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Coordinates

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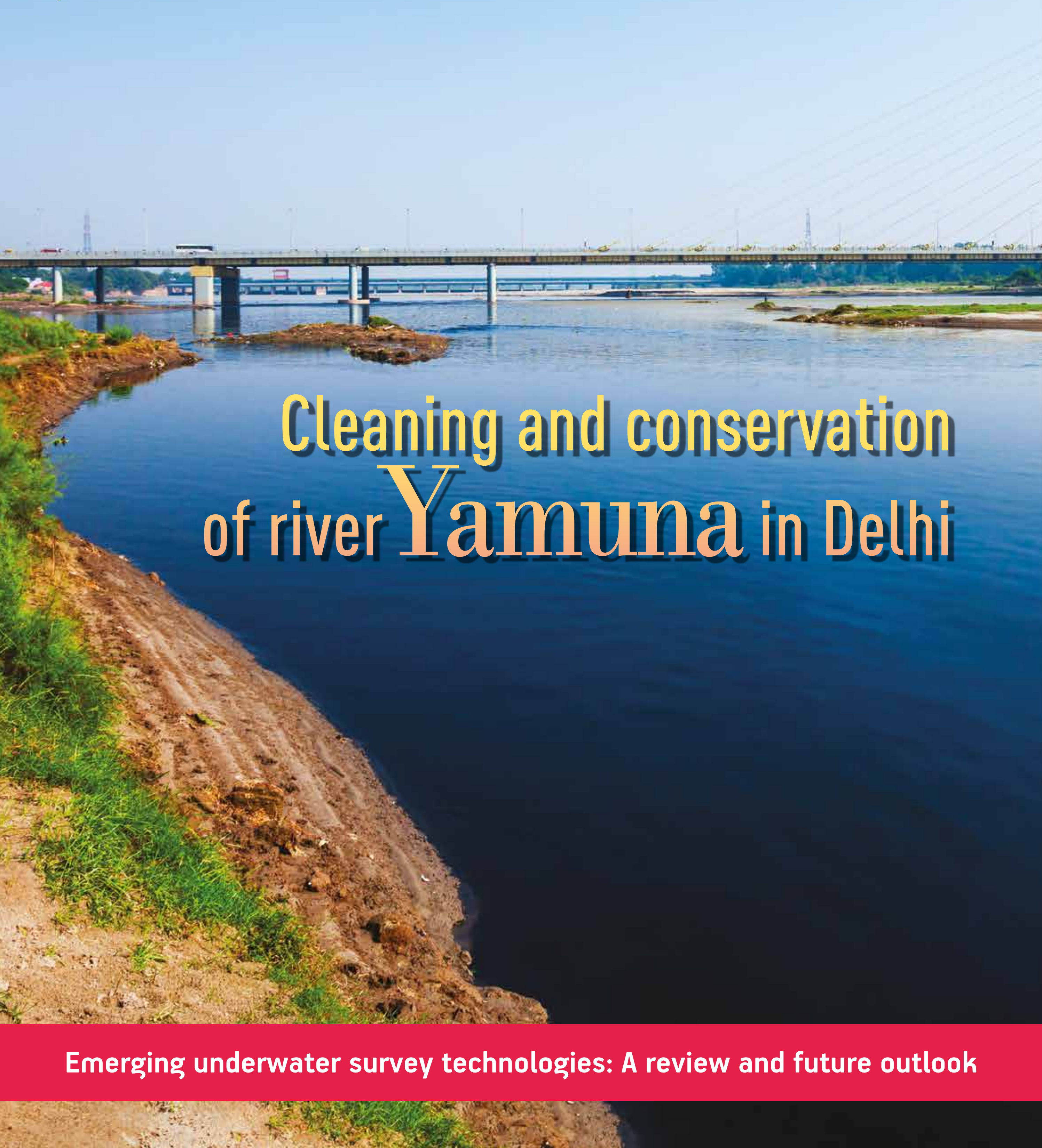
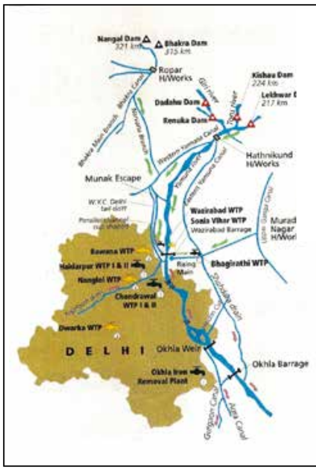
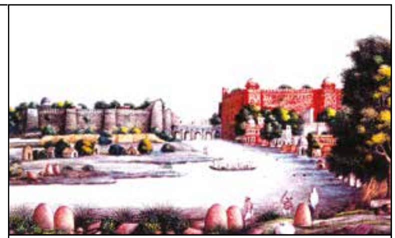
THE MONTHLY MAGAZINE ON POSITIONING, NAVIGATION AND BEYOND

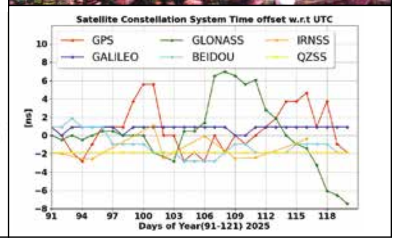


Cleaning and conservation of river Yamuna in Delhi

Emerging underwater survey technologies: A review and future outlook







In this issue

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Articles

Columns

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Destined to die?

The river Ganga and Yamuna are India's lifelines,

Revered as divine and vital for millions.

Yet the paradox is, these sacred rivers rank among the world's most polluted,

Suffocated by waste.

The Ganga alone carries untreated sewage from over 100 cities along its banks,

Worsened further by industrial effluents, heavy metals, and so on.

High BOD and faecal coliform levels make these rivers unfit for bathing or drinking.

The Ganga Action Plan promised revival.

Namami Gange aimed to clean the Ganga comprehensively.

The situation of Yamuna is no better.

Where do we go wrong - inconsistent policies, weak enforcement, public apathy,…?

Without relentless commitment,

These rivers may meet the fate

We dread to imagine!

Bal Krishna, Editor
bal@mycoordinates.org

Cleaning and conservation of river Yamuna in Delhi

Yamuna 25 the identity of Delhi. While the immediate cleaning operations include trash skimming, weed harvesting and dredging, these will have to be long-term, overarching the entire region

A. K. Jain
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).

Rivers have always occupied a central place in India's heritage and ethos and have traditionally been sources of spiritual inspiration, cleansing and penance. A critical component of environment and our ecosystem, we have accorded divine status to rivers, worshipping them as a life-giving mother. River conservation is one of the highest priorities and we have made Namani Gange a template in our mission of river conservation, particularly in urban areas. The establishment of 'River Cities Alliance' (RCA) comprising 95 river cities across the country is one such step in this direction. It aims to offer interesting solutions such as sponge cities, reuse of used water, river health monitoring, pollution control, water sensitive city design and floodplain management.

Prime Minister Narendra Modi's message dated 10th. Feb 2023 for DHARA Forum, Pune

From times immemorial, the villages and the cities came up along the rivers that evolved the cultures. Among various Delhis, Shahjahanabad (17th Century), was built along the river Yamuna, a 1370 km long river emanating from the Himalayas and merging into the River Ganga at Prayag (Fig.1). The river Yamuna which had been the lifeline of the city, started losing its connections during the 20th century after the building of New Delhi. The Ring Road, thermal Power stations, industrial areas, waste dumping and sewerage treatment plants were located along the river Yamuna.

As a result, today the River Yamuna in Delhi has become a dirty drain. During the Delhi Assembly election (February 2025) the toxic water of the river Yamuna became a contentious issue. As committed by the Prime Minister Narendra Modi, the new government has to take up the river cleaning on priority so that the Yamuna becomes the identity of Delhi. While the immediate cleaning operations include trash skimming, weed harvesting and dredging, these will have to be long-term, overarching the entire region. The river zone in Delhi covers 9934 Ha and the river flows in a length of 48 km. It is flanked by Hindon River in the East, and Sahibi River (Najafgarh drain) in the West (Figs.2 and 3). The Yamuna is integral to Ganga riverine systems connected by a network of natural stream, nallahs and canals. The river Zone in Delhi has been used for power stations, samadhis, housing, offices, stadia, temples, cremation ground, and an IT Park. Sand mining has impacted its water regime (Fig. 4). More than 161 unauthorised colonies have come up in this zone which discharge their effluents and wastes in the river. These have altered the river regime and endangered its water quality.

The figure 5 shows the dangerous levels of dissolved oxygen at 70 mg/litre against acceptable level of 6.1 mg /litre, faecal coliform as high as 84 million mpn/100 ml., against acceptable limit of 1200 mpn/100m, and ammonia level at 7.2 mg/l, against acceptable 3.0 mg/l.

The analysis of the water quality data in the river reveals the following:

- The levels of Dissolved Oxygen (DO) above the threshold limit (5 mg/ litre)
- The levels of Biochemical Oxygen Demand (BOD) above the acceptable limit of 3 mg/ litre.
- The dangerous levels of coliform (faecal and total) in the river water, mainly due to untreated sewage.

It is estimated that during last 50 years freshwater vertebrate in the river have declined by 83%, groundwater has depleted and there is a serious loss of biodiversity. The embankments to bind the floodplain have constricted the water flow, resulting into frequent flooding. With indiscriminate urbanization, industries, unsewered colonies, fly ash and garbage dumping, the river has become a corridor of filth, garbage, squatting and insanitation (Fig. 6).

About 90 per cent of river water is diverted into drains and canals upstream and most of the remaining water is stored for urban use, leaving the river high and dry, especially during the summer. River without a continuous flow lacks oxidation and becomes stagnant and polluted. A significant problem is eutrophication which results from the excessive levels of nutrients in municipal, industrial, irrigation and drainage effluents. Nearly 75% of pollution of river is from municipal sewage, and the balance coming from effluents generated from industries, run-off from agricultural fields, solid waste dumps, open defecation, etc.

According to Delhi Pollution Control Committee 28 major drains are falling into River Yamuna in Delhi which dispose of sewerage and wastes:

1. Najafgarh
2. Metcalf House
3. Khyber
4. Sweeper Colony
5. Magazine Road
6. ISBT
7. Tonga Stand
8. Civil Mill
9. Sen Nursing Home
10. Drain Number 14
11. Power House
12. Indra Puri
13. Sonia Vihar
14. Kailash Nagar
15. Shashtri Park
16. Barapulla
17. Maharani Bagh
18. Old Agra Canal
19. Jaitpur Drain
20. Sarita Vihar Pool
21. Tughlakabad
22. Drain near LPG Bottling Plant
23. Drain near Sarita Vihar Bridge
24. Shahdara
25. Sahibabad
26. Molarband
27. Abul Fazal
28. Supplementary drain

Against the disposal of 792 MGD sewerage, the current treatment capacity is only 550 MGD. New STPs have been planned at Okhla, Sonia Vihar and Delhi Gate. Rehabilitation of 3 STPs at Kondli Phase II, Rithala Phase I and Yamuna Vihar Phase II is in progress. Also the desilting of 10 trunk lines (200 kilometres) is in progress.

Besides 31 planned Industrial Areas, the Government of Delhi vide gazette notifications dated 2nd December 2005 and 30th June 2006 regularised 23 non-conforming industrial clusters in Delhi. These are without any safeguards for disposal of their effluents, that ultimately gets into the river through drains. In 2023, the Delhi Government initiated a study to assess the presence of microplastics in the river and identify potential sources of microplastic contamination and analyse leaching impact of microplastics on the river, Najafgarh drain and Supplementary drain. The relative quantification, nature source and characteristic of pollutants are essential to develop short-, medium- and long-term action plans.

Delineation of River Basin and Floodplain

Based on the topographical characteristics, the National Capital Territory of Delhi has been divided in to 6 drainage basins as follows:

- Najafgarh Basin (332 Sq.Km.)
- Alipur Basin (170 Sq.Km.)
- Kanjhawla Basin (216 Sq.Km.)

