://www.jgg09.com/EN/Y2021/V41/I11/1127)

Kj, Nirmal & Sreejith, A. & Mathew, Joice & Sarpotdar, Mayuresh & Suresh, Ambily & Prakash, Ajin & Safonova, Margarita & Murthy, Jayant. (2016). Noise modeling and analysis of an IMU-based attitude sensor: improvement of performance by filtering and sensor fusion. 99126W. 10.1117/12.2234255.

Li M, Wang Y, Li W (2023) performance evaluation of real-time orbit determination for LUTAN-01B satellite using broadcast earth orientation parameters and multi-GNSS combination, GPS Solutions, Vol 28, article number 52

Li W, Chen G (2023) Evaluation of GPS and BDS-3 broadcast earth rotation parameters: a contribution to the ephemeris rotation error Montenbruck

Liu, Yue & Liu, Fei & Gao, Yang & Zhao, Lin. (2018). Implementation and Analysis of Tightly Coupled Global Navigation Satellite System Precise Point Positioning/Inertial Navigation System (GNSS PPP/IMU) with IMUufficient Satellites for Land Vehicle Navigation. Sensors. 18. 4305. 10.3390/s18124305.

Mayer-Guerr, T., Behzadpour, S., Eicker, A., Ellmer, M., Koch, B., Krauss, S., Pock, C., Rieser, D., Strasser, S., Suesser-Rechberger, B., Zehentner, N., Kvas, A. (2021). GROOPS: A software toolkit for gravity field recovery and GNSS processing. Computers & Geosciences, 104864. https://doi.org/10.1016/j.cageo.2021.104864

Montenbruck O, Steigenberger P, Hauschlid A (2014) Broadcast versus precise ephemerides: a multi-GNSS perspective, GPS Solutions

Liu T, Chen H, Jiang Weiping (2022) Assessing the exchanging satellite attitude quaternions from CNES/CLS and their application in the deep eclipse season, GPS Solutions 26(1)

Montenbruck O, Steigenberger P (2024) The 2024 GPS accuracy improvement initiatives, GPS Solutions

Montenbruck O, Steigenberger P, Hauschlid A (2014) Broadcast versus precise ephemerides: a multi-GNSS perspective, GPS Solutions

Montenbruck O, Hauschlid A (2014 a) Differential Code Bias Estimation using Multi-GNSS Observations and Global Ionosphere Maps, ION

Montenbruck, O., Schmid, R., Mercier, F., Steigenberger, P., Noll, C., Fatkulin, R., Kogure, S. & Ganeshan, A.S. (2015) GNSS satellite geometry and attitude models. Advances in Space Research 56(6), 1015-1029. DOI: 10.1016/j.asr.2015.06.019

Niu, Z.; Li, G.; Guo, F.; Shuai, Q.; Zhu, B (2022) An Algorithm to Assist the Robust Filter for Tightly Coupled RTK/IMU Navigation System. *Remote Sens.* **2022**, *14*, 2449. https://doi.org/10.3390/rs14102449

Schmidt, G, Phillips, R (2010) IMU/GPS Integration Architecture Performance Comparisons. NATO.

Space (2025) https://www.space.com/astronomy/earth/mysterious-boost-to-earths-spin-will-make-aug-5-one-of-the-shortest-days-on-record

Steigenberger P, Montenbruck O, Bradke M, Ramatschi M (2022) Evaluation of earth rotation parameters from modernized GNSS navigation messages, GPS Solutions 26(2)

Strasser S (2022) Reprocessing Multiple GNSS Constellations and a Global Station Network from 1994 to 2020 with the Raw Observation Approach, PhD Thesis, Graz University of Technology

Suvorkin, V., Garcia-Fernandez, M., González-Casado, G., Li, M., & Rovira-Garcia, A. (2024). Assessment of Noise of MEMS IMU Sensors of Different Grades for GNSS/IMU Navigation. *Sensors*, *24*(6), 1953. https://doi.org/10.3390/s24061953

Sylvain L, Banville S, Geng J, Strasser S (2021) Exchanging satellite attitude quaternions for improved GNSS data processing consistency, Vol 68, Issue 6, pages 2441-2452

Tanil, Cagatay & Khanafseh, Samer & Pervan, Boris. (2016). An IMU Monitor agaIMUt GNSS Spoofing Attacks during GBAS and SBAS-assisted Aircraft Landing Approaches. 10.33012/2016.14779.

Walter T, Blanch J, Gunning K (2019) Standards for ARAIM ISM Data Analysis, ION

Wang, C & Jan, S (2025). Performance Analysis of MADOCA-Enhanced Tightly Coupled PPP/IMU. NAVIGATION: Journal of the IMUtitute of Navigation March 2025, 72 (1) navi.678; DOI: https://doi.org/10.33012/navi.678

Wang N, Li Z, Montenbruck O, Tang C (2019) Quality assessment of GPS, Galileo and BeiDou-2/3 satellite broadcast group delays, Advances in Space Research

Wang J, Huang S, Lia C (2014) Time and Frequency Transfer System Using GNSS Receiver, Asia-Pacific Radio Science, Vol 49, Issue 12

https://cggtts-analyser.streamlit.app

Yang N, Xu A, Xu Z, Xu Y, Tang L, Li J, Zhu H (2025) Effect of WHU/GFZ/CODE satellite attitude quaternion products on the GNSS kinematic PPP during the eclipse season, Advances in Space Research, Volume 75, Issue 1,

Note: References in this list might also include references provided to previous issues.

Data sources and Tools:

https://cddis.nasa.gov (Daily BRDC); http://ftp.aiub.unibe.ch/CODE_MGEX/CODE/ (Precise Products); BKG "SSRC00BKG" stream; IERS C04 ERP files

(The monitoring is based on following signals- GPS: LNAV, GAL: FNAV, BDS: CNAV-1, QZSS:LNAV IRNSS:LNAV GLO:LNAV (FDMA))

Time Transfer Through GNSS Pseudorange Measurements: https://e-learning.bipm.org/login/index.php

Allan Tools, https://pypi.org/project/AllanTools/

gLAB GNSS, https://gage.upc.edu/en/learning-materials/software-tools/glab-tool-suite

Empirical orthogonal function based modelling of ionosphere using Turkish GNSS network

The study investigates ionospheric TEC variation over the Turkish region using 5 GNSS stations. The results showed that the overall TEC values display the trend of normal diurnal and annual TEC variations.

Kutubuddin Ansari
Faculty of Geodesy and Cartography, Warsaw University of Technology, Warsaw, Poland

Janusz Walo
Faculty of Geodesy and Cartography, Warsaw University of Technology, Warsaw, Poland

Selcuk Sagir
Department of Physics, Faculty of Arts and Sciences, Mus Alpaslan University, 49250, Mus, Turkey

Kinga Wezka
Faculty of Geodesy and Cartography, Warsaw University of Technology, Warsaw, Poland

Abstract

The study investigates ionospheric total electron content (TEC) variation over Turkey from the five selected global navigation satellite system (GNSS) stations situated in diverse parts of Turkey. The geomagnetic indices are used and observed TEC are modeled with the technique known as Empirical orthogonal function (EOF). It is valuable to note that the correlation coefficient between observed GNSS TEC values and EOF TEC values varies from 0.8020 to 0.9394. The root means square error (RMSE) values between observed GNSS TEC values and EOF TEC lie between 3.1665 TECU to 4.4220 TECU. These results show that the EOF model performs quite well in the Turkish region and can present the model TEC variations perfectly. Finally, these GNSS observed and EOF- predicted TEC values along with geomagnetic indices are studied with the tropospheric wind speed. The results showed that both observed and modeled TEC have very low correlations with tropospheric wind speed and do not provide any significant value. Hence, we concluded that the ionospheric region is not affected by tropospheric wind speed. It happens because the tropospheric wind speed is a matter of the lower troposphere and its atmospheric pressure while the ionosphere is far from the earth and depends upon the number of free electrons.

1. Introduction

The ionospheric region that affects the global navigation satellite system (GNSS) signals is a major error source for single-point positioning measurements. The ionospheric range error, which is directly related to the ionospheric total electron content (TEC) keeps on changing and depends upon the solar and geomagnetic activities, geographical or geomagnetic coordinate systems, local and universal time, and seasonal effects (Júnior et al., 2020; Ansari et al., 2018; Seok et al., 2022; Sharma et al., 2020). The ionospheric delay gradient magnitude occurs often and directly influences the values of TEC; so that an error in positioning could be reachable up to several 10 m (Seeber, 2003). Hence modeling and prediction of spatiotemporal ionospheric TEC error is very necessary for the applications of weather investigations. Since the ionosphere contains a dispersive medium, hence first-order approximation delay in the ionosphere can be estimated by applying simultaneous measurements at two different frequencies. However, this approach is not successful for the single frequency operations (Júnior et al., 2020. Their many techniques and forecasting models have been developed such as quasi-experimental model (IRI, IRI Plus, NeQuick2) and theoretical hypothetical models such as Auto-regressive Moving Average, Empirical Orthogonal Function and others (Bilitza et al., 2017; Jakowski et al., 2011; Nigussie et al., 2012; Tuna et al., 2014; Zhang and Moore, 2015; Ansari et al., 2019). These models are

used in remote areas where no device is available. In general, it is expected from empirical models that they will reflect the actual ionospheric features, however, they come across numerous kinds of modeling limitations depending upon the data used to reconstruct them such as considered instantaneous space weather situations, implicated techniques, etc. In contrast to the direct reconstruction, modes of principal component analysis related to the physics of the ionosphere can be utilized for various conditions. They can duplicate the desired result and present empirical results at some level. Hence, these kinds of models are still needed to describe the variability of the ionosphere.

