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Quantitative Assessment of Non-Revenue Water and Reduction Strategies: A Case Study of Kulgaon - Badlapur Municipal Council, Maharashtra, India

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Abstract: Water is becoming scarcer day by day and along with that losses in water are also increasing putting stress on water utilities. Non-revenue water refers to the volume of water that do not contribute to the revenue generation of water utilities, and is a part of system input volume (SIV). This research paper reviews the assessment of NRW, components of NRW and quantitative assessment of NRW done in the case study area of Kulgaon – Badlapur Municipal Council, Maharashtra, India. A generalized methodology was developed depending upon the available data and referring IWA standard water audit method. Following this methodology, results obtained. Depending upon this assessment done, some NRW reduction strategies are suggested such as authorization of illegal connections, provision of bulk meters and leakage control.
Keywords: Non revenue water (NRW), assessment, physical losses, apparent losses, Reduction strategies.

I. INTRODUCTION

Water is a natural resources of utmost importance. Water is vital for life to exist and has become scarcer because of various reasons and this is a major problem in urban India. As per 2011 census of India, about 380 million of population is living in urban area, which is projected to rise to 600 million by 2030. This rapid escalation of urbanization is causing severe resource constraints, especially water. Water services worldwide are getting affected by high quantum of water losses, either by physical losses or apparent losses or both. Water gets lost during its transmission from water treatment plant to consumers' tap. This water losses affect the financial viability of water utilities. In general, Non-revenue water (NRW) is the water supplied by the water utilities which is lost and do not contribute to the generation of revenue to water utility. NRW impacts both water utility and customers of water utility. Kingdom et al. (2006) stated that, "Non-revenue water is the difference between the volume of water put into a water distribution system and the volume that is billed to customers". NRW comprises of three components: physical (or real) losses, commercial (or apparent) losses, and unbilled authorized consumption". They also stated that, globally the average of NRW levels is 35% of supplied water amounting to 48.6 billion m^3/ year. The cost of NRW generated on global level is the US$14 billion per year around the world. The reduction of these losses to reduce NRW is very important considering water scarcity. The levels of NRW indicates the water utility performance.

The NRW varies widely from 15% to 70% of total volume entered in water distribution system (WDS), within Indian cities. Reduction and control of water loss is becoming more important, due factors such as diminishing water resources, increasing demand for water due to population growth. In developing countries like India where an economic loss is a concerned issue, reducing Non-Revenue Water becomes very important. Hence it is needed to study the present scenario of NRW in urban areas of India where levels of NRW are higher.

II. OBJECTIVES AND SCOPE OF RESEARCH WORK

Objectives of the study of NRW in a selected urban area are as follows:

1) To assess the present NRW levels in a selected case study area.
2) To identify the reasons behind water losses.
3) To design a suitable NRW strategy according to results of above objectives.

Scope of this research work is quantitative assessment of NRW and its components and to suggest a suitable strategy based upon assessment done.

A. *Assessment of NRW*

NRW Assessment and calculation of its components and Performance Indicators (PI) is imperative to reduce it and design a suitable NRW reduction strategy. During the 1990s assessment of NRW was often more of an estimation by guessing process instead of a scientific one. However, since 2000, because of efforts by International water association (IWA), there is a significant progress in this field of assessment of NRW. There are different methods of assessing NRW volumes of water utilities in quantitative manner. These methods depend upon the condition of infrastructure of the Water utility, data availability and its suitability to a particular water utility.

Methods such as water balance or water audit, district metered areas (DMAs), leakage hydraulic analysis for quantitative analysis, Minimum night flow (MNF), Burst And Background Estimate (BABE) methodology and Fixed And Variable Area Discharge (FAVAD) theory analysis are used for assessment of NRW. Transients, pressure management, acoustics and network loss management are the tools to reduce physical losses. Some optimization techniques like multi-objective optimization, Multi-criteria decision analysis (MCDA) are also used to minimize losses and ultimately to reduce NRW.

The water balance summarizes the NRW and its components and provides accountability, as all of the water input in WDS should be equal to all the water distributed and water losses. Software named ‘water audit system’ developed by IWA is used for water balance. Following figure shows the standard water balance by IWA.