Fig. 1: River Yamuna in Delhi (1850 Lithograph by Mazhar Ali Khan)
Source: British Library, London

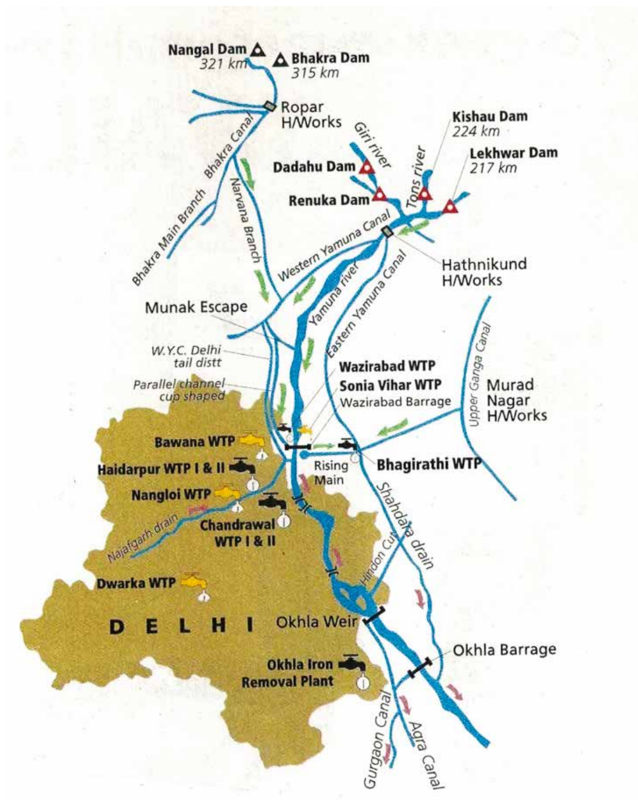

Fig. 2: The Origin and Arrival of River Yamuna in Delhi
Source: Centre For Science and Environment, 2012

- Shahdara Basin (55 Sq.Km.)
- Khushak Nallah - Barapulla Nallah System (95 Sq.Km.)
- Mehrauli Basin (160 Sq.Km.)

Each basin has a main drain serviced by several tributary drains. The Gazetteers of Delhi 1883 and 1912 state that there were 65 species of fish in the river Yamuna such as mahseer, rohu, bachwa, mulley, tengra, silund, mohi, mirgal, lalbans, chilwa, gunch and katla, besides, turtles and gharials and magars [now extinct]. The Gazetteers record the river to be navigable all along. History books mention the boats from Delhi to Agra, Lucknow, Patna and Calcutta.

The National Green Tribunal (NGT) in its order on 6th February 2025 reminded the Delhi Development Authority (DDA) of non-compliance of its 2019 order to remove encroachments from the Yamuna floodplain and delay in Yamuna floodplain demarcation based on a one-in-100-year flood probability model. Earlier Delhi Government in its report dated September 18, 2024, had informed the NGT that a committee has been formed comprising district magistrate, Delhi Development Authority and the Revenue Department to assess the encroachments on the Yamuna floodplain. The legal demarcation of flood zone is a prerequisite for assessing the exact areas under encroachments in Zone 'O', the zonal plan of which stand approved in 2010 (Fig. 7). The orthorectified aerial images have been generated by interpretation of drone images, and ground surveys by the joint teams of DDA and Revenue Department. Authenticated ground coordinate details and submitted to the Geo-Spatial Delhi Limited (GSDL) for assessing the encroachments in the flood plain (Zone 'O'), which are yet to be finalised.

The issue of demarcation of flood plain has been hanging since 1978 floods in Delhi. The Yamuna Standing Committee in 1978 recommended that the minimum spacing between future embankments on the banks of the river Yamuna be 5 km and the embankments be aligned at a minimum distance of 600 m from the 'active river edge'. In 2006 Delhi High Court appointed Yamuna Removal of Illegal Encroachment Monitoring Committee headed by Justice (Retd.) Usha Mehra in WPC 689/2004 dated 29th March 2006. The Committee directed that no construction within vicinity of 300m on either side of the edge of the water channel of Yamuna River shall be allowed.

In 2014, the Committee constituted by National Green Tribunal (NGT) observed that "unfortunately its decision had not been followed and the flood water carrying capacity of the river had been greatly compromised". In 2015, in a case filed by Manoj Mishra, the NGT formed a Principal Committee to identify all the existing structures in the floodplains and recommended that ought to be demolished. This is yet to be done.

As per the Delhi Master Plan 2021, the floodplain is termed as 'Zone O'. In the Draft Delhi Master Plan 2041, the floodplains have sub-divided into Zone 'O-1' and Zone 'O-II'. While no construction would be permitted in Zone O-I or the river (6295 Ha), regulated development will be allowed in 'Zone O-II' (3638.36 Ha). This will reduce the drainage capacity of the river by one-third. It will also have serious ecological consequences, besides increasing the frequency and extent of flooding.

Delhi has 3740 km of storm drains, of which the PWD and GNCTD own 2588km. The MCD, NDMC and Cantonment Board control a length of 475 km. The Irrigation and Flood Control Department controls 426.55 km, and 251 km are with the DSIIDC and NTPC. The DDA is responsible for preparation of Delhi Master Plan and the Zonal Plan

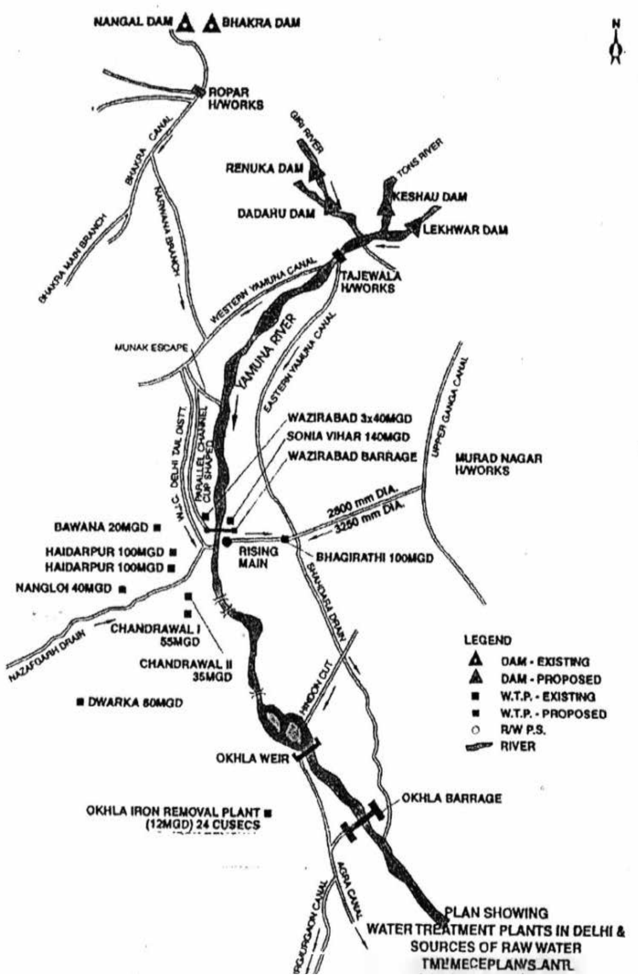

Fig. 3: River Yamuna in Delhi flows in a length of 48 km and covers 9934 Ha of area as river flood plain. Delhi has a 350 km long network of canals and major drains and more than 1,045 water bodies
Source: WAPCOS

Fig. 4: Sand Mining in Riverfront
Source: India Rivers Forum, INTACH, Virasat June 2021

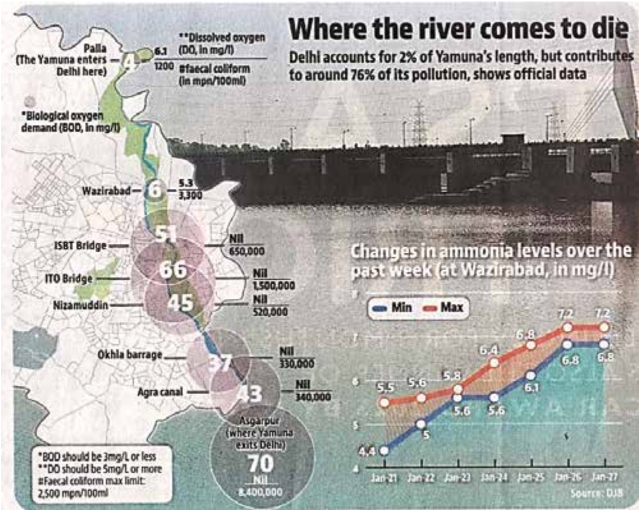

Fig. 5: Pollution levels of River Yamuna in Delhi
Source: Delhi Jal Board/ Hindustan Times, 29th January 2025

Fig. 6: Sources of Water Pollution in River Yamuna and Ganga
Source: Worldwatch, 1995/ Jain A.K. 2021

of River Zone 'O', which integrate the plans of water supply, drainage and environmental control, etc.

Keeping the River Flowing

Dumping of solid and liquid wastes into the river Yamuna in Delhi not only violates the Water (Prevention and Control of Pollution) Act, 1974, and Environment Protection Act 1986., but also effects the environment flow (e flow) of water channel. Against the present e-flow of 0.86 million cubic metre/day, Yamuna in Delhi needs minimum 6.6 mcm/day e-flow. The Supreme Court of India in 1999 directed that a minimum10 cumecs of water be ensured in the river Yamuna throughout, together with pollution abatement and up-gradation of water quality to meet the burgeoning demand of water supply.

An Integrated Strategy

The river is intimately connected with the water supply, sanitation, flooding, drainage, and transport networks. As such, several agencies dealing with the environmental management and pollution control, land, water, flood control and drainage. power, irrigation, transport, and sewerage need to work together. As such, Unified Centre for Rejuvenation of River Yamuna (UCRRY) was constituted vide DDA Notification dated 28th July 2015 under the Chairmanship of the Lieutenant Governor of Delhi to bring the diverse stakeholders/agencies on one platform.

The publication of the Centre for Science and Environment under the Namami Ganga Mission – Handbook for Planning and Designing Water Sensitive Cities for the Ganga Basin (2023) suggests watershed catchments as a basis for water sensitive design and conservation of existing water bodies and wetlands to optimise water harvesting and ecological sustainability. It stresses upon the revival of traditional water systems, and water harvesting by lakes, pond, catchment areas and wetlands. The INTACH has suggested installation of aeration and bioremediation systems to increase dissolved oxygen in water.

According to government records, Delhi had 1367 water bodies, ponds and lakes of which 1045 were found in the revenue records, but only 631 could be identified by field surveys. Of the 322 water bodies identified by Geospatial Delhi Limited (GSDL), only 43 were found on ground. Delhi also had about 65 baolis or stepwells (dug out water tanks), which collected rainwater. Vikramjit Singh Rooprai in his book Baolis (Niyogi. 2019) has listed 32 baolis in Delhi (Fig. 8 and Fig. 9).

The Delhi Jal Board has initiated the work on the rejuvenation of 155 water bodies including Jahangir Puri marshes, Najafgarh Lake, Mayur Vihar, Shahdara Lake, Neela Hauz, Hauz Khas and Hauz Rani. The rejuvenation of Najafgarh lake and Najafgarh drain (from Delhi-Gurgaon border to Wazirabad/river Yamuna-45 km) is being taken up by the I & F Department and DTTDC, GNCTD.

Circular Water Management

Rainwater harvesting and groundwater recharge are the essential tools of circular water management. This involves:

- Arresting groundwater decline and improving its accessibility water quality
- Preventing surface water run-off during monsoons
- Reducing water wastage and recycling of wastewater

A range of options for circular management of water include surface and sub-surface storage; net zero building design, recycling, and biological treatment of wastewater. A circular plan for water management incorporates the following strategies:

- Reviewing the Water Supply Standards
- Consumption efficiency
- Resource catchment
- Improvement in the quality of water when returning it to the environment

There is a huge potential for conserving water in the buildings, as only 5% of water is used for drinking or hygiene purposes, while 95% is used for evacuation of wastes.