The Empirical Orthogonal Function (EOF) method, which is based on principal component analysis, reported improved ionospheric prediction results. Ercha et al. (2012) established a global ionospheric TEC model based on EOF analysis using global ionospheric maps (GIM) data from one decade (1999–2009). According to them, overall TEC variation including the influence of geomagnetic activity and solar radiation toward TEC can be presented very well by the characteristics of EOF-associated coefficients and base functions. Therefore, a global TEC model was established incorporating the EOF of the TEC time series. The modeled TEC time-series was validated with the observed TEC to check the accuracy and quality of the model, which pointed out that the model can reflect the spatiotemporal feature of the global TEC variation. Later several studies that followed this EOF model validated the outcome at the local level (Ansari et al., 2019; Jamjareegulgarn et al., 2020; Dabbakuti et al., 2016). Ansari et al. (2019) used ionospheric data from South Korea and presented an EOF-modeled study of the ionosphere. They used 14 GNSS stations covering the area of South Korea from 2010 to 2017. They included the PCN index including the other geomagnetic indices such as Ap, Dst, and F10.7, and evaluated their EOF-based modeled TEC values with NeQuick-2 and IRI-2016 models. They noticed that their results showed better performance compared to the IRI and NeQuick 2 models. Jamjareegulgarn et al. (2020) presented their EOF method modeled ionospheric study over the region of Nepal using three years (2017–2019) TEC observations from 5 GNSS stations. Both modeled and observed TEC values with the global ionospheric maps (GIM) models are compared. They found that the correlation coefficient of observed GNSS TEC with EOF-modeled TEC was higher compared to the correlation coefficient of observed TEC with GIM TEC values. Dabbakuti et al. (2016) constructed an EOF model using data from IISC (India) IGS station during the extended period of 2009–2016 in the 24th solar cycle. The modeled TEC was validated during day and night-time as well as under distinct geomagnetic and solar activity situations. The reliability and validity of the EOF model were verified with the comparison of standard global IRI 2016 and SPIM models. They noticed that the EOF model performance was relatively better during the period of high solar activity compared to the period of low solar activity.

Although the studies based on the above discussion enhance the utility of ionospheric variations. However, to understand the relative contribution of neutral winds, neutral temperature, neural electric field, and neural density periodicities on the ionosphere, further developments, more simulated models, and additional data are required. The ionospheric region which lies between 50 and 1000 km above the earth's surface includes the mesosphere (50–85 km), the thermosphere (100–690 km), and the partial part of the Exosphere (690–10,000 km). Since during the estimation of TEC, it is assumed that the ionosphere to be a thin shell and located at 350 km altitude above the Earth, hence in the current study, we investigated the geomagnetic activity and its relationship with tropospheric wind speed in the mesospheric and thermosspheric regions of Turkey. The new findings of the study introduce a solar-terrestrial relation that yields in the ionosphere. We used GNSS data from five GNSS stations across Turkey covering the one year of January 2015 to December 2015. First, the relation between GNSS TEC including geomagnetic indices with tropospheric wind speed was presented. A small description of data collection and utilized geomagnetic indices has been given in Section 2. In the next step observed TEC was modeled by using the EOF method and their comparison result is presented. A summary of the proposed EOF method can be seen in Section 3. Later this EOF modeled TEC again compared with the tropospheric wind speed and the obtained results are explained. The result and discussion of the whole study have been presented in Section 3. The conclusion and future of the study have been written in Section 4.

2. Data collection and method of processing

The paper presents ionospheric TEC variation using the GNSS data from the Turkish Permanent GNSS Network (TPGN) including the Turkish IGS stations. TPGN is a huge GNSS network of Turkey containing around 150 stations across all over Turkey. This study includes three TPGN stations namely POZANTI, SAMSUN, and ERZURUM, and two IGS stations namely Ankara (ANKR) and Istanbul (ISTA) from January 2015 to December 2015 (Fig. 1, Table 1). The TPGN data has been accessed from the TUSAGA-Aktif website (https://www.tkgm.gov. tr/tr/icerik/tusaga-aktif-0) and while IGS data was downloaded from the CDDIS website (ftp://cddis.gsfc.nasa.gov/).

To retrieve the TEC data from the RINEX files, three major steps are required. First, is the preprocessing of RINEX observations to compute the TEC values, the second task is the computation of TEC and the third is the data presentation to be used for research. IONOLAB-TEC (www.io nolab.org) software successfully provides all these steps in online mode. The Reg-Est, which applies IONOLAB-BIAS and is programmed by JAVA language, began to use an online trial version of TEC estimation in 2007. The Scientific and Technological Research Council of Turkey (TUBITAK)

granted this program and IONOLAB-BIAS has been developed further for near real-time space weather applications known as IONOLAB-TEC. The IONOLAB-TEC method is a regularized TEC (D-TEI) algorithm and was developed to estimate TEC by utilizing all GNSS signals measured at a period on the selected day. In the current study, we have used IONOLAB- TEC software to retrieve the TEC and tried to detect abnormal ionospheric activities over Turkey using the GNSS data from Turkey stations.

In the current study, we also used the solar and geomagnetic indices data such as the Dst Index, F10.7, Ap Index, IMF-B, Kp Index, and sunspot number (R) including the tropospheric wind speed accessed from the server of NASA (omniweb.gsfc.nasa.gov). Including. These indices are used to measure the geomagnetic activity, for the signature of the ionospheric response and magnetosphere of the Earth to solar forcing. They played a considerable role in describing the magnetic formation of the ionized Earth environment. Detailed information about geomagnetic indices can be studied by Menvielle et al. (2010).

Table 1: TPGN stations namely POZANTI, SAMSUN, and ERZURUM, and two IGS stations namely Istanbul (ISTA) and Ankara (ANKR) covering the period of January 2015 to December 2015.

Station Name	Geographic Latitude	Geographic Longitude
ANKARA	39.57	32.53
POZANTI	37.03	35.21
SAMSUN	41.20	36.15
ISTANBUL	40.58	29.05
ERZURUM	40.39	40.42

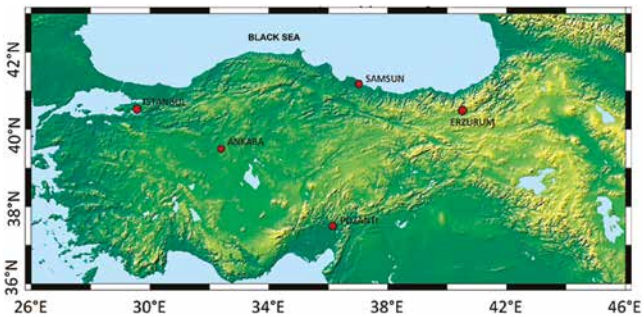


Fig. 1. TPGN stations namely POZANTI, SAMSUN, and ERZURUM, and two IGS stations namely Istanbul (ISTA) and Ankara (ANKR) covering the period of January 2015 to December 2015.

3. Summary of EOF modeling

Let us suppose the matrix of observed TEC measurement is given by X, arranged in the order such that its diurnal variation presents a row of the matrix while hourly variation shows a column of the matrix X. In the current study, only one year (2015) of data has been used, hence there will be 365 rows and 24 columns in the given observed matrix of X. This matrix is not square; hence we can obtain a square matrix of Z like this:

$$Z = X^T X \tag{1}$$

If we decompose the Z matrix in terms of the base function (E_k) and the associated coefficient (A_k). The original data set of X can be written in following form:

$$X = A_k x \; E_k \tag{2a}$$

Ercha et al. (2012) suggested that the A_k values of decomposed time-series can be replaced with geomagnetic indices where base function will present the factor of hourly TEC variation. Hence Eq. (2) can be written in general form:

$$X = A_k \; (g_1, g_2, g_3, ..., g_n) \; x \; E_k \; (h) \tag{2b}$$

Where g_1, g_2 and … g_n are the values of daily geomagnetic indices.