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent* Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real* Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the measurement point</td></tr>
</table>

Fig. 1. IWA Water Balance (source: IWA manual)

Four basic steps were involved in the NRW calculation. The total volume of water putted in WDS from current sources considering adjustments for meter errors. Volume of water purchased, exported out of the WDS is separately considered. Authorized consumption (billed and unbilled) was taken from registered customers’ meters. Authorized consumption includes item like water used for fire extinguishing in city, cleaning of sewers and water mains, street cleaning and water given at free of cost to some institutions and used by the water utility itself.

B. *Components of NRW*

As per IWA standard water balance and its terminology, the NRW comprises three components: physical (or real) losses, commercial (or apparent) losses, and unbilled authorized consumption. Physical losses involve leakages in the WDS and its components and overflows at the utility’s storage tanks. Poor operations and maintenance, leakage control, and poor quality of underground components of WDS also causes real losses. Commercial (Apparent) losses are caused by under registration of customer meter, data handling errors and illegal water consumption. Unbilled authorized consumption includes water used by the utility for operational purposes, water used for firefighting, and water provided for free to certain consumer groups.

Physical losses relates to the condition of WDS, because the majority of leaks i.e. physical losses occur on service connections. Physical losses in litres/service connection/day is a more suitable indictor. Based on the extensive experience and research, a simple matrix named as ‘ Physical loss assessment matrix’ was developed in 2005 by Roland Liemberger. This matrix gives physical losses in litres/service connection/day according to the average pressure in water utilities and Infrastructure Leakage Index (ILI) and technical performance categories which are shown in figure below.

Table 5: Physical Loss Assessment Matrix

Technical performance category	ILI[a]	Liters/connection/day when the system is pressurized at an average pressure of: 10 m	20 m	30 m	40 m	50 m
Developed countries						
A	1-2		< 50	< 75	< 100	< 125
B	2-4		50-100	75-150	100-200	125-250
C	4-8		100-200	150-300	200-400	250-500
D	> 8		> 200	> 300	> 400	> 500
Developing countries						
A	1-4	< 50	< 100	< 150	< 200	< 250
B	4-8	50-100	100-200	150-300	200-400	250-500
C	8-16	100-200	200-400	300-600	400-800	500-1,000
D	> 16	> 200	> 400	> 600	> 800	> 1,000

Source: Roland Liemberger.
m = meters
a. The Infrastructure Leakage Index (ILI), a leakage benchmarking indicator developed by the IWA, is the ratio between the present volume of physical losses to the minimum achievable volume at the present pressure. (It was used to develop this table, but is not discussed in this report.)

Category A: Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective improvement
Category B: Potential for marked improvements; consider pressure management; better active leakage control practices, and better network maintenance.
Category C: Poor leakage record; tolerable only if water is plentiful and cheap; even then, analyse level and nature of leakage and intensify leakage reduction efforts
Category D: Highly inefficient; leakage reduction programs imperative and high priority

Fig. 2. Physical loss assessment matrix (source: kingdom *et al.*, 2006)

The apparent (commercial) losses are the volume of water which is used by the customers but not paid for. Apparent losses mainly consists of following primary components: customer meter inaccuracy, meter reading errors, unauthorized consumption which includes water theft, meter bypass, illegal connections, etc. and data handling and billing errors.

As per IWA Manual, Unbilled authorised consumption is water used by authorised customers, but not billed for and is of two types, Unbilled metered consumption and unbilled unmetered consumption.

C. Study Area

Case study area selected for the study of ‘Quantitative assessment of NRW and reduction strategies’ is Kulgaon – Badlapur Municipal council (KBMC). KBMC, is an Urban local body (ULB) located in Ambernath Tehsil of Thane district, Maharashtra state, India. Thane district is a part of Konkan region. KBMC is a part of Mumbai Metropolitan Region Development Authority (MMRDA) notified area named as, “Ambernath, Kulgaon – Badlapur and surrounding Notified Area”. Kulgaon – Badlapur Municipal Council is divided into 34 wards for the administration purpose.

Population of KBMC, According to Census 2011, by the Government of India (GoI) is 1,74,226 souls; of which male and female are 90,365 and 83,861 respectively. The sex ratio of the city is 928 females per 1000 males. The literacy rate of the city is 82%.