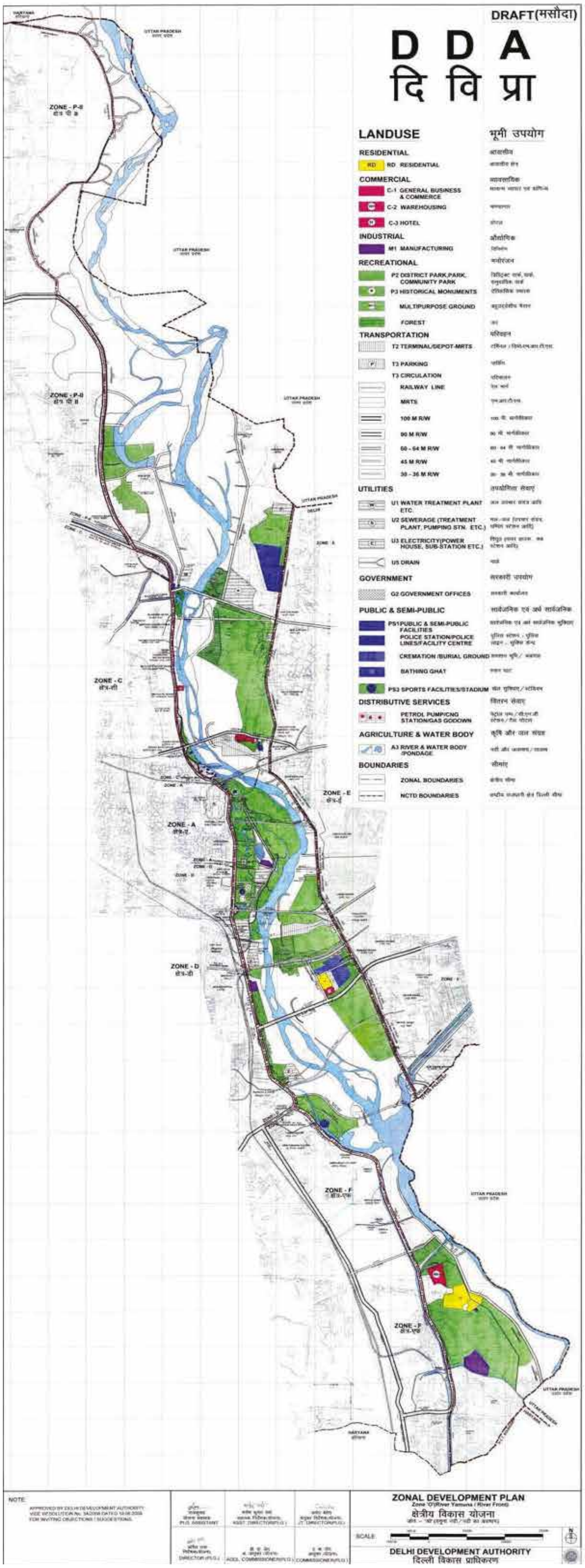

Fig. 7: Zonal Plan of Zone 'O' (River Yamuna)
Source: DDA

The river, water bodies and wetlands need to be protected from ingress of the sanitation and sewerage. Recycling of wastewater and Zero run-off drainage with the provision of swales, retention ponds, etc. can help in optimizing the surface and groundwater. Adoption of new technologies, such as Blockchain and SCADA systems, can also help in a circular water management.

Creating balancing ponds for slow surface run off can immensely recharge the water table. The organic reed beds and aerators can clean the sewage entering the drains and replenish the aquifers. Drainage, integrated with rejuvenation of lakes, canal and riverfront can help to prevent flooding of urban areas, damage to roads and buildings and reduce risk of water-borne diseases. The South Greenways along Barapulla Nalla is being converted into a beautiful, lively area by primary water treatment, bioremediation, desilting sewerage by micro-STPs and wastewater recycling.

Based on natural topography, water catchment zones are identified and reserved of water bodies, parks and green strips, bio-swales, storage tanks and recharging pits (Figs.10 and 11). The storm water from the roads and unpaved areas can be conserved that enriches the groundwater. It is essential to put up decentralised wastewater and sewerage treatment facilities (Fig, 12).

Circular Water Management focuses on the principles of reduce, reuse, recycle, restore and recover. Decentralised Wastewater Treatment System (DEWAT), bioswales and revival of water bodies are important tools for circular and sustainable water management (Figs 13 & 14).

The lakes, water bodies and riverfront can be rejuvenated and landscaped by recycled carbon neutral materials, planting and water recycling strategies (Fig 15). The soft landscape and vegetation along the riverbank allows rainwater to be absorbed rather than running off. Natural in-stream elements, e.g. root

Fig. 8: Baolis in Delhi
Source: Rooprai, Vikramjit Singh (2019) Baolis, Niyogi

wads provide slow-water habitat for fish and insects that regenerate native wetlands and conserve the river biodiversity.

A Scientific Approach

A scientific approach to address the issues of river pollution needs building the interceptor sewers and STPs along the major drains to check its ingress into the sewage flowing into the river. This also needs augmenting the capacity of various existing STPs, such as Delhi Gate and Dr. Sen Nursing Home drains (from the existing 2.2 MGD to 15 million gallons daily each). The unsewered areas, viz. slums, unauthorized colonies, resettlement colonies, villages, etc. can be provided with alternative, decentralized sewage systems, such as Up-flow Anaerobic Sludge Blanket (UASB), sewage treatment through afforestation (Karnal Technology) and Constructed Wetland. Resource recovery options like methane generation, aquaculture and Bioremediation of the open drains carrying sewage can be adopted for reduction of pollution load.

Fig. 9: Step well (baoli) at Red Fort– an important feature of traditional water system

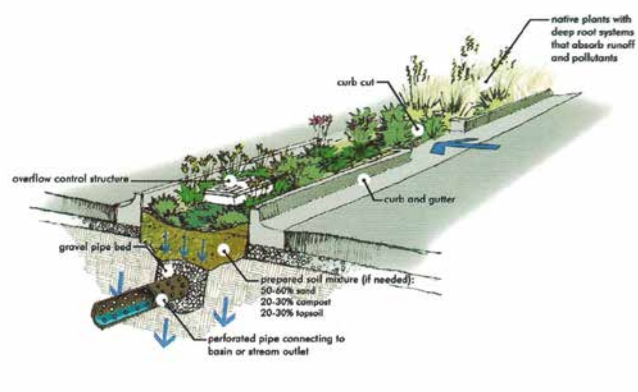

Fig. 10: A Bioswale for Sustainable Urban Drainage
Source: http://thewhiteriveralliance.org/eaglecreek//involved/images/bioswale%20enlargement.jpg

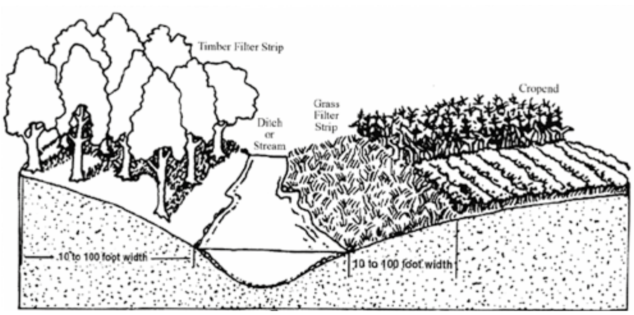

Fig. 11: Green filter strip along a Bio-Swale
Source: Jain A.K. (2021) Environment, Urbanisation and Development, Discovery Publishing House, New Delhi

For treatment of pesticide traces, capping the existing sand bed with bituminous charcoal or coconut shells can be an easy and inexpensive solution. Increasing flocculants by adding powered activated carbon (PAC) or bentonite clay with doses varying from 25-30 mg/l and the use of granular activated carbon can be effective, subject to its cost. Raw water tanks and rainwater storage can be protected by clay beds, which should be secured from getting washed away during the monsoons. The best way to get rid of the pesticides (non-point) and industrial toxins is through "source protection measures", such as organic biological farming.

Restoration Projects for Yamuna Flood Plains

Several projects for restoration and landscape development have been taken up. An MOU was signed between the DDA and INTACH on 20th March 2019 under which the development plan of Qudsia Ghat (16 ha) has been taken up (Fig. 16).

The DDA and Delhi University's Centre for Environment Management and Degraded Ecosystems have developed the following biodiversity parks:

- Yamuna Biodiversity Park near Wazirabad (183 Ha.)
- Aravalli Biodiversity Park near Vasant Vihar (278 Ha.)
- Northern Ridge Biodiversity Park near Delhi University (87 Ha.)
- Tilpat Valley Biodiversity Park near Sainik Farms (70 Ha.)
- Yamuna River Front (O Zone) (97.70 Ha.)
- Neela Hauz Biodiversity Park near South Central Ridge (3.90 ha)
- Sanjay Lake Biodiversity Park near Mayur Vihar Ph-II (56.65 ha)
- Okhla Bird Sanctuary

Eco- Park at Tejpur Pahari near Badarpur border covering 10 acres (4 Ha) of the derelict mining pits has been filled up with inert soil/good earth and landscaped.

Other projects include the following:

- Asita East Old Railway Bridge to ITO Barrage (98 Ha to109 Ha)
- Asita West Old Railway Bridge to ITO Bridge (93 Ha to107 Ha)
- Asita East Bird Sanctuary
- Amrut Biodiversity Park (108 Ha)

- Kalindi Aviral NH 28 to DND Flyway (100 Ha)
- Kalindi Biodiversity Park, DND to proposed Kalindi Bye pass
- Yamuna Vanasthali Wazirabad Barrage to ISBT Bridge
- Eco Tourism Area, Geeta Colony Bridge to ITO Barrage
- Mayur Nature Park and Hindon Sarovar NH-24 to DND Flyway
- Wetlands Restoration (19 Hectare) augmenting 5-6 lakh cumec of water
- Constructed Wetlands near Kalindi Biodiversity Park and Dhobi Ghat each treating 15 to 20 MLD of sewage

Bridging the Implementation Gaps

The cleaning and conservation of river Yamuna involves various States and Central Government, Departments and organisations. Its implementation is contingent upon meticulous planning, coordinated management, new technologies and financing. The Government of India has recently implemented some challenging projects, like Z morh tunnel in Sonamarg (J & K), Chenab Railway Bridge, Bagibeel bridge in Assam, Mumbai Trans Harbour Link (Atal Setu), Delhi Mumbai Industrial Corridor, PM Gati Shakti Master Plan, High Speed Railways, etc. Their successful implementation has been possible by innovative digital platforms as given below:

The PRAGATI (Pro- Active Governance and Timely Implementation) Platform, launched in 2015 by the Prime Minister has helped completion of more than 340 major infrastructure projects with effective resource utilisation, environmental sustainability and ensuring accountability. It leverages new technologies in planning, breaking the silos of departmentalisation to achieve synergy in project management. It has engaged Geo-Informatics and the geo-spatial planning tools that optimise the resources and reduce their environmental impact.

The Whole of Government Platform comprises over 1200 GIS based data layers from Central Government Departments and 755 from the States/ Union Territories, covering data of land, soil, geology, water bodies, forests, mines, revenue maps and administrative boundaries. It enables easier collaborations across departments for seamless implementation of the projects and plans. Citizen engagement becomes easier and viable by virtual town halls, and online consultation over plans and programmes.

Financing: Apart from the budget sources, innovative financing, such as Blended Green, Social and

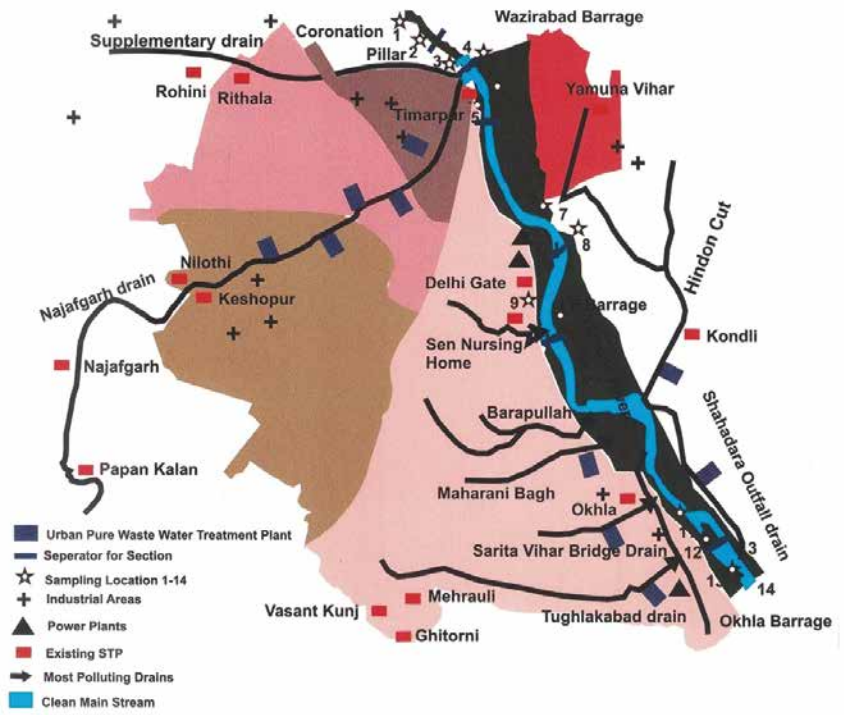

Fig. 12: Map of Delhi showing major drains and sewage treatment plants
Source: Uploaded by Nandimandalam Janardhana Raju, Researchgate