Ercha et al. (2012) suggested a feasible model to understand the behavior of geomagnetic and solar activity on solar cycle, semiannual and annual TEC variations in terms of associated coefficient (A_k) by using harmonic function in following form:

$$A_k = A_{k1}(g_1, g_2, g_3, ..., g_n) + A_{k2}(g_1, g_2, g_3, ..., g_n) + A_{k3}(g_1, g_2, g_3, ..., g_n), \tag{3}$$

where

$$A_{k1} = a_1 + a_2 g_1 + a_3 g_2 + a_4 g_3 ..... a_{n+1} g_n \quad \} \; solar \; cycle \; TEC \; variation$$

$$A_{k2} = (b_1 + b_2 g_1 + b_3 g_3 + b_4 g_3 ..... b_{n+1} g_n) \cos \frac{2\pi}{365.25} \mathrm{DOY} + (c_1 + c_2 g_1 + c_3 g_3 + c_4 g_3 ..... c_{n+1} g_n) \sin \frac{2\pi}{365.25} \mathrm{DOY} \Big\} Semiannual \; TEC \; variation$$

$$A_{k3} = (d_1 + d_2 g_1 + d_3 g_3 + d_4 g_3 ..... d_{n+1} g_n) \cos \frac{4\pi}{365.25} \mathrm{DOY} + (e_1 + e_2 g_1 + e_3 g_3 + e_4 g_3 ... ... e_{n+1} g_n) \sin \frac{4\pi}{365.25} \mathrm{DOY} \Big\} Annual \; TEC \; variation$$

where a_i, b_i, c_i and di (i = 1, 2 ….n) are the arbitrary constants, those are estimated by method of least square using MATLAB code.

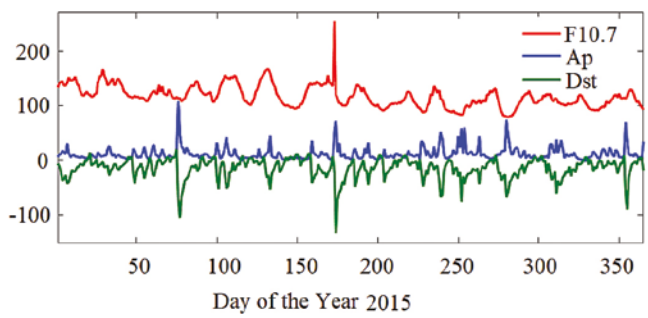


Fig. 2. Three basic (F10.7, Dst, and Ap) indices variations during the year 2015.

4. Result and discussion

4.1. Ionospheric TEC and geomagnetic indices

The geomagnetic field is responsible for the regulation of ionospheric variation, which is the fundamental parameter of the

ionosphere (Council, 1993). The basic indices used to express the changes in the geomagnetic field are the indices F10.7, Dst, Ap, Kp, and AE indices (Atıcı et al., 2020). We plotted three basic (F10.7, Dst, and Ap) indices variations during the year 2015 as shown in Fig. 2. The appearance of one peak (lower side for Dst, upside for F10.7 and Ap and) can be seen during the period of selection. These peaks point out the time of high solar activity (HSA) on 173 days of the year 2015 when the Dst value reached - 133 nT and F10.7 became 255 s.f.u. GNSS observed ionospheric variation is investigated to understand its attributes over Turkey. Temporal variations in GNSS VTEC over POZANTI, SAMSUN, and ERZURUM have been shown in Fig. 3. On the day of HSA, the VTEC showed 40.15 TECU at POZANTI, 36.32 TECU at SAMSUN and 38.53 TECU at ERZURUM. Regarding the X-axis of the plot, the diurnal pattern of VTEC variation shows some low VTEC values (about 25 TECU) during the start of the year, which start to increase more during the days of 50–60 and reach up to 40 TECU at almost all stations. This variation showed a few low values during the day of 200 and later decreased more and became the lowest (about 18 TECU) at the end of the year. Regarding the Y-axis which are hourly plots, the VTEC showed the lowest values around 15 TECU at the statement of the day at 04:00 UT and started to increase till 08:00 UT, reaching up to 25 TECU. The plots showed the highest value between 06:00 UT to 14:00 UT which is highest at noon UT. This is notable because this highest value at noon UT keeps on varying for up to a whole year. Overall TEC values display the trend of normal diurnal and annual TEC variations. This happens due to the revolution and rotational motion of the Earth around the Sun (Rat-nam et al., 2017).

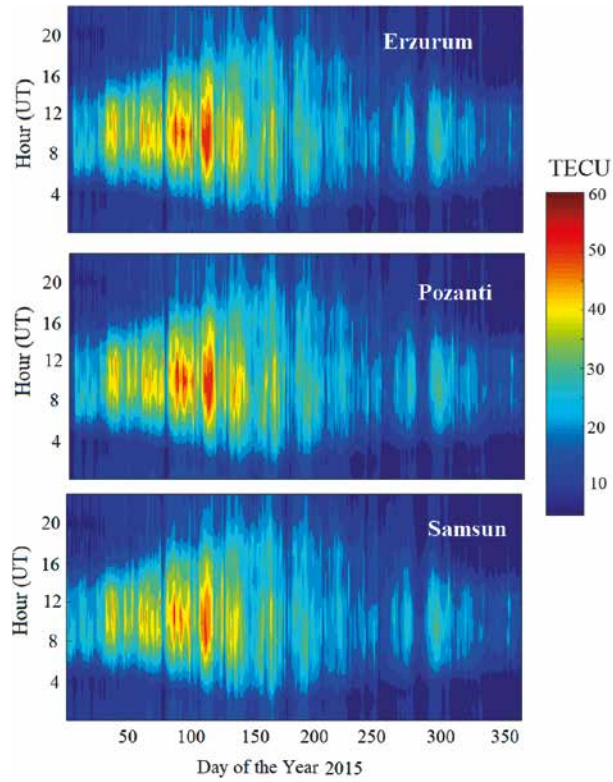


Fig. 3. GNSS TEC temporal variations in Turkey over POZANTI, SAMSUN, and ERZURUM stations.

4.2. EOF modeled TEC variation

This is clear from Eq. (3), if we take one geomagnetic index in the Fig. 3. GNSS TEC temporal variations in Turkey over POZANTI, SAMSUN, and ERZURUM stations.

analysis, we need to handle 10 constant coefficients, and if we take two geomagnetic indices, there will be 15 constants, that need to be handled. To avoid a more complex analysis, we selected three basic indices (F10.7, Dst, and Ap) and estimated 20 constant coefficients by using the least square method. There are several studies already done, that used these three indices only in their EOF analysis (Dabbakuti et al., 2016; Jamjareegulgarn et al., 2020). In the current analysis, we used these three basic indices (F10.7, Dst, and Ap) as described in Fig. 2 and predicted EOF TEC values at stations i.e., Ankara, Erzurum, Istanbul, and Pozanti (Fig. 4). Here it is difficult to compare Fig. 4 with the corresponding GPS TEC of Fig. 3 in the first view, as they do not exhibit the same kind of variation. Hence, the EOF TEC values are used to do a comparative analysis with the observed GNSS TEC values by using the correlation coefficient and RMSE as shown in Table 2. It is valuable to note that the correlation coefficient of observed GNSS TEC values with EOF TEC values are 0.8020 at Ankara, 0.8287 at Erzurum, 0.9199 at Istanbul,

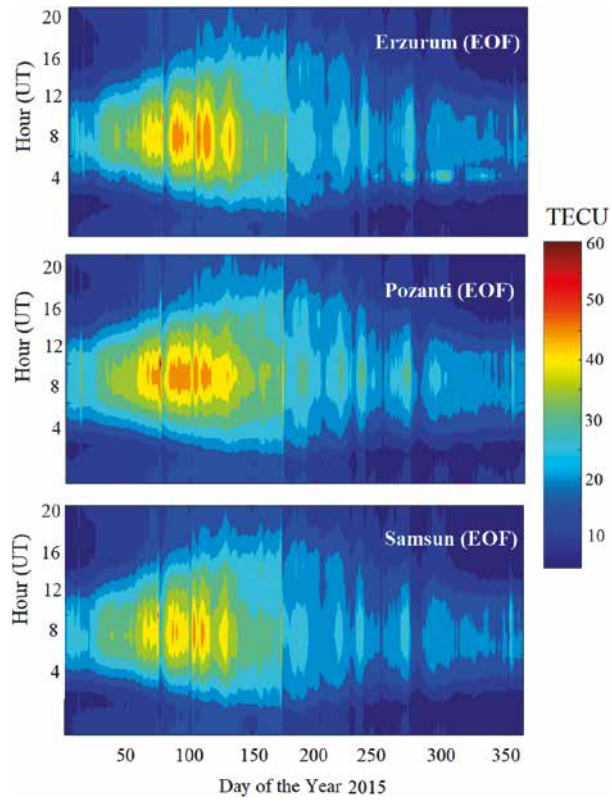


Fig. 4. EOF modeled GNSS TEC temporal variations in Turkey over POZANTI, SAMSUN, and ERZURUM stations.

0.9380 at Pozanti, and similarly 0.9394 at Samsun sites (Table 2). The result shows that the correlation coefficients have different values at each station. This type of variation is nothing but because of some data issues. Some station data variations were affected badly due to any physical cause, hence the performance of the EOF method could not become proper. In the next step, we estimated RMSE between observed TEC and EOF TEC values as shown in Table 2. This is clear from the Table that the RMSE varies from 3.1665 TECU (Samsun) to 4.4220 TECU. These values are very low with a small variation at each station. The station which has a high correlation shows low RMSE and the station which has a low correlation shows high RMSE. In conclusion, it can be said that the EOF model performs quite well and can present the model TEC variations perfectly.

Table 2: Correlation coefficient and RMSE between the TEC extracted from Turkey GNSS stations and EOF modeled TEC during the year 2015.