For KBMC, Maharashtra Jeevan Pradhikaran (MJP), a Maharashtra state government board which operates and maintains the water supply system. The Ulhas river, a notified river is a source of the water supply system. After the power generation at Tata hydro-power generation station, Bhivpuri, water of Andhra dam is let out in the Ulhas river, and therefore, it is a perennial river. Following figure shows the location map of KBMC.

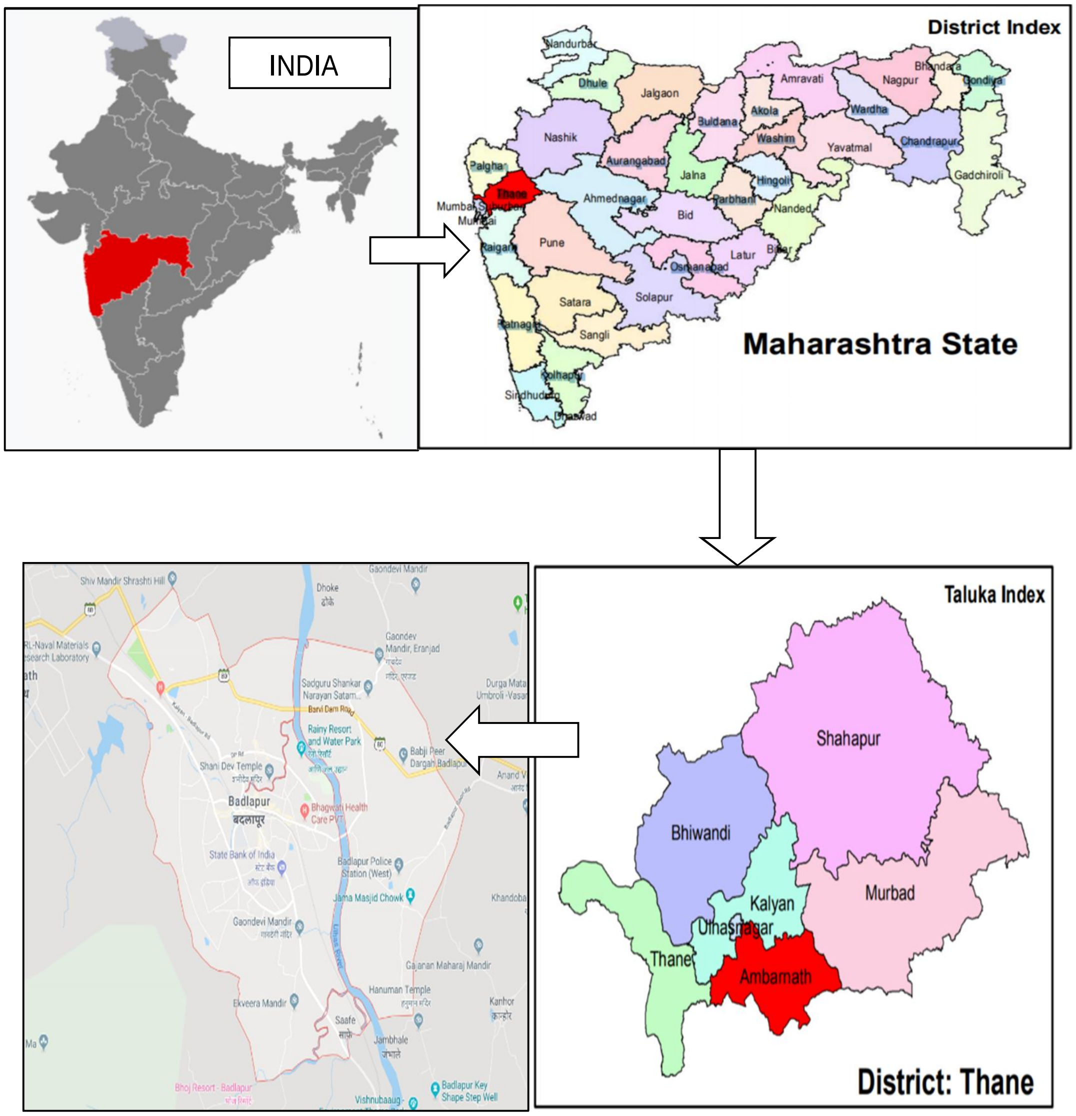

Fig. 3. Location Map of KBMC

At present, pumped volume of water at the pumping station of BHW is between 90 – 105 MLD as per acquired data. As per general report of MJP in 2016, the estimated population of KBMC is 2,50,006 souls and that of year 2021 are projected as 3,49,239.