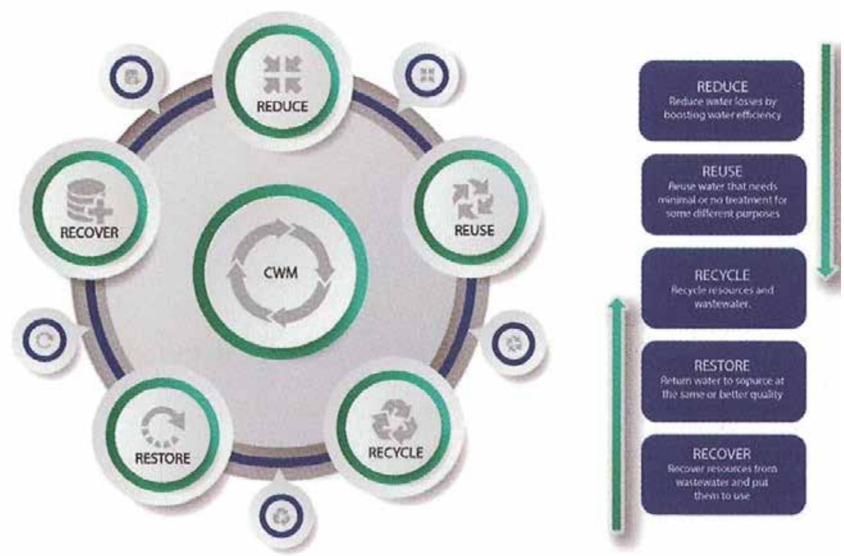

Fig. 13: Circular Water Management
Source Baudh Raj, Kumar and Mohammed Salim (2022) Ancient Waters for the Future, TERI, New Delhi

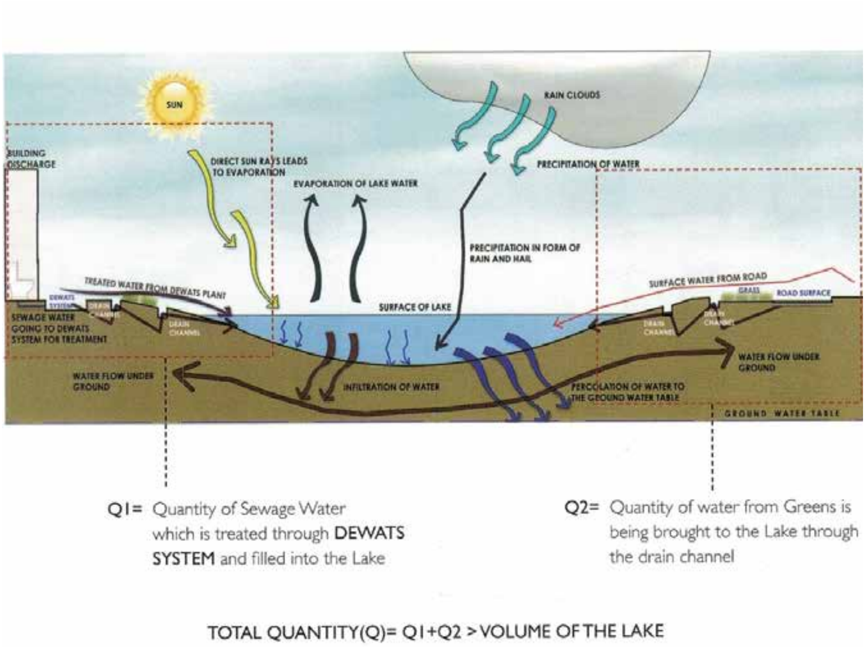

Fig. 14: DEWATS and Stormwater Harvesting for Revival of an Urban Water Body
Source: DUAC/Rahoul B Singh (2014) Hari Nagar Greens, DUAC, New Delhi

Fig 15: Carbon Neutral Biomaterials, Planting and Water Recycling for Ellinikon Park, Foster and Partners
Source: Joann Gonchar, Drawing it Down, Houston Memorial Park, Architectural Record, Sep. 2024

Sustainability Bonds (BGSSB) can be explored for financing. Other sources may include Urban Infrastructure Development Fund, Value Capture Finance, Land Banking, Tax Increment Financing, Impact Fee, Air Rights, Infrastructure Trust, EPC Contracts, Transit Oriented Development, Transferable Development Rights, Land Value Tax, Capital Gains Tax, Betterment Levy. However, the Yamuna Project should closely work with the National Mission for Clean Ganga (NMCG) and River Cities Alliance (RCA). Their experience of implementation and financing can provide important lessons for the Yamuna project.

In-Situ Community Engagement

In-situ community engagement stresses upon participatory, collective efforts for clean, pollution-free and pristine river. Besides formal regulations, local, community-based regulations are usually more effective with respect to water use, storage, pollution control and social audit. This poses certain challenges, like sensitising local communities towards conservation of river and water bodies.

It is also necessary to map the socio-cultural activities, festivals and cultural resources and assess dependency of riparian communities on riverine resources. The local people can also help to deter illegal construction, sand mining and fishing in the river. A judicious integration of ecological scientific research, digital planning and committed participation of the local communities can be helpful for a sustained connect with the river. The experience of Swachh Bharat Mission (SBM) indicates that besides a robust plan, legal framework and financial allocations, the success of a mission hinges upon changing the collective behaviour of the people. As such, the communities should be motivated to avoid disposal of sewage, effluents and other wastes in the river.

Conclusions

The River Cities Alliance (RCA) and the National Mission for Clean Ganga (NMCG) have initiated DHARA- Driving Holistic Actions for Urban Rivers. Its motto ‘Swasth Dhara- Sampann Kinara’ can be a theme to clean and conserve the Yamuna by five-fold principles of nirmal, aviral, gyan, jan and arth. This would resonate the Yamuna with the identity of Delhi.

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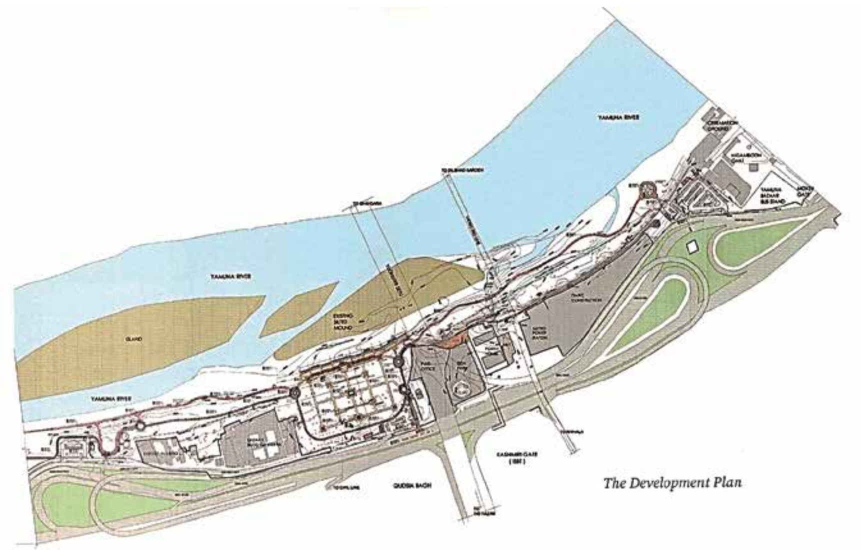

Fig. 16: Conservation Plan of Qudsia Ghat Riverfront
Source: INTACH

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GNSS Constellation Specific Monthly Analysis Summary: April 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

The article is a continuation of monthly performance analysis of the GNSS constellation. Please refer to previous issues for past analysis. As an addition, there is a section that explores mathematical concepts of variational equations used in the estimation of satellite clocks and orbits. This is in turn linked to the challenges of estimating orbits of inclined geosynchronous and geo-stationary satellites in QZSS and Beidou constellations.

Analyzed Parameters for April 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**)

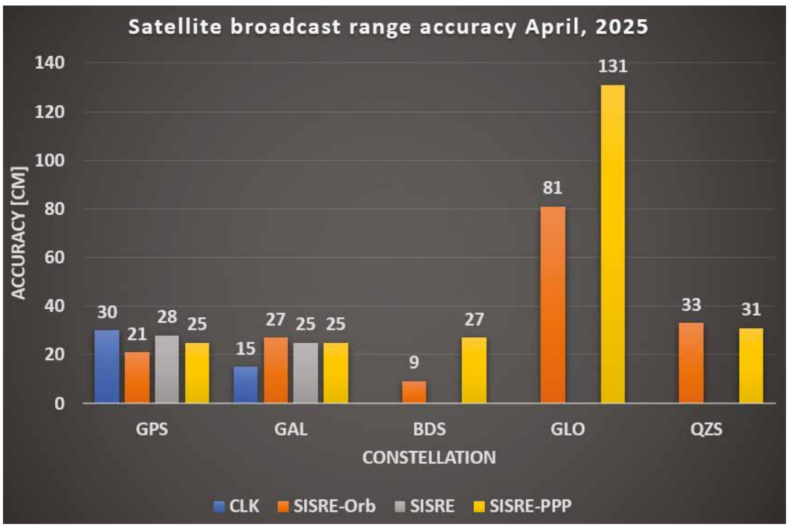
c. **Clock Discontinuity**: The jump in the satellite clock offset between two consecutive batches of data uploads from the ground mission segment. It is indicative of the quality of the satellite atomic clock and associated clock model.

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. **Variational Equations and Satellite Orbit Estimation**: The variational equations are a key set of differential equations to reliably capture the dynamics of the satellite motion in the orbit determination process. The solution to these equations is indicative of quality of the initial orbit determination and force models.

(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.

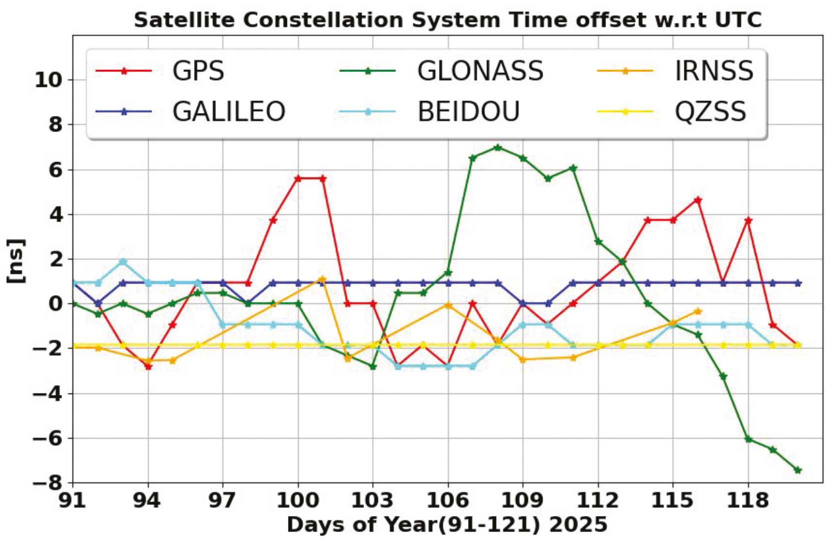
(c) Satellite Clock Jump per Mission Segment Upload

Const	Mean [ns]	Max [ns]	95_Percentile [ns]	99_Percentile [ns]	Remark (Best and Worst 95 %)
IRNSS	99	626985.45	5.64	68.72	Best I02 (4.51 ns) Worst I10 (14.07 ns) Big jumps for each satellite in multiple days; I02 had the largest jump
GPS	0.43	14.28	0.94	2.44	Best G15 (0.51 ns) Worst G03 (2.86 ns) No big jumps observed.
GAL	0.94	66541.54	0.20	0.50	Best E03 (0.15 ns) Worst E19 (0.36 ns). E12 had a large jump (approx. 400 ns) on DOY 091. Similarly, E11 had a very large jump on DOY 105.

(d) User Range Accuracy (Number of Occurrences in Broadcast Data 01-30 April)

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	2814	37	3	-	2	1	1	32 (18)
I03	-	-	-	-	-	-	-	-
I06	2876	3	-	-	3	-	5	32 (2)
I09	518	3	1	-	-	-	-	-
I10	1041	3	3	1	3	2	-	16 (2)

(e) GNSS-UTC Offset



(f) Variational Equations and Satellite Orbit Estimation

Satellite **orbit and clock parameters** form the backbone of **broadcast navigation messages**, providing essential data for users worldwide. Since January 2024, monthly performance reports in mycoordinates have analyzed their characteristics and quality. This series of articles now shifts focus to the **computational aspects** of these parameters—not to rehash existing mathematical methods, but to distill key concepts in a **simplified, yet insightful manner**. By doing so, this analysis aims to enhance comprehension of the **performance variations** observed in different GNSS constellations. In this issue, a brief linkage to the performance characteristics of IGOS and GEO satellites is provided.

Variational equations are fundamental to modern orbit determination and adjustment algorithms. They enable efficient and accurate refinement of estimated parameters by providing sensitivity information, which is crucial for adjusting the satellite's trajectory to match observations.

Linearization and the Role of the Jacobian

In the first step of orbit determination, the highly nonlinear GNSS observation equations are linearized around an initial state. This yields a Jacobian matrix that contains the partial derivatives of the measurements with respect to the estimated parameters—primarily the satellite's position and velocity.