Station Name	Correlation Coefficient	RMSE
ANKARA	0.8020	4.4220
ERZURUM	0.8287	3.3497
ISTANBUL	0.9199	3.6810
POZANTI	0.9380	3.4434
SAMSUN	0.9394	3.1665

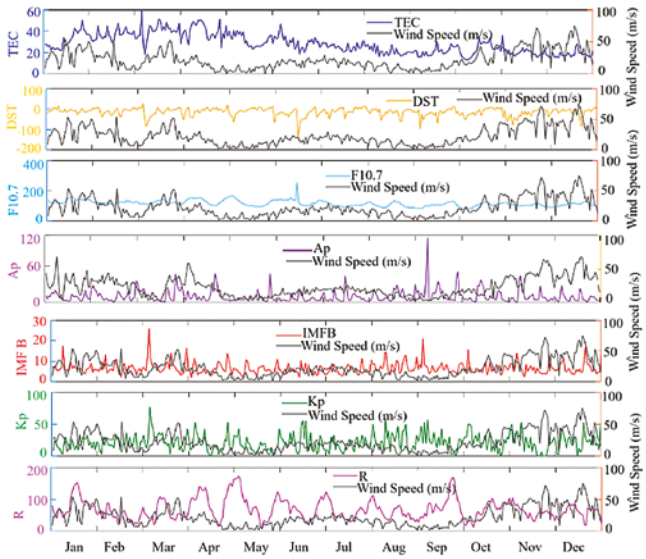


Fig. 5. Tropospheric wind speed relationship with the TEC extracted from Turkey GNSS (ERZURUM) stations during the year 2015. The impact of geomagnetic indices such as the Dst Index, F10.7, Ap Index, IMF-B, Kp Index, and sunspot number (R), on tropospheric wind speed also has been shown in the lower panel.

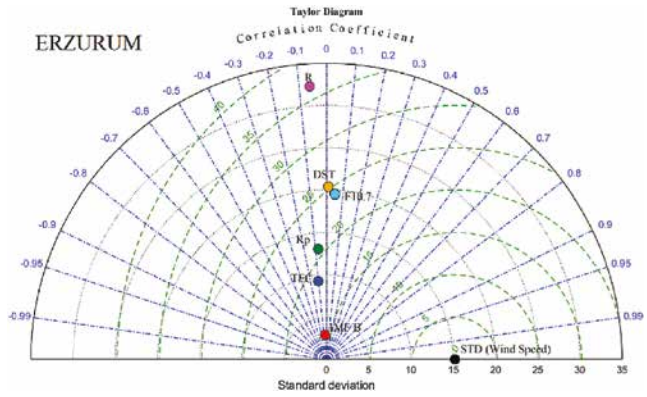


Fig. 6. The relation between tropospheric wind speed and TEC (for ERZURUM) including the geomagnetic indices using a Tailor correlation plot.

The accuracy of the EOF model has been already tested in various regions. For example, Jamjareegulgarn et al. (2020) noticed that the correlation coefficients between observed TEC and EOF TEC over the Nepal region (2017–2019) was up to 0.978, indicating the perfectness of the model. Ansari et al. (2019) used data from January 2010 to December 2017 and computed the correlation and best-fit line of GNSS-VTEC with EOF TEC. The EOF-VTEC was highly correlated (~0.97) at all stations, reflecting the realistic modeling and dependency of geographical as well as geomagnetic variation characteristics of TEC. Dabbakuti and Ratnam (2016) investigated ionospheric variability in a low-latitude region of India based on the EOF. The accuracy of the EOF model was validated by the evaluation of observational TEC data with International Reference Ionosphere (IRI) 2012 models. The EOF model coefficients for each GNSS station showed a strong correlation with the IRI models and also described the correlation between the impacts of the level of geomagnetic activity on the ionosphere. The correlation coefficients for the first three EOFs were more than 0.95. Li et al. (2019) used the EOF decomposition technique and studied the spatiotemporal characteristics of TEC from 2007 to 2016 in China. The results showed that the first-order EOF component dominated the overall TEC variation because it accounted for 97.35% of the total variance. However, in the current study, the correlation coefficient of observed GNSS TEC values with EOF TEC values is low (0.80–0.9199) compared to the above studies. These low correlation coefficients are happening because of badly affected data due to any physical causes. This type of decreasing performance of the EOF method points out some limitations of the EOF model. Finally based on the above discussion we can conclude that the EOF-based TEC model can demonstrate the temporal and spatial variation characteristics of TEC, and the EOF-based model can obtain significantly smaller modeling errors and achieve better performance in terms of TEC modeling.

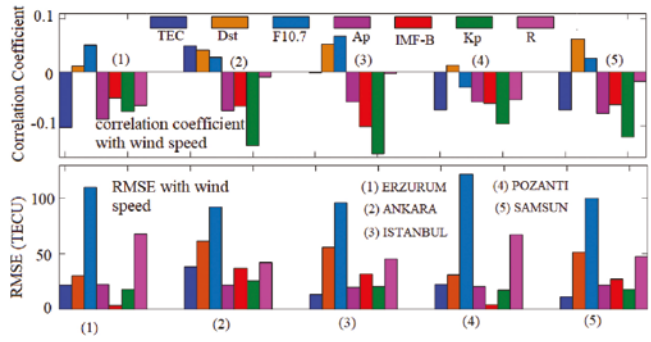


Fig. 7. The relation between tropospheric wind speed and TEC including the geomagnetic indices.

4.3. Tropospheric wind speed and geomagnetic indices

The solar radiation warms the air in the surrounding region, and then this warm air rises and creates a low pressure in the region. In the case of large-scale circulation, the tropospheric wind speed simply depends upon the difference in temperature and pressure (Ansari, 2016; Ansari et al., 2021). To understand the effect of tropospheric wind speed on the available electron densities of the ionospheric region, we studied the tropospheric wind speed relationship with the TEC extracted from Turkey GNSS (ERZURUM) stations during the year 2015 (Fig. 5). The impact of geomagnetic indices such as the Dst Index, F10.7, Ap Index, IMF-B, Kp Index, and sunspot number (R), on tropospheric wind speed also has been shown in Fig. 5. Here we are showing only one plot (ERZURUM only) to save the space because all other plots will be almost the same. Since the tropospheric wind speed is a vector quantity, hence the tropospheric wind speed average and its direction always depict a wider difference compared to the instantaneous value of speed and direction (Lolis et al., 2018; Ansari et al., 2021). To avoid such a type of wider difference analysis we choose the timing of TEC and tropospheric wind speed at noon only. The timing of noon is chosen because generally, TEC provides the highest variation at this due to the solar radiation. It is clear from Fig. 5, that the tropospheric wind speed varies from 0 to 70 m/s which has no common trend with TEC (first panel). Similarly, other geomagnetic panels such as the Dst Index, F10.7, Ap Index, IMF-B, Kp Index, and R also do not provide any kind of trend with tropospheric wind speed. The relation between tropospheric wind speed and TEC including the geomagnetic indices has been studied using a Tailor correlation plot as shown in Fig. 6 (for ERZURUM only) and Fig. 7 (for other stations). These relationships in terms of correlation coefficient have been tabulated in Table 3. All the correlation coefficient values from the table clearly showed less than or equivalent to 0.10 which means they have no relationship or very negligible effect of tropospheric wind speed on TEC or geomagnetic values. The tropospheric wind speed is a matter of lower troposphere and its atmospheric pressure while the ionosphere is very far from the earth and depends upon the number of free electrons, hence without a doubt they are not affecting the ionospheric region. For more confirmation, we studied root mean square error (RMSE) with tropospheric wind speed and geomagnetic parameters as shown in Table 4. This is notable that RMSE for each parameter is very high which again indicates a negligible relation of tropospheric wind speed with the ionosphere.

4.4. EOF modeled TEC and tropospheric wind speed

We used the EOF method and predicted TEC at all selected Turkey stations by using observed TEC and three basic geomagnetic indices (F10.7, Dst, and Ap). It means EOF TEC is a function of TEC, F10.7, Dst, and Ap. To analyze the relation between modeled TEC and tropospheric wind speed, the correlation coefficient, and RMSE at noon of each station have been estimated as shown in Table 5. It is clear from the Table that the correlation after applying EOF is less than or equivalent to 0.10 which means they have no relationship or very negligible effect of tropospheric wind speed on EOF TEC. The RMSE for EOF is also very high which again indicates negligible relation of EOF TEC with tropospheric wind speed. There is a little bit of change before EOF (observed TEC) and after the implication of EOF, but not obtained results do provide any significant information. Since tropospheric wind speed does not have any kind of

Table 3: Correlation coefficient between tropospheric wind speed with the TEC extracted from Turkey GNSS (ERZURUM) stations during the year 2015, including to the Dst Index, F10.7, Ap Index, IMF-B, Kp Index, and sunspot number (R).