III. METHODOLOGY

The methodology to assess the NRW and its components and strategy to reduce NRW levels in a selected study area depends upon the various factors which are responsible for the generation of NRW. A generalised methodology should be adopted applicable to selected case study area. Referring the IWA water loss manual and referring the research work done in this field of assessment of NRW taking case studies, following are some methodological steps towards an assessment and reduction of NRW considering literature review.

1) Step 1: Identification of water supply sources for a case study area
2) Step 2: Data collection of an existing water distribution system (WDS) network
3) Step 3: Collection of metered tap connections and its billing data for a case study area
4) Step 4: Calculation of NRW volume
5) Step 5: Categorization of NRW
6) Step 6: Designing of NRW reduction strategy

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A. Data Collection

Following is the data of pumped water through Ulhas River and billed volume of water to customers. Following **Table 3 and 4** shows the data of pumped volume during April 2017 to March 2018 and during April 2018-March 2019.

Table 1. Pumping Volumes for year 2017-18

Month	Total water lifted in ML during the month	Water share of KBMC (52%) in ML	Average water lifted in ML	Average Water share of KBMC	Energy cost per ML
Apr-17	2750.81	1430.43	91.69	47.68	1246.22
May-17	2843.15	1478.44	91.71	47.69	1588.06
Jun-17	2901.24	1508.65	96.71	50.29	1540.86
Jul-17	3052.34	1587.22	98.46	51.2	1302.7
Aug-17	3038.74	1580.15	98.02	50.98	1420.89
Sep-17	2915.54	1516.09	97.18	50.54	1351.29
Oct-17	2990.55	1555.09	96.47	50.17	1339.68
Nov-17	2967.11	1542.9	98.9	51.43	1410.8
Dec-17	3036.11	1578.78	97.94	50.93	1322
Jan-18	3054.9	1588.55	98.55	51.25	1315.1
Feb-18	2876.65	1495.86	102.74	53.43	1339.36
Mar-18	3145.81	1635.83	101.48	52.77	1193.76
Total	35572.95	18497.99			
Average			97.49	50.7	1364.23

Table 2. Pumping Volumes for year 2018-19

Month	Total water lifted in ML during the month	Water share of KBMC (52%) in ML	Average water lifted in ML	Average Water share (ML) of KBMC	Energy cost per ML
Apr-18	2825.65	1469.34	94.19	48.98	1119.41
May-18	3049.07	1585.52	98.36	51.15	1251.15
Jun-18	3073.88	1598.42	102.46	53.28	1296.14
Jul-18	3091.02	1607.34	99.71	51.85	1225.64
Aug-18	2961.82	1540.15	95.54	49.69	1257.98
Sep-18	2967.01	1542.85	98.9	51.43	1425.32
Oct-18	3074.59	1598.79	99.18	51.58	1469.08
Nov-18	2817.06	1464.88	93.9	48.83	1424.25
Dec-18	2762.37	1436.44	89.11	46.34	1455.88
Jan-19	2717.18	1412.94	87.65	45.58	1466.15
Feb-19	2443.56	1270.66	87.27	45.39	1432.18
Mar-19	2738.16	1423.85	88.33	45.94	1452.66
Total	34521.37	17951.18			
Average			94.55	49.17	1356.32

Following Table No. 5 and Table No. 6 shows the data of billed water volume to customers during years 2017-18 and 2018-19 respectively.