However, the satellite's state itself evolves according to nonlinear equations of motion. Therefore, to understand how changes in the initial state affect the satellite's position at later times, we must also linearize the dynamics. This is where the state transition matrix and sensitivity matrix come into play.

Dynamics and Variational Equations

The satellite's trajectory is governed by a set of differential equations where acceleration is a function of position, velocity, and dynamical parameters (e.g., drag coefficient, solar radiation pressure). A particular orbit solution is uniquely determined by its initial state and dynamical parameters.

Numerical integration of the equations of motion yields a predicted orbit. However, this orbit is only accurate if the initial conditions and force models are close to the truth. To refine this orbit using observations, we need to understand how small changes in these inputs affect the output trajectory.

Why Variational Equations?

Using finite differences to compute these sensitivities of the orbit trajectory to small changes in initial values is computationally expensive and numerically unstable. Instead, variational equations provide a continuous and efficient way to compute:

State Transition Matrix (Φ):

$$\Phi(t_k, t_o) = \frac{\partial x_k}{\partial x_k}$$

Describes how small errors in the initial state propagate over time.

Sensitivity Matrix (S):

$$S(t_k) = \frac{\partial x_k}{\partial p}$$

Quantifies how uncertainties in dynamical parameters affect the trajectory.

These matrices are integrated alongside the equations of motion using the same force models. At each observation epoch, they provide the necessary partial derivatives for the Jacobian matrix used in batch least squares estimation, for example.

Constructing the Jacobian Matrix

The full Jacobian matrix (J) used in orbit determination is built using the chain rule:

$$\frac{\partial y_k}{\partial x_o} = \frac{\partial y_k}{\partial x_k} \cdot \frac{\partial x_k}{\partial x_o}$$

- $\frac{\partial y_k}{\partial x_k}$: Observation Jacobian (geometry)
- $\frac{\partial x_k}{\partial x_o}$: State transition matrix (Φ)

This formulation ensures that the measurement sensitivity accounts for how errors in the initial state propagate to the observation epoch.

What If We Ignore Variational Equations?

If we compute only $\frac{\partial y_k}{\partial x_k}$ and ignore Φ, we assume that the measurement sensitivity depends only on the current state. This leads to:

- Loss of sensitivity to initial conditions
- Poor convergence in least squares estimation
- Inaccurate orbit corrections and higher residuals

Practical Implications

- **Large values in Φ** indicate strong dependence on initial conditions—small errors grow significantly over time.
- **Stable orbit solutions** are achieved when the sensitivity to initial conditions and dynamical parameters becomes small.
- **Variational equations** reduce the number of iterations needed and improve convergence speed and accuracy.

Taking examples of IGSO and GEO satellites of Beidou and QZSS, the changes in observation geometry for **GEO and IGSO satellites** are much smaller compared to **MEO satellites**. As a result, strong correlations often arise between:

- **State parameters** (e.g., orbital elements),
- **Dynamical parameters** (e.g., solar radiation pressure coefficients),
- And **measurement model parameters** (e.g., ambiguities, differential code biases).

The reduced orbit quality of IGSO satellites can also be attributed to:

- Limited and regional ground station coverage,
- Radiation pressure modeling issues, especially due to large communication antennas not accounted for in standard box-wing models.

For GEO, additional SRP modeling difficulties from large communication antennas with undisclosed shape and material properties impact the orbit quality.

Moreover, **delta-V maneuvers** (for orbit maintenance) and **attitude control maneuvers** (for yaw and orbit normal attitudes) are hard to model precisely. Both GEO and IGSO satellites need frequent maneuvers in comparison to MEO satellites. All above mentioned characteristics introduce discontinuities or biases that are not easily captured by variational equations.

In fact, analysis of the **sensitivity matrix** often reveals large values associated with dynamical parameters—an indicator of modeling deficiencies. Ideally, a well-converged solution should show:

- **Diagonal elements** close to 1 (indicating stable propagation),
- **Off-diagonal elements** that are small (indicating low parameter correlation).

To dig deeper into these challenges, future work will involve using advanced tools for detailed analysis of the **sensitivity and covariance matrices** in reduced-dynamics orbit determination.

In this regard, this section serves as an introductory overview, laying the foundation for deeper investigations into these modeling and estimation challenges.

Monthly Performance Remarks:

1. Satellite Clock and Orbit Accuracy:
   - The performance of all constellations is relatively stable with some minor changes from previous month.
   - The satellite clock jumps identified a couple of issues in Galileo satellites. E11 and E12 had large jumps on DOY 91 and DOY 105, respectively. Satellite E19 continues to have the noisiest clock (95 percentile is 0.36 ns vs 95 percentile of 0.2 ns of the whole constellation).
   - The improvement in the QZSS satellite clock and orbit accuracy is visible. It is improved by 5 cm. Further investigation (once the QZSS operational history is available) is needed to correlate to the Sun angle and the switches between the yaw attitude and orbit normal modes of the satellites.
   - The URA for I02 showed a little more scatter in comparison to previous months. It suggests a degraded confidence in its satellite orbit.

2. UTC Prediction (GNSS-UTC):

- GPS showed some variations as in previous months. Glonass UTC prediction started to deviate significantly in the second half of the month.

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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

"Z" axis breakthrough in GPS-denied areas

Balboa Geo, in partnership with the Texas A&M Engineering Extension Service (TEEX) and the George H.W. Bush Combat Development Complex (BCDC), completed a rigorous field testing campaign of its POINTER system, a "dual-use," real-time alternative positioning, navigation and timing (A-PNT) technology designed for GPS-denied, degraded and disrupted environments, including indoor, subterranean and obstructed urban settings.

The POINTER field test plan involved 130 tests across seven challenging testing and training venues located at TEEX and the BCDC.

Test venues included:

- A three-story concrete structure with 10-inch-thick, rebar-reinforced concrete walls
- A compartmentalized steel-hulled ship with three decks reaching approximately 25 ft high
- A steel shipping container (CONEX)
- A simulated collapsed structure and rubble pile composed of steel, concrete, and a 90° tunnel network
- A simulated industrial oil refinery with processing equipment and complex, elevated steel piping
- A six-story steel training tower with metallic siding throughout
- The BCDC military-grade subterranean tunnel network, featuring a main tunnel at about 10 ft deep and a heavily shielded segment with Faraday cage properties simulating greater depth

Highlights of the summary results and key findings:

- MQS field penetration and position location were achieved at all seven test venues.
- Real-time, three-dimensional distance measurements were obtained for all 130 tests.
- The mean positional uncertainty across all venues was 12.62 cm.
- Positional uncertainty ranged from 2.5 cm to 36 cm, depending on venue complexity, receiver location, and transmitter-receiver distance.
- Vertical measurements at the concrete structure showed uncertainties as low as 2.5 centimeters at a distance of about 11 m, and up to 24 cm at about 30 m.
- The POINTER system demonstrated penetration into and out of the BCDC military-grade tunnel network, including the shielded portion, indicating flexibility and performance in challenging subterranean environments.

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Emerging underwater survey technologies: A review and future outlook

AI and ML technologies are revolutionizing underwater surveying by enhancing data analysis, interpretation, and decision- making capabilities

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Abstract

Emerging underwater survey technologies are revolutionizing the way we explore and understand the underwater world. This review examines the latest advancements in underwater survey equipment, highlighting their operational benefits and potential areas for future development. Recent developments in underwater survey technologies have led to significant improvements in accuracy, efficiency, and data quality. Advanced sonar systems, such as multibeam and sidescan sonars, provide high-resolution images of the seafloor, allowing for detailed mapping of underwater features. Autonomous underwater vehicles (AUVs) equipped with sophisticated sensors and cameras enable precise data collection in challenging environments, such as deep-sea areas or complex underwater structures. The operational benefits of these technologies are vast. They allow for faster surveying, reduced costs, and improved safety for personnel. Additionally, the high-quality data obtained from these surveys can lead to better decision-making in various industries, including offshore energy, marine research, and underwater archaeology. Looking ahead, the future of underwater survey technologies is promising. There is a growing interest in developing integrated systems that combine multiple sensors and data processing capabilities to provide a more comprehensive view of underwater environments. Artificial intelligence and machine learning algorithms are also being increasingly utilized to analyze large datasets and extract valuable insights. However, several challenges remain, such as the need for better underwater communication systems, improved battery life for autonomous vehicles, and enhanced data processing capabilities. Addressing these challenges will be crucial for the continued advancement of underwater survey technologies. In conclusion, the latest advancements in underwater survey technologies offer exciting opportunities for enhancing our understanding of the underwater world. By leveraging these technologies and addressing key challenges, we can unlock new possibilities for underwater exploration and research.

1.Introduction

The exploration of the underwater world has always presented unique challenges due to the inherent difficulties of conducting surveys in aquatic environments (Biu, et. al., 2024, Eboigbe, et. al., 2023). However, recent advancements in underwater survey technologies have significantly improved our ability to explore and understand the depths of our oceans, lakes, and rivers (Chemisky, et. al., 2021, Mohsan, et. al., 2022). This review aims to analyze the latest advancements in underwater survey equipment, including their operational benefits and potential areas for future development.

Underwater survey technologies encompass a wide range of equipment and techniques used to map and explore underwater environments (Sodiya, et. al., 2024, Sonko, et. al., 2024). These technologies include advanced sonar systems, autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs), and specialized cameras and sensors. Each of these tools plays a crucial role in helping researchers, scientists, and engineers study and document underwater ecosystems, map the ocean floor, and assess underwater structures (Atadoga, et. al., 2024, Dada, et. al., 2024).

The importance of advancements in underwater survey equipment cannot be overstated. These advancements not only improve our understanding of the underwater world but also have practical applications in various industries. For example, in offshore energy exploration, accurate underwater surveys are essential for locating and assessing potential oil and gas reserves (Adekanmbi, et. al., 2024, Nwokediegwu, et. al., 2024). In marine biology, underwater surveys help researchers study marine life and ecosystems, leading to conservation efforts and the protection of marine biodiversity.

This review will analyze the latest advancements in underwater survey equipment, focusing on their operational benefits and potential areas for future development. By examining the latest technologies and their applications, we can gain insights into how these advancements are shaping the future of underwater exploration and research.

Advancements in underwater survey technologies have not only expanded our knowledge of the underwater world but also revolutionized industries such as offshore energy, marine research, and underwater archaeology (Adeleke, et. al., 2024, Etukudoh, et. al., 2024). These technologies have enabled us to conduct detailed surveys and mapping of underwater environments with unprecedented accuracy and efficiency. The operational benefits of these advancements are far-reaching, leading to cost savings, improved safety, and enhanced environmental protection measures.

Despite these advancements, there are still areas for improvement and further development in underwater survey equipment (Ayorinde, et. al., 2024, Hamdan, et. al., 2024). This review will explore the latest advancements in underwater survey technologies, including their operational benefits and potential areas for future development. By analyzing these advancements, we can gain a deeper understanding of the current state of underwater survey technologies and identify opportunities for future innovation.

2. Advanced Sonar Systems

Advanced sonar systems are at the forefront of emerging underwater survey technologies, offering significant advancements in underwater mapping and exploration (Dada, et. al., 2024, Ebirim, et. al., 2024). This review examines two key types of sonar systems - multibeam sonar and sidescan sonar - analyzing their operational benefits and potential areas for future development.

Multibeam sonar systems have revolutionized underwater surveying with their ability to generate detailed, high-resolution maps of the seafloor (Adekanmbi, et. al., 2024, Obiuto, et. al., 2024). These systems emit multiple sonar beams simultaneously, allowing for rapid and accurate mapping of large areas. The operational benefits of multibeam sonar. Multibeam sonar systems can generate detailed 3D maps of the seafloor, providing valuable information for offshore infrastructure development, environmental monitoring, and marine research.

The ability to map large areas quickly and accurately reduces surveying time and costs, making multibeam sonar an attractive option for industries such as offshore oil and gas exploration, underwater archaeology, and marine resource management (Aderibigbe, et. al., 2023, Nwokediegwu, et. al., 2024).

Applications of multibeam sonar in underwater surveying are vast and varied, including: Multibeam sonar is used to map the seafloor and identify potential drilling sites, helping to reduce exploration risks and optimize resource extraction. Multibeam sonar can be used to map underwater habitats, providing valuable information for conservation efforts and ecosystem management.

Sidescan sonar systems are another essential tool in underwater surveying, offering detailed imaging of the seafloor and underwater structures (Ohalete, et. al., 2023, Oke, et. al., 2024). Unlike multibeam sonar, which provides depth information, sidescan sonar generates detailed images of the seafloor's surface (Al-Hamad, et. al., 2023, Ogedengbe, et. al., 2023). Sidescan sonar systems can capture detailed images of underwater features, including shipwrecks, pipelines, and geological formations, aiding in archaeological surveys and infrastructure inspections. Sidescan sonar can be deployed from surface vessels or towed behind boats, making it a flexible tool for a wide range of underwater surveying applications (Sonko, et. al., 2024, Umoga, et. al., 2024).