Correlation Coefficient with Tropospheric wind speed (m/s)							
Station Name	TEC	Dst	F10.7	Ap	IMF-B	Kp	R
ERZURUM	- 0.104	0.011	0.051	- 0.089	- 0.049	- 0.074	- 0.062
ANKARA	0.050	0.041	0.027	- 0.072	- 0.064	- 0.138	- 0.009
ISTANBUL	- 0.001	0.052	0.067	- 0.056	- 0.102	- 0.153	- 0.002
POZANTI	- 0.071	0.012	- 0.029	- 0.056	- 0.058	- 0.096	- 0.052
SAMSUN	- 0.071	0.061	0.026	- 0.078	- 0.061	- 0.121	- 0.017

Table 4: Root mean square (RMSE) between tropospheric wind speed with the TEC extracted from Turkey GNSS (ERZURUM) stations during the year 2015, including to the Dst Index, F10.7, Ap Index, IMF-B, Kp Index, and sunspot number (R).

RMSE with Tropospheric wind speed (m/s)							
Station Name	TEC	Dst	F10.7	Ap	IMF-B	Kp	R
ERZURUM	21.733	30.417	109.84	22.712	3.643	18.322	67.829
ANKARA	38.634	61.481	92.134	21.961	37.249	25.670	42.213
ISTANBUL	13.642	56.234	96.148	20.227	31.564	20.896	45.428
POZANTI	22.870	31.203	121.741	20.991	4.341	17.616	67.189
SAMSUN	11.421	51.389	100.354	22.214	27.147	17.965	47.623

Table 5: Correlation coefficient and RMSE between tropospheric wind speed and TEC values before EOF and after EOF from Turkey GNSS stations during the year 2015.

Station Name	Correlation Coefficient between TEC and Tropospheric wind speed		RMSE (TECU) between TEC and Tropospheric wind speed	
	Before EOF	After EOF	Before EOF	After EOF
ERZURUM	- 0.104	- 0.189	21.733	19.478
ANKARA	0.050	0.118	38.634	19.000
ISTANBUL	- 0.001	- 0.018	13.642	17.203
POZANTI	- 0.071	- 0.146	22.870	19.617
SAMSUN	- 0.071	- 0.104	11.421	18.517

relationship with observed TEC and other geomagnetic indices, hence the same kind of negligible relationship was expected with EOF TEC, because EOF TEC is a function of TEC and geomagnetic indices.

5. Conclusions

The study investigates ionospheric TEC variation over the Turkish region using 5 GNSS stations. The results showed that the overall TEC values display the trend of normal diurnal and annual TEC variations. This happens due to the revolution and rotational motion of the Earth around the Sun. The EOF TEC values are used to do a comparative analysis with the observed GNSS TEC values and found that the correlation coefficient of observed GNSS TEC values with EOF TEC values are 0.8020 at Ankara, 0.8287 at Erzurum, 0.9199 at Istanbul, 0.9380 at Pozanti, and similarly 0.9394 at Samsun sites. These variations of correlation coefficients are nothing but because of some data issues. The tropospheric wind speed at the selected location of GNSS sites is correlated before EOF and after EOF model TEC. All the correlation coefficient values from the table clearly showed less than or equivalent to 0.10 which means they have no relationship or very negligible effect of tropospheric wind speed on TEC or geomagnetic values. Similarly, other geomagnetic panels such as the Dst Index, F10.7, Ap Index, IMF-B, Kp Index, and R also do not provide any kind of trend with tropospheric wind speed. This indicates that the tropospheric wind speed is not related to the ionospheric conditions because the tropospheric wind speed is a matter of the lower troposphere and its atmospheric pressure while the ionosphere is far from the earth and depends upon the number of free electrons.

Funding

The research was funded by the Warsaw University of Technology within the Excellence Initiative: Research University (IDUB).

CRediT authorship contribution statement

Kutubuddin Ansari: Writing – review & editing, Writing – original draft, Data curation, Conceptualization. Janusz Walo: Writing – review & editing. Selcuk Sagir: Writing – review & editing. Kinga Wezka: Writing – original draft.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

References

Atıcı, R., Aytas¸, A., Sa˘gır, S., 2020. The effect of solar and geomagnetic parameters on total electron content over Ankara, Turkey. Adv. Space Res. 65, 2158–2166. https:// doi.org/10.1016/j.asr.2019.07.018.

Ansari, K., Panda, S.K., Corumluoglu, O., 2018. Mathematical modelling of ionospheric TEC from Turkish permanent GNSS Network (TPGN) observables during 2009–2017 and predictability of NeQuick and Kriging models. Astrophys. Space Sci. 363 (3), 1–13. https://doi.org/10.1007/s10509-018-3261-x.

Ansari, K., Park, K.D., Panda, S.K., 2019. Empirical orthogonal function analysis and modeling of ionospheric TEC over South Korean region. Acta Astronaut. 161, 313–324. https://doi.org/10.1016/j.actaastro.2019.05.044.

Ansari, K, 2016. Monitoring and prediction of precipitable water vapor using GPS data in Turkey. Journal of Applied Geodesy 10 (4), 233–245. https://doi.org/10.1515/jag- 2016–0037.

Ansari, K., Bae, T.S., Lee, J., 2021. Spatiotemporal variability of total cloud cover measured by visual observation stations and their comparison with ERA5 reanalysis over South Korea. Int. J. Climatol. 41 (S1), E1757–E1774. https://doi.org/10.1002/ joc.6805.

Bilitza, D., Altadill, D., Truhlik, V., Shubin, V., Galkin, I., Reinisch, B., Huang, X., 2017. International Reference Ionosphere 2016: from ionospheric climate to real-time weather predictions. Space Weather 15, 418–429. https://doi.org/10.1002/ 2016SW001593.

Council, N.R., 1993. The National Geomagnetic Initiative. The National Academies Press, Washington, DC. https://doi.org/10.17226/2238.

Dabbakuti, J.K., Ratnam, D.V., 2016. Characterization of ionospheric variability in TEC using EOF and wavelets over low-latitude GNSS stations. Adv. Space Res. 57 (12), 2427–2443. https://doi.org/10.1016/j.asr.2016.03.029.

Ercha, A., Zhang, D., Ridley, A.J., Xiao, Z., Hao, Y., 2012. A global model: empirical orthogonal function analysis of total electron content 1999–2009 data. https:// doi. org/10.1029/2011JA017238.

Jakowski, N., Mayer, C., Hoque, M.M., Wilken, V., 2011. Total electron content models and their use in ionosphere monitoring. Radio Sci. 46 (6) https:// doi.org/10.1029/ 2010RS004620.

Jamjareegulgarn, P., Ansari, K., Ameer, A., 2020. Empirical orthogonal function modeling of total electron content over Nepal and comparison with global ionospheric models. Acta Astronaut. 177, 497–507. https://doi.org/10.1016/j. actaastro.2020.07.038.

Júnior, P.D.T.S., Aquino, M., Veettil, S.V., Alves, D.B.M., da Silva, C.M., 2020. Seasonal analysis of Klobuchar and NeQuick G single-frequency ionospheric models' performance in 2018. Adv. Space Res. https://doi.org/10.1016/j.asr.2020.11.013.

Li, S., Zhou, H., Xu, J., Wang, Z., Li, L., Zheng, Y., 2019. Modeling and analysis of ionosphere TEC over China and adjacent areas based on EOF method. Adv. Space Res. 64 (2), 400–414. https://doi.org/10.1016/j.asr.2019.04.018.

Lolis, C.J., Kotsias, G., Bartzokas, A., 2018. Objective definition of climatologically homogeneous areas in the southern Balkans based on the ERA5 data set. Climate 6 (4), 96 doi:10.3390/cli6040096.

Menvielle, M., Iyemori, T., Marchaudon, A., Nos´e, M., 2010. Geomagnetic indices. In: Geomagnetic Observations and Models. Springer Netherlands, Dordrecht, pp. 183–228.

Nigussie, M., Radicella, S.M., Damtie, B., Nava, B., Yizengaw, E., Ciraolo, L., 2012. TEC ingestion into NeQuick 2 to model the East African equatorial ionosphere. Radio Sci. 47 https://doi.org/10.1029/2012RS004981.

Ratnam, D.V., Sivavaraprasad, G., Devi, N.L., 2017. Analysis of ionosphere variability over low-latitude GNSS stations during 24th solar maximum period. Adv. Space Res. 60 (2), 419–434. https://doi.org/10.1016/j.asr.2016.08.041.

Seok, HW, Ansari, K, Panachai, C, Jamjareegulgarn, P, 2022. Individual performance of multi-GNSS signals in the determination of STEC over Thailand with the applicability of Klobuchar model. Advances in Space Research 69 (3), 1301–1318. https://doi.org/10.1016/j.asr.2021.11.025.

Sharma, SK, Singh, AK, Panda, SK, Ansari, K, 2020. GPS derived ionospheric TEC variability with different solar indices over Saudi Arab region. Acta Astronautica 174, 320–333. https://doi.org/10.1016/j.actaastro.2020.05.024.

Seeber, G., 2003. Satellite Geodesy, 2nd Completely Revised and Extended Edition, vol. 10785. Walter de Gruyter GmbH & Co. KG, pp. 303–304.

Tuna, H., Arikan, O., Arikan, F., Gulyaeva, T.L., Sezen, U., 2014. Online user-friendly slant total electron content computation from IRI-Plas: IRI-Plas-STEC. Space Weather 12, 64–75. https://doi.org/10.1002/2013SW000998.