Table 4. Billed water volume data from abstract reports for 2017-18

0	Billed water volume (m^3)	Billed water volume(ML)
Apr-17	932699	932.699
May-17	894732	894.732
Jun-17	1008793	1008.793
Jul-17	960696	960.696
Aug-17	997205	997.205
Sep-17	911159	911.159
Oct-17	962909	962.909
Nov-17	971475	971.475
Dec-17	1075714	1075.714
Jan-18	1008518	1008.518
Feb-18	1020213	1020.213
Mar-18	936001	936.001
Total	11680114	11680.114

Table 5. Billed water volume data from abstract reports for 2018-19

Month	Billed water volume (m^3)	Billed water volume (ML)
May-18	948213	948.213
Jul-18	974519	974.519
Sep-18	943866	943.866
Nov-18	917115	917.115
Jan-19	933289	933.289
Mar-19	911460	911.46
Apr-18	959345	959.345
Jun-18	1055125	1055.125
Aug-18	1022232	1022.232
Oct-18	1018410	1018.41
Dec-18	991785	991.785
Feb-19	1037847	1037.847
Total	11713206	11713.206

Total Number of metered service connections in KBMC is 19,561 out of which around 10% meters are not working as per billing abstract sheet. Length of water mains in the KBMC is approximately 170 Km. Average pressure in the WDS is 20 m of water and average length of customer connection from water main is 30 m. above data is used in the calculation of NRW, its components and PI's such as UARL and ILI.

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IV. RESULTS AND DISCUSSION

Because of limited availability of data and some restraints, it was possible to assess NRW volume. Components of NRW and PI's are calculated by taking some guidelines and assumptions from IWA water audit method. Following are some formulae used in the required calculations.

1) NRW volume = water losses + Unbilled authorised consumption = (Volume of water supplied) – (Volume of water that is actually billed to customers) + Unbilled authorised consumption.
2) UARL (L/connection/day) = (18 x Lm + 0.80 x Nc + 25 x Lp) x P

   Where,

   L_m = Length of water mains in km.

   N_c = Number of service connections.

   L_p = Total length of private pipe, means length of customer connection from water main.

   = $N_c \times$ average distance of customer meter from the curb stop.

   P = Average pressure in the WDS in metres.

3) Infrastructure leakage index = $\frac{\text{CARL}}{\text{UARL}}$
4) % NRW calculation = $\frac{\textit{NRW in the city}}{\textit{Total water supplied to city}} \times 100$

Following are the results obtained from calculations and summarized as below:

Table 6. Results of NRW calculation for year 2017-18

Year	System input volume (ML/Year)	NRW volume (ML/Year)	NRW in %
2017-18	18498	7049.11	38.1

NRW water volume in 2017-18 for KBMC was 7049.11ML/Year which was 38.1% of the system input volume.
NRW water volume in 2018-19 for KBMC is 6462.18NL/Year which is 36% of the system input volume. UARL for year 2018-19 is 247.6 ML/Year which gives the ILI value of 25.2. Using Physical loss Assessment Matrix (refer Fig. 2), physical looses were calculated as 2855.9 which accounts to 44% of total NRW. Apparent losses were found to be 3382.06 ML/Year. Results are summarised as below:

Table 7. Results of NRW calculation for year 2018-19

Year	System input volume (ML/Year)	NRW volume (ML/Year)	NRW in %	UARL (ML/Year)	ILI
2018-19	17951.18	6462.18	36	247.6	25.2

A. NRW Reduction Measures

1) *Identification and Regularisation Of Illegal Connection:* Water is an essential need and basic right of a human being, hence, water utilities cannot refuse water supply to anyone. Hence illegal connections should be identified on regular basis, by forming a task force and such connections should be regularised in regular intervals of time.
2) *Assessment of WDS assets:* Assets of WDS such as pipes carrying water, which may be open or underground, fittings at connections, different types of valves are prone to leakages. Their regular check-up and leakage monitoring is must in order to reduce or minimize the physical/real losses in the WDS.
3) *Provision of Bulk meters:* It has been observed that there are no bulk meters for the water mains entering a particular zone in KBMC as well as at the ESR's. This leads to difficulty in maintaining the water balance and data of water entering different zones. Hence, bulk meters should be provided at the distribution main entering a particular zone or at least at the outlet of the ESR's.
4) *Increase in Capacity of WTP with Suitable Population Estimation:* As Badlapur is situated near and well connected to the State capital, Mumbai and also is a part of MMRDA notified region, population is increasing rapidly since Year 2011. Hence the capacity of the existing WTP should be increased considering increasing population of the KBMC. So that the standard demand of targeted population can be satisfied as per standard norms.