Sidescan sonar is used to locate and map shipwrecks, providing valuable insights into maritime history and archaeology. Sidescan sonar can be used to inspect underwater pipelines and cables for damage or leaks, ensuring the integrity of critical infrastructure (Ani, et. al., 2024, Ibekwe, et. al., 2024). In conclusion, multibeam and sidescan sonar systems are integral components of advanced underwater survey technologies, offering enhanced mapping capabilities and operational efficiencies. Future developments in these technologies are likely to focus on improving resolution, increasing mapping speeds, and enhancing data processing capabilities, further advancing our ability to explore and understand the underwater world (Nwokediegwu, et. al., 2024, Obaigbena, et. al., 2024).

Despite its many benefits, multibeam sonar technology continues to evolve, with ongoing research and development aimed at further improving its capabilities (Sodiya, et. al., 2024, Uwaoma, et. al., 2024). Researchers are working on enhancing the resolution of multibeam sonar systems to provide even more detailed maps of the seafloor (Alahira, et. al., 2024, Etukudoh, et. al., 2024). This could be achieved through advancements in sensor technology and signal processing algorithms. There is a growing interest in developing real-time data processing capabilities for multibeam sonar systems. This would allow surveyors to obtain immediate feedback on survey results, enabling faster decision-making and more efficient survey operations (Obiuto, et. al., 2024, Ohalete, et. al., 2024). Future multibeam sonar systems may be integrated with other sensors, such as cameras and magnetometers, to provide a more comprehensive view of underwater environments. This integrated approach could improve the accuracy and reliability of survey data.

Sidescan sonar technology is also undergoing continuous development, with researchers exploring new ways to improve its performance and capabilities (Olu-lawal, et. al., 2024, Umoga, et. al., 2024). Researchers are working on developing new imaging techniques for sidescan sonar systems to improve image quality and resolution (Adeleke, et. al., 2024, Ibeh, et. al., 2024). This could involve advancements in signal processing algorithms and sensor technology. There is growing interest in developing autonomous sidescan sonar systems that can be deployed and operated without human intervention (Nwokediegwu, et. al., 2024, Ogunkeyede, et. al., 2023). This would enable more efficient and cost-effective survey operations, particularly in remote or hazardous environments. Like multibeam sonar, future sidescan sonar systems may be integrated with other sensors to enhance their capabilities. For example, integrating sidescan sonar with bathymetric sensors could provide a more complete picture of underwater topography. In conclusion, multibeam and sidescan sonar systems are key components of advanced underwater survey technologies, offering a range of operational benefits and applications. Continued research and development in these areas are likely to lead to further advancements, improving our ability to explore and understand the underwater world (Obiuto, et. al., 2024, Olajiga, et. al., 2024).

3. Autonomous Underwater Vehicles (AUVs)

Autonomous Underwater Vehicles (AUVs) are revolutionizing underwater surveying and exploration by offering a range of advanced sensor capabilities and operational benefits (Adekanmbi, et. al., 2024, Nwokediegwu, et. al., 2024). This article explores the sensor capabilities of AUVs, including imaging sensors and sonar systems, as well as their operational benefits, such as efficiency in data collection and safety advantages. AUVs are equipped with various imaging sensors, such as cameras and optical scanners, which allow them to capture high-resolution images of the underwater environment. These imaging sensors can provide detailed visual information about underwater structures, marine life, and other features.

AUVs are also equipped with sonar systems, which use sound waves to map the seafloor and detect underwater objects (Abatan, et. al., 2024, Ebirim, et. al., 2024). There are several types of sonar systems used in AUVs, including side-scan sonar and multibeam sonar, which provide detailed images of the seafloor and underwater structures. AUVs are capable of collecting large amounts of data in a short amount of time, making them highly efficient for underwater surveying and exploration. Their autonomous nature allows them to operate for extended periods without human intervention, further increasing their efficiency.

AUVs offer significant safety advantages over manned submersibles and remotely operated vehicles (ROVs). Since they operate autonomously, there is no need for direct human involvement in underwater operations, reducing the risk to human life. Additionally, AUVs can operate in hazardous or hard-to-reach environments, making them ideal for tasks that would be dangerous for humans (Atadoga, et. al., 2024, Ilojianya, et. al., 2024). In conclusion, AUVs are a vital tool in underwater surveying and exploration, offering advanced sensor capabilities and operational benefits. Their ability to collect high-quality data efficiently and safely makes them invaluable for a wide range of applications, from marine research to offshore oil and gas exploration. As technology continues to advance, AUVs are likely to play an even greater role in underwater exploration, expanding our understanding of the underwater world.

AUVs are used extensively in marine research to study oceanography, marine biology, and underwater geology. Their ability to collect data in remote and inaccessible areas makes them invaluable for studying marine ecosystems and underwater phenomena (Afolabi, et. al., 2023, Hamdan, et. al., 2024). AUVs are used for environmental monitoring, including mapping and monitoring of coral reefs, seagrass beds, and other sensitive marine habitats. They can also be used to monitor water quality and detect pollution. In the offshore industry, AUVs are used for a variety of applications, including pipeline and cable inspections, seabed mapping for oil and gas exploration, and offshore infrastructure inspections. Their ability to operate autonomously and collect high-quality data makes them ideal for these tasks (Sodiya, et. al., 2024, Usman, et. al., 2024).

AUVs are used by military and defense agencies for tasks such as mine countermeasures, underwater surveillance, and reconnaissance (Nwokediegwu, et. al., 2024, Ohalete, et. al., 2023). Their ability to operate autonomously and covertly makes them valuable for military applications. Future AUVs are likely to be equipped with more advanced sensor technology, including improved imaging sensors and more sophisticated sonar systems (Aderibigbe, et. al., 2023, Majemite, et. al., 2024). This will allow them to collect even more detailed and accurate data. Future AUVs are expected to become more autonomous, with the ability to make decisions and adapt to changing conditions without human intervention. This will further increase their efficiency and effectiveness in underwater operations.

Future AUVs may be integrated with other technologies, such as artificial intelligence and machine learning, to enhance their capabilities (Adeleke, et. al., 2024, Obaigbena, et. al., 2024). This could include the ability to analyze data in real-time and make decisions based on that analysis. In conclusion, AUVs are a versatile and valuable tool in underwater surveying and exploration, offering advanced sensor capabilities, operational benefits, and a wide range of applications. As technology continues to advance, AUVs are likely to become even more capable and play an increasingly important role in our understanding of the underwater world.

4. Integrated Survey Systems

Integrated survey systems are at the forefront of emerging underwater survey technologies, offering a comprehensive approach to underwater mapping and exploration (Atadoga, et. al., 2024, Dada, et. al., 2024). This review examines the latest advancements in integrated systems, analyzing their operational benefits and potential areas for future development. Integrated survey systems combine multiple sensors and technologies into a single platform, allowing for more comprehensive and efficient data collection. These systems typically include a combination of imaging sensors, such as cameras and sonar systems, as well as navigation and positioning systems (Etukudoh, et. al., 2024, Nwokediegwu, et. al., 2024). By integrating these sensors, integrated survey systems can provide a more detailed and accurate picture of the underwater environment.

By combining multiple sensors, integrated survey systems can provide more accurate and reliable data, leading to better decision-making in underwater operations. Integrated survey systems can streamline data collection processes, reducing the time and resources required for underwater surveys (Ayorinde, et. al., 2024, Obiuto, et. al., 2024). Integrated systems can collect a wide range of data, including bathymetric data, imagery, and environmental data, providing a more complete picture of the underwater environment.

Future integrated survey systems are likely to feature even more advanced sensor integration, combining a wider range of sensors and technologies to provide more comprehensive data collection (Hamdan, et. al., 2024, Ibekwe, et. al., 2024). Future systems may focus on improving data processing capabilities, including real-time data analysis and automated data interpretation, to further enhance efficiency and accuracy. There is growing interest in developing integrated survey systems that can operate autonomously, without the need for human intervention. This would enable more efficient and cost-effective underwater surveys.

In conclusion, integrated survey systems represent a significant advancement in underwater survey technologies, offering enhanced data collection capabilities and operational benefits (Nwokediegwu, et. al., 2024, Olajiga, et. al., 2024). Continued research and development in this area are likely to lead to further advancements, improving our ability to explore and understand the underwater world. Integrated survey systems rely on advanced data fusion techniques to combine data from multiple sensors and sources (Dada, et. al., 2024, Majemite, et. al., 2024, Sodiya, et. al., 2024). These techniques involve algorithms that can integrate data in real-time, taking into account the different characteristics and uncertainties of each sensor. By fusing data from multiple sensors, integrated survey systems can provide a more accurate and reliable picture of the underwater environment.

Future developments in integrated survey systems may involve the integration of multimodal sensors, which can provide a more comprehensive view of the underwater environment. For example, systems that combine imaging sensors with chemical or biological sensors could provide valuable information about underwater ecosystems and habitats (Ebirim, et. al., 2024, Ohalete, et. al., 2024). As technology advances, integrated survey systems are likely to become smaller, lighter, and more portable. This would make them easier to deploy and operate, especially in remote or hard-to-reach areas. Miniaturization could also lead to the development of autonomous underwater vehicles (AUVs) that are equipped with integrated survey systems, further enhancing their capabilities.

Integrated survey systems may incorporate real-time data transmission capabilities, allowing data to be transmitted to the surface or to a control center in real-time (Obiuto, et. al., 2024, Okoli, et. al., 2024). This would enable researchers and operators to monitor survey progress and make decisions based on up-to-date information, improving the efficiency and effectiveness of underwater surveys (Etukudoh, et. al., 2024, Olajiga, et. al., 2024). In conclusion, integrated survey systems are a key area of advancement in underwater survey technologies, offering enhanced data collection capabilities and operational benefits. Continued research and development in this field are likely to lead to further advancements, improving our ability to explore and understand the underwater world.

5. Artificial Intelligence and Machine Learning

Artificial Intelligence (AI) and Machine Learning (ML) are playing an increasingly important role in underwater surveying, offering advanced capabilities for data analysis, interpretation, and decision-making (Alahira, et. al., 2024, Dada, et. al., 2024). This article explores the role of AI and ML in underwater surveying, their applications, and future prospects.

AI and ML algorithms can process large volumes of data collected by underwater survey equipment, such as sonar systems and imaging sensors, more efficiently than traditional methods. This allows for faster data analysis and interpretation (Adeoye, et. al., 2024, Nwokediegwu, et. al., 2024). AI and ML algorithms can analyze images captured by underwater cameras and sensors to identify objects and features of interest, such as marine life, underwater structures, and geological formations. This helps researchers and operators to better understand the underwater environment.

AI and ML algorithms can be used to develop autonomous underwater vehicles (AUVs) that can navigate underwater environments and conduct surveys without human intervention. These algorithms enable AUVs to make real-time decisions based on environmental data and sensor inputs (Aderibigbe, et. al., 2023, Etukudoh, et. al., 2024). AI and ML algorithms can detect and classify objects in underwater images, such as shipwrecks, pipelines, and marine life, providing valuable information for underwater surveys and research. AI and ML algorithms can be used to plan optimal paths for AUVs to navigate underwater environments, avoiding obstacles and maximizing survey coverage.

AI and ML algorithms can integrate data from multiple sensors and sources to create comprehensive maps and models of underwater environments, improving the accuracy and reliability of survey data (Adeleke, et. al., 2024, Ohalete, 2022). AI and ML algorithms are expected to continue to improve data analysis capabilities, enabling researchers and operators to extract more insights from underwater survey data. AI and ML algorithms will enable AUVs to operate more autonomously and make more sophisticated decisions based on environmental data, leading to more efficient and effective underwater surveys.

AI and ML algorithms are likely to be integrated with other technologies, such as advanced sensors and communication systems, to further enhance underwater survey capabilities (Nwokediegwu, et. al., 2024, Olu-lawal, et. al., 2024). In conclusion, AI and ML are driving significant advancements in underwater surveying, offering new possibilities for data analysis, interpretation, and autonomous operation (Ebirim, et. al., 2024, Ibekwe, et. al., 2024). Continued research and development in this field are expected to lead to further improvements in underwater survey technologies.

AI and ML algorithms can interpret complex data patterns in underwater environments, such as underwater topography, marine life distribution, and geological features. By analyzing these patterns, researchers can gain deeper insights into the underwater ecosystem (Atadoga, et. al., 2024, Ohalete, et. al., 2023). AI and ML can be used to create predictive models for underwater environments, helping to forecast changes in marine habitats, water quality, and underwater infrastructure. These models can assist in decision-making for conservation efforts and resource management.