Zhang, Z., Moore, J.C., 2015. Chapter 6 - empirical orthogonal functions. In: Zhang, Z., Moore, J.C. (Eds.), Mathematical and Physical Fundamentals of Climate Change. Elsevier, Boston, pp. 161–197. https://doi.org/10.1016/B978-0-12-800066- 3.00006-1.

Orginally published in Journal of Atmospheric and Solar–Terrestrial Physics 261 (2024) 106294. Published by Elsevier Ltd.

UAVs assist forest officials

ideaForge Technology Limited deployed its Q6V2 UAV to support forest officials in preventing a potential human-elephant conflict in the Silli region of Jharkhand, India. The incident occurred when a herd of elephants strayed from the forest into nearby villages, creating panic among residents. Q6V2 UAV was launhced, which was equipped with Daylight and Night Vision payloads, enabling continuous tracking of the elephants' movement across dense forest cover and village boundaries.

The UAV captured high-definition optical and thermal visuals in real time, which were streamed directly to forest officials. This provided situational awareness of the herd's geo-tagged location and movement, even during low-light and rainy conditions. *www.ideaforgetech.com*

Boosting UAV anti-jamming capabilities

UAV Navigation-Grupo Oesía has collaborated with Septentrio to enhance navigation resilience for unmanned aircraft systems. The partnership focuses on ensuring compatibility between UAV Navigation's guidance, navigation and control systems and Septentrio's GNSS receivers. The collaboration integrates high-precision RTK capabilities with AIM+ anti-jamming and anti-spoofing technology, which utilizes the Galileo OSNMA service alongside Septentrio's proprietary algorithms to defend against signal interference and manipulation. *www.uavnavigation.com*

Multibeam echosounder payload for UAVs

SPH Engineering has released a multibeam echosounder system for UAVs that uses the Cerulean Surveyor 240-16, a compact bathymetric sensor designed for shallow-water mapping. The system expands drone-based hydrographic surveying capabilities by providing high-resolution bathymetric data collection over shallow waters. It operates at 240 kHz with a measurement range of 0.5 m to 50 m, targeting inland waterways, reservoirs, ports and environmental monitoring locations. *www.sphengineering.com*

Volatus Aerospace gains approval for scalable drone services

Transport Canada has issued a Special Flight Operations Certificate (SFOC) to Volatus Aerospace Inc., authorizing the company to conduct beyond visual line of sight (BVLOS) drone operations using MatrixSpace's radar technology integrated with Kongsberg Geospatial's IRIS Terminal platform. *volatusaerospace.com*

SimActive enables 3D calculations

SimActive Inc. has announced that its Correlator3D™ software is being used in Germany to generate volumetric calculations from drone imagery. The technology creates dense point clouds at mining sites, enabling accurate volume measurements and detailed terrain analysis. *simactive.com*

RICS launches global AI standard for surveying

The Royal Institution of Chartered Surveyors (RICS) has published the first global professional standard for the responsible use of artificial intelligence (AI) in surveying practice.

Set to take effect on 9 March 2026, the new standard sets out mandatory requirements and best practice expectations for RICS members and regulated firms worldwide. Some of the key provisions of the new standard include:

- **Governance & Risk Management**
  Firms must implement clear policies around data use, AI system governance, and risk documentation - including the creation of risk registers and due diligence procedures.
- **Professional Judgment & Oversight**
  Surveyors must assess the reliability of AI outputs and remain accountable for all work, applying professional scepticism and expertise throughout.
- **Transparency & Client Communication**
  Clients must be informed, in writing, of when and how AI will be used in service delivery, including options for redress or opting out.
- **Ethical Development of AI**
  For firms developing their own AI systems, the standard mandates assessments of data quality, stakeholder involvement, sustainability impact, and legal compliance.

www.rics.org

USGS unvelis national geologic map

The new USGS map, called The Cooperative National Geologic Map, was created using more than 100 pre-existing geologic maps from various sources and is the first nationwide map to provide users with access to multiple layers of geologic data for one location. This feature allows users to access the multiple data sources included in the map to look at or beneath the surface to understand the ancient history of the nation recorded in rocks.

The new interactive web tool was designed to be as user friendly as possible, making it accessible to both geologists and the public. Users can search for specific properties of geologic units or click on the map for additional geologic information and links to more detailed maps of local areas. *www.usgs.gov*

Ghana launches digital geospatial data system

The Lands Commission unveiled the Continuous Operating Reference System (CORS) Network to enhance data accuracy of fieldwork and survey operations across the country. The global positioning system (GPS) CORS Network would provide 24/7 nationwide geospatial data access, ensure real-time centimetre-level accuracy for fieldwork and boost revenue stream for the Commission. Currently, 52 COPS Network stations are deployed nationwide and zoned into southern, middle belt and upper sectors. *www.ghanabusinessnews.com*

Taiwan's Integrated Disaster Management

Taiwan, highly exposed to natural disasters, has transformed its disaster management through the Taiwan National Federated Research Data Repository (NFRDR). Powered by the datacube engine rasdaman, this platform integrates satellite imagery, UAV data, and IoT sensor streams across agencies, overcoming long-standing silos. By enabling real-time AI analytics, 3D flood simulations, and secure inter-agency data sharing, it enhances national resilience and supports evidence-based decision-making.

Historically, government agencies collected and stored Earth observation data in isolated silos, preventing timely sharing and reducing interoperability. This fragmentation hampered rapid decision-making during emergencies. To overcome these limitations, Taiwan launched a national federated data infrastructure under the leadership of the National Center for High-Performance Computing (NCHC), supported by academic and public partners. *https://rasdaman.com*

Sixth GLONASS-K satellite lifts off

The liftoff of the Soyuz 2-1b/Fregat rocket with the sixth GLONASS-K satellite took place as scheduled on Sept. 13, 2025, from Site 43 in Plesetsk. Around five hours after the launch, the Ministry of Defense reported that both payloads had been delivered into their orbits on time. Roskosmos also reported that the spacecraft were designated Kosmos-2595 and Kosmos-2596. *https://russianspaceweb.com*

ESA's Celeste LEO-PNT demonstrator mission set to launch in December

The European Space Agency (ESA) has confirmed plans to launch the first two satellites in its low-Earth orbit (LEO) positioning navigation and timing (PNT) constellation in the second half of December 2025. The launch will use a Rocket Lab Electron Vehicle, marking Europe's first venture into LEO-based satellite navigation.

The LEO-PNT in-orbit demonstrator mission, called Celeste, aims to test satellite navigation capabilities in LEO and evaluate its integration with existing medium-Earth orbit (MEO) systems. Celeste features a constellation of ten satellites that will fly close to Earth to test innovative signals across various frequency bands. The first two Celeste satellites, built in parallel by GMV and Thales Alenia Space, are set to launch in the coming months. *www.esa.int*

New satellite strengthens EGNOS

The European Commission announces a major milestone for EGNOS, Europe's satellite-based augmentation system. On 25 August 2025, the GEO-3 satellite Eutelsat 5 West B officially transitioned from test to operational status, broadcasting the EGNOS Signal-in-Space. This upgrade forms part of the EGNOS System Release 2.4.3, which deployment started in August 2025. The system release ensures that EGNOS continues to provide reliable and

uninterrupted services while paving the way towards its future evolution, including the next-generation EGNOS V3. *defence-industry-space.ec.europa.eu*

Next-gen automotive navigation application

TomTom has launched its Automotive Navigation Application, a navigation solution designed for automakers that combines TomTom Orbis Maps with an enhanced user interface layer built on the company's Navigation SDK. The company said the integrated solution allows car manufacturers to deploy navigation systems more quickly while reducing development costs and timelines. *www.tomtom.com*

Logan Scott receives Kepler award

Institute of Navigation's (ION) Satellite Division awarded Logan Scott its Johannes Kepler Award on September 12, 2025, during the ION GNSS+ 2025 conference in Baltimore, Maryland, USA for sustained contributions to satellite navigation signal design, recognition and mitigation of interference and spoofing threats to GPS, and advocacy for civil GNSS assurance.

Logan Scott's seminal contributions to satellite navigation over his 45+ year career include digital receiver design; early recognition of threats to GPS from interference and spoofing; invention of location-based encryption, "J911" crowd-sourced geolocation of interference sources; and use of cryptographic signal authentication for civil radionavigation signals.

Scott was a key technical leader in pioneering receiver designs at Texas Instruments, including signal acquisition and tracking, adaptive arrays, jamming, and fade resistance. In 1985, Logan and his team developed the world's first all-digital GPS receiver, paving the way towards the low-cost, compact, lightweight, and energy efficient receivers now numbering in the billions.

Scott was the first to describe methods for civil signal authentication. He invented a new and fundamental delayed-key asymmetric navigation security paradigm now embodied in the GPS Chimera signal, next generation WAAS, and Galileo systems; and he participated in the creation of the Chimera authentication signal.

Scott discovered and described how an adaptive array can bias phase and pseudorange measurements to adversely affect high precision receivers; particularly how such biases could cause Real Time Kinematic (RTK) ambiguity resolution to fail. This work became essential to the success of the Joint Precision Approach and Landing System (JPALS) program.