V. CONCLUSION

The research work carried out in the case study area gave some findings as required in objectives of research work. Results shows that the NRW levels in the case study area ranges between 35 - 43% which are higher levels than the standard benchmark of 20% given Government of India. Some NRW reduction measures are suggested suitable to the case study area. These will help in reduction of losses if practiced by water utilities.

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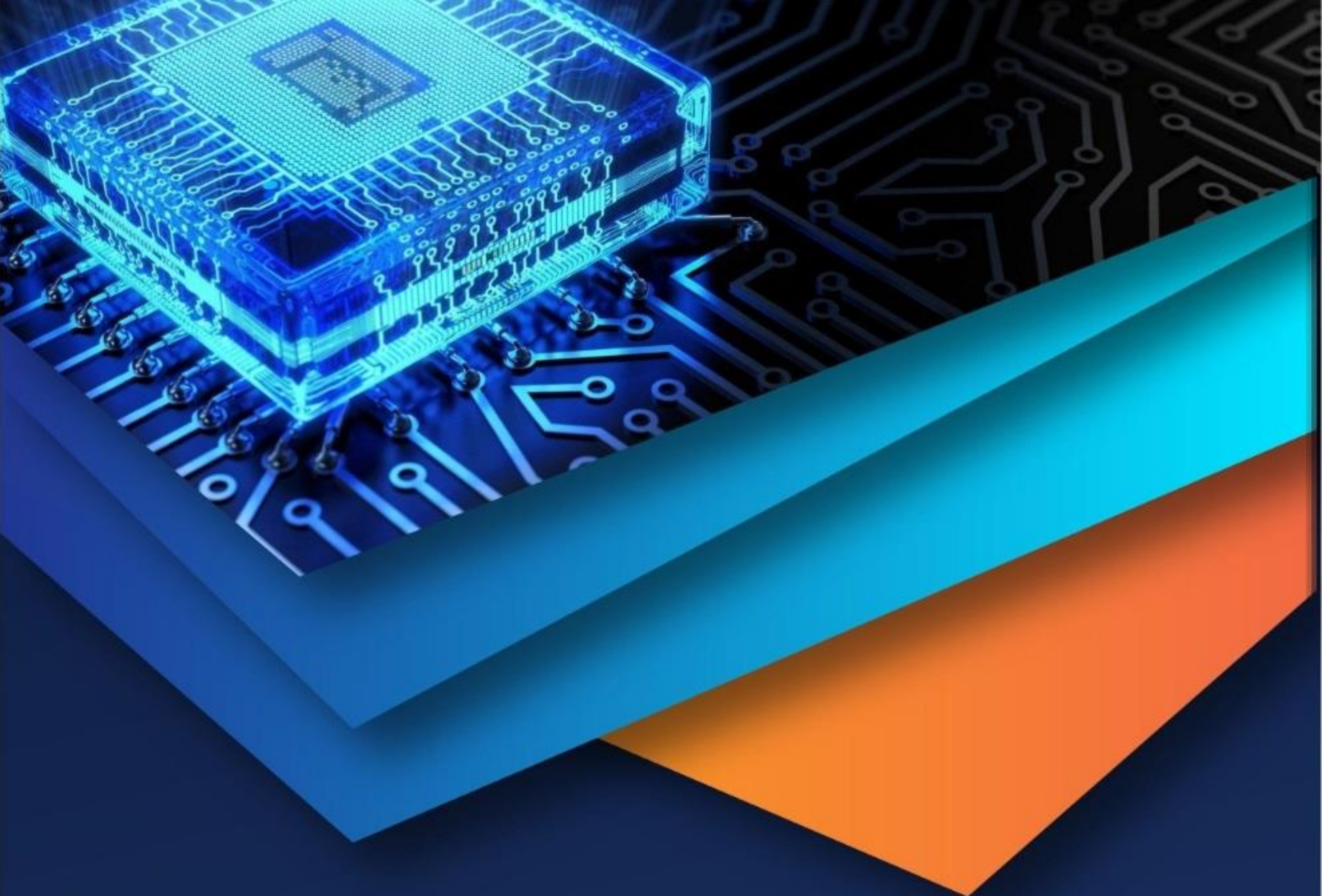

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