AI and ML technologies can enhance the efficiency and cost-effectiveness of underwater surveys by automating repetitive tasks, reducing human error, and optimizing survey routes (Nwokediegwu, et. al., 2024, Sodiya, et. al., 2024). This can lead to significant time and cost savings in underwater exploration and research. AI and ML algorithms can enable real-time monitoring of underwater environments, allowing for immediate responses to changes or anomalies. This capability is particularly valuable for environmental monitoring, disaster response, and underwater infrastructure maintenance.

Future developments in AI and ML for underwater surveying may include the integration of advanced sensor technologies, such as hyperspectral imaging and acoustic sensors, to further enhance data collection and analysis capabilities (Abatan, et. al., 2024, Sonko, et. al., 2024). Additionally, advancements in AI and ML algorithms may lead to the development of more autonomous and intelligent underwater vehicles for surveying and exploration. In conclusion, AI and ML technologies are revolutionizing underwater surveying by enhancing data analysis, interpretation, and decision-making capabilities (Ugwuanyi, et. al., 2024, Usman, et. al., 2024). Continued research and innovation in this field are expected to drive further advancements in underwater survey technologies, enabling a deeper understanding of the underwater world and its ecosystems.

6. Challenges and Future Directions

Underwater survey technologies have made significant advancements in recent years, offering improved capabilities for mapping and exploring the underwater world. However, several challenges remain that hinder the full realization of their potential (Ebirim, et. al., 2024, Obiuto, et. al., 2024). This article examines the key challenges facing emerging underwater survey technologies, strategies for overcoming these challenges, and future directions for development.

The underwater environment is often challenging to access, requiring specialized equipment and vehicles (Etukudoh, et. al., 2024, Nwokediegwu, et. al., 2024). This can make it difficult to conduct surveys in remote or deep-sea locations. Collecting accurate and reliable data in underwater environments can be challenging due to factors such as water turbidity, acoustic noise, and signal attenuation. Additionally, interpreting the collected data to extract meaningful information can be complex and time-consuming. Underwater survey equipment and operations can be costly, requiring significant financial resources. This can limit the scope and frequency of surveys, particularly in resource-constrained environments.

The development of advanced sensor technologies, such as high-resolution imaging sensors and multi-beam sonar systems, can improve data collection and accuracy in underwater surveys (Ohalete, et. al., 2024, Sodiya, et. al., 2024). The use of autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs) can improve accessibility and reduce the need for human intervention in underwater surveys. These systems can also be equipped with AI and ML algorithms for real-time data processing and analysis. Collaboration between industry, academia, and government agencies can help pool resources and expertise to overcome challenges in underwater survey technologies (Sonko, et. al., 2024, Uwaoma, et. al., 2024). This can lead to the development of innovative solutions and best practices.

The integration of AI and ML algorithms into underwater survey equipment can enhance data processing and analysis capabilities, leading to more efficient and accurate surveys (Nwokediegwu, et. al., 2024, Olajiga, et. al., 2024). Future underwater survey equipment is likely to become smaller, lighter, and more portable, allowing for easier deployment and operation in remote or challenging environments. There is growing interest in using underwater survey technologies for environmental monitoring, such as tracking changes in marine habitats and monitoring pollution levels. Future developments in this area are expected to focus on improving the accuracy and scope of environmental monitoring efforts (Ray, 2023, Sodiya, et. al., 2024).

While underwater survey technologies face several challenges, there are promising strategies and future directions that can help overcome these challenges and further advance the field (Ibekwe, et. al., 2024, Obaigbena, et. al., 2024). Continued research and development in underwater survey technologies are essential for enhancing our understanding of the underwater world and its ecosystems. Underwater survey equipment must withstand extreme temperatures and pressures, which can affect their performance and longevity. Exposure to saltwater can cause corrosion and fouling on underwater survey equipment, leading to degradation of performance and reliability. Marine organisms can attach to underwater survey equipment, affecting its accuracy and efficiency (Sodiya, et. al., 2024, Uwaoma, et. al., 2024). Developing anti-fouling coatings and cleaning mechanisms can help mitigate this issue.

Using corrosion-resistant materials for underwater survey equipment can help improve durability and performance (Abatan, et. al., 2024, Ebirim, et. al., 2024). Applying protective coatings to equipment can help prevent corrosion and fouling, extending the lifespan of the equipment. Regular inspection and maintenance of underwater survey equipment can help identify and address issues before they become major problems. Future underwater survey equipment may be designed with sustainability in mind, using eco-friendly materials and energy-efficient components (Sonko, et. al., 2024, Ugwuanyi, et. al., 2024). Advances in sensor technologies can enable underwater survey equipment to monitor environmental parameters, such as water quality and marine life, providing valuable data for conservation efforts.

Autonomous underwater vehicles (AUVs) equipped with maintenance capabilities, such as cleaning mechanisms, could help address environmental challenges associated with fouling and corrosion (Nwokediegwu, et. al., 2024, Obiuto, et. al., 2024). In conclusion, addressing environmental challenges and considering sustainability in the design and operation of underwater survey technologies are crucial for the future of underwater exploration and research (Alahira, et. al., 2024, Etukudoh, et. al., 2024). Continued research and development in this area are essential for improving the reliability, efficiency, and sustainability of underwater survey equipment.

7. Conclusion

In conclusion, the review of emerging underwater survey technologies highlights significant advancements that are transforming the field of underwater exploration and research. Key advancements include the development of advanced sonar systems, autonomous underwater vehicles (AUVs), integrated survey systems, and the integration of artificial intelligence (AI) and machine learning (ML). These advancements offer operational benefits such as improved data quality, efficiency, and safety in underwater surveys.

The future of underwater survey technologies looks promising, with ongoing research and development focusing on addressing key challenges and exploring new possibilities. Strategies for overcoming challenges include the development of advanced sensor technologies, autonomous systems, and collaboration between industry, academia, and government agencies. Future directions for development include the integration of AI and ML, miniaturization and portability of equipment, and environmental monitoring.

To further advance underwater survey technologies, continued research and development are recommended. This includes exploring new sensor technologies, enhancing autonomous capabilities, and improving environmental monitoring capabilities. Collaboration between researchers, industry partners, and government agencies will be key to driving innovation and ensuring the sustainable development of underwater survey technologies. In conclusion, the future of underwater survey technologies is promising, with advancements in equipment and techniques enhancing our ability to explore and understand the underwater world. Continued research and development will be essential to unlock the full potential of underwater survey technologies and ensure their effective and sustainable use in the future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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Prototype sensor against GNSS signal threats

A new prototype sensor developed by the NATO Communications and Information Agency has completed a significant round of testing, marking a step forward in NATO's electromagnetic warfare capabilities. The sensor, GANDALF 4, underwent a series of tests at an advanced anechoic chamber operated by the NATO Support and Procurement Agency. This facility serves as a controlled environment for precise calibration and detailed performance assessment of the sensor's antenna array, which is critical for ensuring the system's accuracy and reliability.

GANDALF 4 was developed by specialists at the agency's Joint Intelligence, Surveillance and Reconnaissance Centre. The system is designed to detect, classify and locate deliberate attempts to interfere with or manipulate GNSS signals. GNSS jamming and spoofing are becoming more frequent and sophisticated, posing challenges to NATO's operational readiness and resilience. The development of GANDALF 4 is designed to enhance situational awareness in contested electromagnetic environments. The recent testing phase focused on evaluating the antenna performance of the sensor.

Beyond Gravity supplies high-power antenna for ESA mission

On April 29, the European forest satellite "Biomass" was launched into space from Kourou aboard a European Vega-C rocket operated by Arianespace.

The company Beyond Gravity, based in Zurich, Switzerland, supplied several key products for this mission. Its high-power antenna and navigation receiver will provide the satellite's precise position in orbit. Also, the satellite will be protected by the company's thermal insulation. The X-band helix antenna design was developed for ESA by the company's site in Gothenburg, Sweden. It also provided the S-Band TTC (telemetry, tracking and command) antenna. *beyondgravity.com*

Call for reversal of FCC Ligado Order by SSA

In letter to Federal Communications Commission's (FCC), the Satellite Safety Alliance (SSA) and 93 companies and organizations stated the need for the Ligado Order to be overturned by President Trump and Congressional leadership.

"The proposed network is designed to inappropriately use spectrum reserved for satellite communications, causing significant interference to other services," the SSA stated. Interference with GPS is a major concern of the group.

The letter urges the president and the chairs and ranking members of the House and Senate armed services and commerce committees to work with the FCC on granting petitions for reconsideration that will help prevent the building of Ligado's terrestrial wireless network.

"For over two decades, Ligado and its predecessors have tried and failed to build a terrestrial network that wouldn't harm GPS, national security, and other critical interests," commented the SSA. "The FCC's Ligado Order has faced unprecedented opposition, including from 14 federal agencies and over 90 organizations representing huge swaths of the economy — from aviation and agriculture to science and manufacturing. Rarely does any issue garneragreement from such a wide and divergent group of constituencies."

Congress found through independent analysis that the Ligado Order poses unacceptable risks of interference to GPS, satellite communications, weather forecasting, and other services, the SSA explained. "Countless federal staff hours and resources have gone to reviewing, debating, and litigating this issue. It is past time the FCC put the issue to rest by granting the pending petitions for reconsideration."

Geospatial technology delivers 3D city model of Doha

The Centre for Geographic Information Systems (CGIS), the official geospatial agency of the State of Qatar, successfully delivered the country's first advanced, vectorized, watertight 3D city model of Doha.

CGIS collected, in collaboration with Khatib & Alami, aerial data using Vexcel Imaging's UltraCam Osprey 4.1—a large-format photogrammetric camera system capturing both nadir and oblique imagery—and processed it with Vexcel's UltraMap software suite. High-quality, watertight Level of Detail (LOD) 2 and LOD3 models were then generated using advanced tools from RhinoTerrain and DAT/EM Systems International, demonstrating how cutting-edge technologies and strategic collaboration can shape the future of smart cities.

The final deliverable spans 218 square kilometers across 16 designated urban areas, resulting in 43,310 LOD2 buildings and 300 LOD3 buildings. The textured, watertight models conform to CityGML standards, ensuring compatibility and seamless integration into modern GIS platforms.

Safe Software unveils FME Realize

Safe Software has launched FME Realize, an Augmented Reality (AR) solution that connects field workers to an organization's entire data ecosystem, including digital twins, through AR.

FME Realize bridges the gap between the digital world and the physical world, extending the power of the FME Platform to spatial computing.*safe.com*

Woolpert acquires Bluesky International

Woolpert has acquired Bluesky International, UK - the private, multidisciplinary geospatial solutions firm specializes in aerial imaging, lidar, 3D modeling, vegetation, and renewables mapping. It is headquartered in Ashby-de-la-Zouch, Leicestershire.

Woolpert is a global leader in geospatial services, collecting and processing imagery and lidar data from mountaintops to the seafloor. *woolpert.com*

Regulatory framework to support direct-to-device satellite services in China

China has released comprehensive regulations for direct-to-device satellite services, laying the foundation for domestic growth of the emerging sector. Seven government departments issued a notice April 30 entitled "Regulations on the Management of Terminal Equipment Directly Connected to Satellite Services," establishing the legal and technical groundwork for satellite connectivity aligned with national objectives.

The move takes place amid growing international competition and follows earlier developments in the U.S., with the Federal Communications Commission (FCC) last March approving the world's first direct-to-smartphone regulatory framework.

China's new rules appear to refer more broadly to terminal equipment directly connected to satellites. This includes not only smartphones but also Internet of Things (IoT) modules, vehicle terminals and other connected devices. The notice was jointly issued by the National Development and Reform Commission (NDRC), Ministry of Industry and Information Technology (MIIT), Ministry of Public Security, and relevant administrations for cybersecurity, radio, film and television, customs, and market regulations. *spacenews.com*

KASA seeks revision of plan to make next-gen rockets reusable

South Korea's aerospace agency has formally requested a government review to revise the development plan for its next-generation space launch vehicle, aiming to shift toward a reusable rocket system.