Since 2015, Scott has been a core member of the NTS-3 Advanced Signals Team, originating multiple signal design concepts, at least nine of which will be tested on-orbit. His signal designs focus on civil signal assurance, optimization of the navigation data message by leveraging concepts from the communications industry, and advanced waveforms to enhance military receiver performance.

As a member of the U.S. National PNT Advisory Board, Scott promoted the need and methods for resilient and robust PNT, and required spectrum protection. In 2010-2011 he developed and quantified the performance of crowdsourced interference detection and geolocation using cell phones. *ion.org*

Dr. Jason Anderson receives Parkinson award

Institute of Navigation awarded Dr. Jason Anderson its Bradford W. Parkinson Award on September 12, 2025, during the ION GNSS+ 2025 conference in Baltimore, Maryland, for his thesis: Designing Cryptography Systems for GNSS Data and Ranging Authentication.

Jason Anderson received his PhD from Stanford University where his research in the Stanford GPS Lab pertained to constructing efficient cryptosystems for GNSS. Before Stanford, Dr. Anderson received a Mechanical and Nuclear Engineering degree from UC Berkeley. Dr. Anderson has worked at SpaceX, General Atomics, and is currently working at Xona Space Systems as a Senior Security Engineer.

This award, which honors Dr. Bradford W. Parkinson's leadership in establishing both the U.S. Global Positioning System and the Satellite Division of the ION, recognizes an outstanding graduate student in the field of Position, Navigation, Timing (PNT) and/or Applications. *ion.org*

NOAA flood mapping now covers 60% of U.S.

NOAA's National Weather Service (NWS) announced its experimental Flood Inundation Mapping (FIM) tool. The FIM provides near-real-time, high-resolution, street-level visualizations of flood waters to assist NWS forecasters in issuing flood watches and warnings. It helps provide approximate spatial estimates of land area that is covered in water, based on modeled forecast river flows and current conditions, with detailed information on where flooding impacts may occur. *www.noaa.gov*

Locate unmarked graves in northeast Iowa using remote sensing

A team of three Luther College anthropology students led by Colin Betts, professor of anthropology, worked to identify unmarked graves at three pioneer cemeteries in Winneshiek County this summer.

The students conducted their efforts in three cemeteries: Big Canoe Norwegian Methodist, Springwater Cemetery and Crossroads/Metcalf Cemetery. These locations were selected for their high likelihood of containing unmarked graves. By combining survey-grade GPS mapping with ground-based sensing technologies, the students sought to detect subsurface anomalies that may indicate burial sites.

The students used ground penetrating radar, soil resistivity and a magnetic gradiometer to survey the cemeteries. Each of these technologies offer different types of insights into what may lie beneath the surface. When weather was favorable, high-quality data was collected. In several cases, the technology revealed patterns consistent with unmarked burials. *www.luther.*

MBRSC, CAR and AEC sign MoU

The Mohammed Bin Rashid Space Centre (MBRSC) signed a MoU with the Corporación Autónoma Regional de Cundinamarca (CAR) and Colombian Space Agency (AEC) to foster international cooperation in the field of space science and technology. The agreement outlines a framework for collaboration across several key areas in the field of space science and technology, including promoting joint research and innovation, facilitating knowledge transfer, and enhancing data exchange between the UAE and Colombia. The MoU further aims to encourage capacity building and expertise sharing through joint projects designed to strengthen both nations' contributions to global space exploration and technological advancement. *www.zawya.com*

OnGeo Intelligence kicks off global campaign

OnGeo Intelligence has launched a campaign that gives people around the world a chance to get free access to Maxar's high-resolution satellite imagery. The initiative runs until September 30, 2025 and is open to anyone willing to share a personal use case, user story, or idea showing how satellite imagery can be useful in everyday life. Participants can request a Satellite Imagery Report with premium data from Maxar's constellations - WorldView, WorldView Legion, and GeoEye - with resolution as sharp as 30 cm per pixel. *www.ongeo-intelligence.com*

Space Norway Signs New Launch Agreement with SpaceX

Space Norway has signed a contract with SpaceX for the launch of the new communications satellite, THOR 8, into geostationary orbit. The mission, which will launch aboard a SpaceX Falcon 9 rocket in 2027, will strengthen Space Norway's communications capacity for both governmental and commercial clients. THOR 8 is a major undertaking for Space Norway. The satellite will both replace older satellites being phased out in the coming years and provide increased capacity and service offerings for its customers. It is part of Space Norway's multi-orbit strategy, with satellites in low Earth orbit (LEO), geostationary orbit (GEO), and highly elliptical orbit (HEO). *spacenorway.com*

SBG Systems expands its IMU line

SBG Systems has announced the upcoming release of the Pulse-20, a sub-miniature, industrial-grade Inertial Measurement Unit (IMU), which will be available before the end of the year.

Alongside the commercial availability of the Pulse-80, the company now offers a complete range of high-performance IMUs — Pulse-20, Pulse-40, and Pulse-80 — designed to meet the needs of every applications ranging from compact systems to high-end platforms requiring FOG-level performance.

The SBG IMU now covers three levels of performance:

- Pulse-20: Sub-miniature, industrial-grade IMU delivering high performance in a compact form factor. It includes built-in magnetometers for 9-degree-of-freedom measurements and features CAN communication in addition to serial, enabling integration in a large range of applications.
- Pulse-40: Tactical-grade IMU, combining robustness and precision for demanding applications
- Pulse-80: High tactical-grade IMU, offering FOG-level performance without the size, weight, and cost of traditional fiber-optic gyros.

This range with various performance levels allows integrators to select the right solution for their needs while relying on a consistent architecture, software integration and quality requirements across the entire product line.

The Pulse IMUs serve a wide spectrum of industries, including unmanned vehicles, guidance and navigation for munitions, electro-optical systems, satcom-on-the-move, and surveying. Their flexibility, compact size, and high accuracy make it suitable for both volume production and mission-critical applications. *www.sbg-systems.com*

Viasat awarded second SouthPAN contract

Viasat Inc. has received $252 million AUD from Geoscience Australia and Toitū Te Whenua Land Information New Zealand (LINZ) to deliver additional satellite services for the region's Southern Positioning Augmentation Network (SouthPAN) - a collaborative satellite-based augmentation system developed jointly by Australia and New Zealand. It provides precise positioning and navigation services to support aviation, maritime, agriculture, surveying and emergency response. *www.viasat.com*

QZSS Utilization Demonstration Project

ArkEdge Space Inc., Tokyo has been selected for the FY2025 "QZSS Utilization Demonstration Project," jointly organized by the Cabinet Office of Japan and Quasi-Zenith Satellite System Service Inc.

The company will deploy next-generation tide monitoring buoys across island nations in the Asia-Pacific region. Leveraging [2] Multi-GNSS Advanced Orbit and Clock Augmentation for Precise Point Positioning ("MADOCA-PPP"), a high-precision GNSS augmentation service provided by Japan's Quasi-Zenith Satellite System (QZSS) "Michibiki," these buoys will collect sea level data and transmit it via the company's proprietary IoT satellites. *arkedgespace.com*

GPS resilience with new satellites

QinetiQ and Xona Space Systems have demonstrated how GPS navigation can be bolstered by using low Earth orbit (LEO) satellites, in the first UK tests of Xona's new satellite navigation system, Pulsar.

This marks a major milestone in the development of next-generation PNT capabilities, increasing resilience against jamming and spoofing, as well as improving GPS availability in congested or challenged environments. *www.qinetiq.com*

Adtran launches Oscilloquartz SFP grandmaster clock

Adtran launched the OSA 5401XG SyncPlug™, an SFP-based grandmaster clock that delivers precise PTP and NTP synchronization for 10Gbit/s edge and access networks. The new device enables timing distribution through a compact, plug-in form factor that requires no rack space or complex installation, empowering network operators to extend synchronization into space- and power-limited deployments. With multi-band GNSS support, compliance with PRTCB and compatibility with 10Gbit/s-only host platforms, it offers an efficient way to upgrade timing capabilities across sectors. *www.adtran.com*

SFL Missions Inc. to support three new HawkEye 360 satellite Clusters

SFL Missions Inc. has been awarded a contract to provide spacecraft bus units in support of three new HawkEye 360 satellite Clusters, totaling nine spacecraft, which will expand HawkEye 360's RF detection and geolocation constellation. The contract includes Cluster 14, which is similar to those recently launched by HawkEye 360, and Clusters 15 and 16, which SFL Missions is modifying to incorporate advanced capabilities.