According to the Korea AeroSpace Administration (KASA), the agency submitted a request to the finance ministry for a feasibility reassessment of the project revision. It announced in February that it plans to modify its next-generation space rocket into a reusable system and acquire such technology by 2035. *www.deshsewak.org*

Japanese private lunar lander enters moon orbit

A private lunar lander from Japan is now circling the moon, with just another month to go before it attempts a touchdown. SpaceX launched Resilience with U.S-based Firefly Aerospace's lunar lander in January. Firefly got there first in March, becoming the first private outfit to successfully land a spacecraft on the moon without crashing or falling over. Another American company, Intuitive Machines, landed a spacecraft on the moon a few days later, but it ended up sideways in a crater. *www.nbcnews.com*

Forest monitoring satellite Biomass successfully launched

The Airbus built forest monitoring satellite Biomass has been successfully launched into orbit. A European Space Agency (ESA) flagship mission, Biomass will use its revolutionary P-band synthetic aperture radar instrument to measure forest biomass to assess terrestrial carbon stocks and fluxes to enable scientists to better understand the carbon cycle and its effects on climate change. *www.airbus.com*

UP42 and Maxar partnership

UP42 has partnered with Maxar to make Maxar's very high-resolution satellite imagery and tasking products available in the UP42 platform. Its customers can now directly task Maxar's very high-resolution constellation, including its WorldView Legion satellites. *www.up42.com*

UAE and Egypt new MoU

In a milestone development for Arab space collaboration, the UAE Space Agency and the Egyptian Space Agency (EgSA) signed a wide-ranging Memorandum of Understanding (MoU) during the 2025 NewSpace Africa Conference in Cairo. The MoU outlines strategic areas of cooperation, including:

- Knowledge Exchange: Sharing expertise in space legislation, regulatory frameworks, and institutional best practices
- Capacity Building: Developing skilled professionals through joint training programs, academic collaboration, and talent exchange
- Technology & Innovation: Partnering on satellite development, Earth observation missions, and emerging space technologies

spaceinafrica.com

Gilat expands its ESA Antenna Portfolio

Gilat Satellite Networks Ltd. has completed a series of test flights featuring its ESR-2030Ku electronically steered antenna (ESA). Conducted in collaboration with Gogo, which will be the exclusive distributor of the antenna for the business aviation and defense markets, the tests demonstrated outstanding performance of the ESA on the OneWeb Low Earth Orbit (LEO) network. *www.gilat.com*

UAE Space Agency partners with TII

The UAE Space Agency and the Technology Innovation Institute (TII) has signed an agreement to design and develop the EMA Lander which will be aboard the MBR Explorer, and will be deployed to study the 7th asteroid Justitia, as part of the Emirates Mission to the Asteroid Belt (EMA). TII will lead the design, development and testing phases of the lander, as well as providing opportunities for startups' participation in the development of the project, in line with the mission's commitment of allocating 50% of the project to UAE based companies, as it aims to create substantial economic opportunities, spur Emirati startups, and attract international partnerships.

The mission spans 13 years, with a six-year spacecraft development phase followed by a seven-year voyage to the main asteroid belt beyond Mars. The "MBR Explorer" spacecraft will conduct a series of close flybys of seven asteroids, gathering invaluable, unprecedented data during these encounters, and will finally deploy the lander on the seventh asteroid "Justitia". *space.gov.ae*

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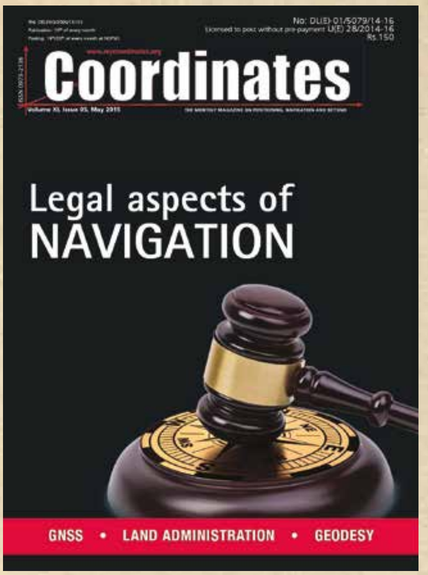

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Legal aspects of navigation

Frans G. von der Dunk
Harvey & Susan Perlman Alumni / Othmer Professor of Space Law at the University of Nebraska-Lincoln, College of Law, LLM Program in Space, Cyber & Telecommunications Law, USA

To illustrate the resulting complexity of the liability situation in particular where the involvement of satellites in navigation arises, in the context of several major advisory projects on Galileo the present author has developed a 'GNSS Legal/Functional Model' to properly map the various potentially or actually applicable liability regimes in this realm.

Studies on revitalized GLONASS from India

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The results presented here are based on long-term study using data collected from scattered locations in India, and therefore is expected to be valid for the wide Indian sub-continent region. GLONASS, as the only current global alternative to GPS, is capable of providing system independence and redundancy to the users in stand-alone mode. With growing interest on Multi-GNSS, efficient use of GLONASS may play an important role in defining the GNSS business road map in the Indian region.

Towards spatially enabled Societies and Governments

Daniel Steudler
Scientific Associate, Swiss Federal Office of Topography swisstopo, Switzerland
Professor Abbas Rajabifard
Head, Department of Infrastructure Engineering Director, Centre for SDIs and Land Administration, The University of Melbourne, Australia

The future of spatial enablement and the realisation of a spatially enabled society, lie in it being a holistic endeavour where spatial (and land data) and non- spatial data are integrated according to evolving standards and with the SDI providing the enabling platform.

Terrestrial LiDAR capabilities for cadastral modelling

Jacynthe Pouliot and Marc Vasseur
Department of Geomatics Sciences, Université Laval, Quebec, Canada

We can state that LiDAR technology offers interesting performance for surveying apartments and producing cadastral data. However our experiment only proposes preliminary results and has many limitations. For instance, two apartment buildings are not sufficient to generate robust recommendations about better practices for LiDAR data acquisition and modelling.

China's land registration: Challenges and efforts

Huanle He
Cadaster Division in China Land Surveying and Planning Institute, Guanyingyuan xiqu, Beijing, China

Currently, a lot of local governments are boosting rural land registration. They try to register what hasn't been registered earlier and to supplement or update what has been registered before. In the new round of rural land registration, new survey methods are widely used to improve the measurement accuracy.

First All-Canadian Antarctic Expedition Draws Underwater Maps with High-Accuracy

In a landmark moment for Canadian science and technology, the first all-Canadian Antarctic research expedition relied on Montreal-made Arrow Gold+™ GNSS technology for precise location data. In one of the most remote, harsh, and unmapped environments on Earth, the expedition brought together Canadian scientists, technicians, and institutions from all over the country, showcasing a variety of expertise on the global stage.

The month-long journey around the South Shetland Islands and the northern Antarctic Peninsula yielded surveys of coastal and oceanic sites. The crew relied on a small, unmanned surface vessel (USV) carrying various equipment for bathymetric surveys including an onboard computer, IMU sensor, and multibeam sonar.

In order to find the USV's precise position in an environment with no land-based RTK infrastructure, the team relied on the Arrow Gold+ GNSS receiver, designed and manufactured by Canadian-based Eos Positioning Systems. It used Galileo High Accuracy Service (GalHAS), a free satellite-based PPP correction available worldwide from the European Agency for the Space Programme (EUSPA). While using GalHAS corrections, the Arrow Gold+ provided estimated accuracies of about 10 centimeters horizontal and 15-20 vertical.

Cutting-Edge RIEGL Mobile Mapping Technology in the Nordic Regions

Field Geospatial AS - a Norwegian technology and geomatics company has procured the advanced RIEGL VMX-2HA, a high-speed, high-performance dual scanner mobile mapping system installable on cars or other moving vehicles. Complementing this system is the Ladybug 6 360-degree camera and advanced pavement analysis cameras, ensuring unparalleled precision in data capture for diverse applications. The new system is fully operational and serving customer projects.

Mobile mapping technology revolutionizes data collection by using advanced laser scanning systems to capture precise environmental information along roads, railways, and other infrastructures. This data is transformed into Field's cloud-based system, Mapspace, allowing customers to visualize, analyze and get insights into the data. Field now provides the most extensive mapping services in the Nordics, serving Norway, Sweden, Finland, and Denmark.

GeoTerra selects Vexcel UltraCam Merlin 4.1

Vexcel Imaging has announced that GeoTerra has acquired the UltraCam Merlin 4.1 2010 digital aerial camera system. This marks GeoTerra's transition to Vexcel's fourth-generation camera systems and reinforces their commitment to delivering versatile, reliable, and high-accuracy imagery for engineering and government mapping projects at all levels. *www.vexcel-imaging.com*

TrustPoint secures NAVAIR contract

TrustPoint has been awarded a $1.2 million Small Business Innovation Research (SBIR) Phase II contract from the United States Navy's Naval Air Systems Command (NAVAIR). This landmark contract will fund the first-ever delivery and initial demonstration of TrustPoint's C-band GNSS service-enabled receivers to the U.S. government, in partnership with Hexagon | NovAtel and Hexagon US Federal, both part of Hexagon. *www.trustpointgps.com*

Resilient GPS technology for US Space Force

Sierra Space has successfully completed another demonstration of its resilient GPS (R-GPS) technology for the U.S. Space Force. This achievement marks the third major milestone for the program, which is designed to enhance the resilience of GPS infrastructure against threats such as jamming and spoofing. The recent demonstration included early integration of R-GPS satellite technology using FlatSat flight software and hardware subsystem testing, as well as successful communication with ground software systems. The R-GPS effort is part of a broader initiative by the U.S. Space Force's Space Systems Command to develop smaller, more cost-effective GPS satellites. *www.sierraspace.com*

Pix4D and Vision Aerial partnership

Pix4D has announced a new partnership with Vision Aerial, USA. Together, both will be launching bundled solutions that deliver a complete, streamlined approach to aerial data capture and processing for industries ranging from surveying to public safety. *www.pix4d.com*

RTK precision to Archer 4 GNSS Expansion Pod added

Juniper Systems Inc. announces that the GNSS Expansion Pod for the Archer 4 Rugged Handheld is now RTK capable. It is also launching a new application for the Archer 4 called Archer Connect. The Archer 4 with GNSS Expansion Pod and RTK connection is now an all-in-one centimeter mapping solution. *junipersys.com*

NAL Research and VectorNav collaboration

NAL Research and VectorNav Technologies are joining forces to develop and produce Iridium STL (satellite time and location)-aided inertial navigation systems (INS) designed to meet the increasing demand for resilient PNT in GNSS-denied environments. Operators of uncrewed systems, in particular, can benefit from implementing an INS solution that leverages NAL's Iridium STL-enabled APNT receivers to maintain critical operations in areas where GPS/GNSS signals are denied or degraded. *www.nalresearch.com*

u-blox launches PointPerfect Global

u-blox has introduced PointPerfect Global, its new high-precision GNSS correction

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04-05 June
London, UK
www.geobusinessshow.com

July 2025

Esri User Conference
14-18 July 2025
San Diego, USA
www.esri.com

September 2025

IAG Scientific Assembly 2025
1-5 September
Rimini, Italy
https://eventi.unibo.it/iag2025

Commercial UAV Expo 2025
2-4, September
Las Vegas
www.expouav.com

Esri India User Conference 2025
September - Delhi 3rd & 4th, Kolkata 9th, Hyderabad 10th, Mumbai 12th
www.esri.in

ION GNSS+
08-12 September 2025
Baltimore, USA
www.ion.org

Baška SIF (Spatial Intelligence Forum) Meeting 2025
21 - 24 September 2025
Baška, Krk Island, Croatia
www.visitbaska.hr/en

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

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

November 2025

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

service designed for applications that require sub-decimeter positioning accuracy. It is engineered to provide convergence times under two minutes and accuracy of less than 10 cm. It uses Precise Point Positioning with Ambiguity Resolution (PPP-AR) corrections and is optimized for products built on the X20 platform. *www.u-blox.com*

Teledyne Marine unveils autonomous navigation solution

Teledyne Marine has launched the Teledyne Compact Navigator, an ultra-compact autonomous integrated navigation system engineered for subsea and surface vehicles. The system operates fully autonomously, eliminating the need for external aiding or operator intervention. Advanced phased array Doppler Velocity Log (DVL) technology enhances performance while allowing the device to be mounted on an autonomous underwater vehicle or ship hull. *www.teledynemarine.com*

Inertial Labs launches tactical-grade MEMS IMU

Inertial Labs has released the IMU-H100, a micro-electromechanical systems inertial measurement unit (IMU) designed to improve tactical guidance and navigation for UAVs, short-range missiles, precision-guided munitions and a range of commercial applications. *inertiallabs.com*

SiTime Symphonic Mobile Clock Generator

SiTime Corporation has introduced Symphonic, its first mobile clock generator featuring its integrated MEMS resonator, the SiT30100. The device is designed to deliver precise and resilient clock signals for 5G and GNSS chipsets, supporting efficient power consumption in mobile and IoT devices. The integrated temperature sensor in the SiT30100 provides accurate data to compensation algorithms, enabling improved frequency stability. *sitime.com*