Under the Flex Production program, SFL Missions provides spacecraft bus units and subsystems based on its space-proven 30-kg DEFIANT platform that SFL has designed in Toronto specifically for HawkEye 360, which are then shipped to HawkEye 360's Herndon, Va. facility for full assembly, integration, and testing. *https://sflmissions.com*

SATNUS performs its third NGWS Flight Campaign

SATNUS has successfully completed its third Flight Test Campaign in the NGWS Program, devoted mainly to the MCSD (MUT & Common Systems Demonstrator) platform validation (including Flight Segment and Ground Segment) and in-flight integration and testing of the Next Generation Autonomy Computer (NGAC). Throughout the campaign, which included three single and three dual platform flights, four NGAC prototypes have been integrated and flight tested as a core element mission payload, along with other MUT & Common Systems Demonstrator improvements in the flight and ground segments (e.g. Communication System, Flight Termination System, Avionics bay, Wing-tip camera POD C2 System, Distribution and Information Management System and Mission Planning Station). A key achievement was the successful end-to-end testing of the onboard and ground functional chains for multi-platform operations. *gmv.com*

M-G370PDT Inertial Measurement Unit

Epson recently showcased the M-G370PDT Inertial Measurement Unit (IMU. The IMU represents the latest evolution of Epson's inertial sensor portfolio, delivering very low-noise performance in a compact 1-inch form factor. It is designed for various applications, from mid-to-low Earth orbit satellites, airborne unmanned vehicles and land-based navigation systems. Epson's proven space heritage is underscored by the deployment of select M-G370 series IMUs in the Internal Ball Camera 2 aboard the International Space Station (ISS), where they deliver microgravity stabilization in one of the harshest environments imaginable.*https://epson.com/microdevices*

Microchip unveils GNSSDO modules

Microchip Technology has announced its portfolio of GNSS Disciplined Oscillator (GNSSDO) Modules that integrate the company's renowned embedded atomic clock and oscillator technologies, including the Chip-Scale Atomic Clock (CSAC), Miniature Atomic Clock (MAC) and Oven-Controlled Quartz Crystal Oscillators (OCXOs). The modules process reference signals from GNSS or an alternative clock source and disciplines the on-board oscillator to the reference signal, enabling precise timing, stability and holdover performance based on end application requirements. *https://ir.microchip.com*

SUBSCRIPTION FORM

YES! I want my Coordinates

I would like to subscribe for (tick one)

☐ 1 year	☐ 2 years	☐ 3 years
12 issues	24 issues	36 issues
Rs.1800/US$140	Rs.3400/US$200	Rs.4900/US$300
*		SUPER saver

First name .....

Last name .....

Designation .....

Organization .....

Address .....

.....

City ..... Pincode .....

State ..... Country .....

Phone .....

Fax .....

Email .....

I enclose cheque no. .....

drawn on .....

date ..... towards subscription

charges for Coordinates magazine

in favour of **'Coordinates Media Pvt. Ltd.'**

Sign ..... Date .....

Mail this form with payment to:

Coordinates
A 002, Mansara Apartments
C 9, Vasundhara Enclave
Delhi 110 096, India.

If you'd like an invoice before sending your payment, you may either send us this completed subscription form or send us a request for an invoice at iwant@mycoordinates.org

***** Postage and handling charges extra.

MARK YOUR CALENDAR

October 2025

Intergeo 2025
7 - 9 October
Frankfurt, Germany
https://dvw.de/intergeo/en

The 8th ISPRS Geospatial Conference
13 - 15 October 2025
Tehran, Iran
https://geospatialconf2025.ut.ac.ir

The Arab Conference on Astronomy and Geophysics
13 - 16 October 2025
Cairo, Egypt
https://acag-conf.org

AOGEO Symposium
15 - 17 October 2025
Bangkok, Thailand
https://aogeo17.gistda.or.th

The 46th Asian Conference on Remote Sensing
27 - 31 October 2025
Makassar, Indonesia.
https://acrs2025.mapin.or.id

3rd MENA Geospatial Forum
29 - 30 October 2025
Riyadh, Saudi Arabia
https://menageospatialforumksa.com

November 2025

Canada's National Geomatics Expo 2025
3 - 5 November
Calgary, Canada
https://gogeomaticsexpo.com

13th International FIG Workshop on the Land Administration Domain Model & 3D Land Administration
3 -5 November 2025
Florianópolis, Santa Catarina, Brazil
https://gdmc.nl

Trimble Dimensions
10-12, November 2025
Las Vegas, USA
www.trimble.com/en/

3rd International Workshop on Evaluation and BENCHmarking of Sensors, Systems and GE-Ospatial Data in Photogrammetry and Remote Sensing (GEOBENCH)
20 - 21 November 2025
Wroclaw, Poland
https://geobench.fbk.eu

Geo World 2025
24 - 27 November
Dubai, UAE
www.geoworldevent.com

February 2026

Geo Week
16 - 18, February 2026
Denver, CO, USA
www.geo-week.com

Dimetor, SkAI partnership

Dimetor and SkAI Data Services are announcing a strategic partnership to increase global airspace security.

SkAI Data Services developed a real-time ADS-B GPS spoofing and jamming tracker — GPSwise. Dimetor is a global leader in connectivity and data analytics for the communications, defense and aerospace industry. The companies aim to deliver a comprehensive, holistic solution for monitoring GNSS disruptions, covering both lower and upper airspace, for crewed and uncrewed flight operations and other users worldwide. *www.dimetor.com*

Skydel AI revolutionizes GNSS simulation

Safran Electronics & Defense unveiled Skydel AI, a breakthrough in GNSS simulation technology that leverages Artificial Intelligence to automate and simplify simulation scenario setups like never before. Skydel AI is designed to streamline GNSS simulation scenario creation through intelligent automation and an intuitive interface. By using natural language commands, it enables users to query about GNSS/Skydel topics, request assistance, and dynamically configure simulation parameters by creating Python code to be used by Skydel. It eliminates complexity and significantly reduces setup time. *safran-navigation-timing.com*

Quectel rolls out four GNSS antennas

Quectel Wireless Solutions has introduced four new GNSS antennas. They include:

- The YFGD000AA high-precision, low-profile antenna which covers all GNSS bands
- The YFGD000BA, optimized for triple-band solutions in GNSS L1, L2 and L5 bands
- The YFGN000H1AC high-precision, lightweight antenna that again covers all GNSS bands

The YEGT010W1AM, designed for general-purpose reception in non-precision applications. *www.quectel.com*

In Coordinates

10 years before...

mycoordinates.org/vol-XI-issue-09-September-2015

Surveying as a profession: Is the shine waning?

Experts share views on issues and prospects of surveying profession

"The shine probably went off the profession of surveying and geomatics in the 1970s and it has been difficult to attract students into education programs since then."
John Trinder
Emeritus Professor, School of Civil and Environmental Engineering, The University of NSW, Australia

"This generation of young surveyors are energetic, promising and leading a new era of innovation."
Virgo Eresta Jaya
President, Ikatan Surveyor Indonesia (ISI) , Indonesia

"This is an exciting profession. No the shine is not waning – it's right there and shining bright. Seriously could somebody ask for a more exciting profession!"
Eva-Maria Unger
Chair, International Federation of Surveyors Young Surveyors Network (FIG YSN)

"There has never been a better time to enter the surveying profession. If I had my chance again, I would most certainly follow the same career path that I chose all those years ago."
Rory M Stanbridge
MRICS, FCInstCES, FRSPSoc
Secretary General – The Survey Association, UK

"People join the profession because it satisfies them intellectually. Surveyors have a unique and valuable set of skills coupled with a powerful ethical and professional outlook."
Muiris de Buitléir
Msc, FRGS FSCSI FRICS Former president of the Irish Institution of Surveyors, Member of the committee of the Geomatics Professional Group of the Society of Chartered Surveyors Ireland

"We have to evolve our mode of operation to keep with the times and remain relevant to society. And more importantly, we have to gear ourselves for the 'new frontiers' that will continue to unfold."
Loi Hwee Yong
President, Land Surveying, Singapore Institute of Surveyors & Valuers, Member, Land Surveyors Board Singapore, Principal, H Y Loi Consultants

"The marine surveying industry will keep its head up by consultancy and training"
Capt Bertrand Apperry
President, International Institute of Marine Surveying (IIMS)

Costing and financing of land administration services
Anthony Burns
Land Equity International, Wollongong, Australia
Kate Fairlie
Land Equity International, Wollongong, Australia
Solomon Haile
UN-Habitat Global Land Tool Network Secretariat, Nairobi, Kenya CoFLAS – the Costing and Financing of Land Administration Services for Developing Countries Tool – has been developed to address a core need of enabling public agencies to effectively cost the establishment and operation of a land administration service (LAS). \\

Understanding Marine Cadastre System in Malaysia

Zakaria MAT AROF and Ashraf ABDULLAH
Department of Geomatic Science, Faculty of Architecture, Planning and Surveying, University Technology of MARA, Perlis Campus, Malaysia

Marine cadastre is about the right, restriction and responsibilities of stakeholder to any marine parcel. Although the concept of giving right to any parcel is about the same, but there are differences between marine parcel and land parcel's right due to each unique phenomena which contributes to the differences of approach in applying the cadastre concept.

Now compatible* with

SBG SYSTEMS | Motion & Navigation you can trust

Inertial Navigation Solutions

For Geospatial, Autonomous, & Defense applications:

- High-performance in the smallest package
- Reliable navigation and positioning everywhere
- Post-processing with Qinertia PPK software

*NavIC compatibility: Apogee, Ekinox, Navsight, Quanta series

www.sbg-systems.com

MADE IN FRANCE