Section A-Research paper

Roof Top Rainwater Harvesting

Faheemul Islam Kirmani, Rahul Maurya, Rajnish Yadav, Hritik Kumar
Department of Civil Engineering, Galgotias College of Engineering &Technology, GreaterNoida (UP)-201306, India
faheemul.islamkirmani@galgotia@golgotiacollege.edu
rahulrazz09211@gmail.com
raj.jdsvm14@gmail.com
hritikbaaliyan9818@gmail.com

doi: 10.48047/ecb/2023.12.si4.1281

Abstract
The previous studies on roof top rainwater harvesting from numerous research papers demonstrate a comprehensive understanding of the benefits, challenges, and implementation strategies of this technique. Numerous studies have highlighted the benefits of roof top rainwater harvesting, such as reducing the demand for groundwater and surface water, mitigating the risk of flooding, and minimizing the impact of stormwater runoff. Additionally, the papers have indicated that this method is cost-effective, environmentally friendly, and promotes self-sufficiency. The challenges of roof top rainwater harvesting have also been studied, including the potential for contamination, the need for regular maintenance, and the limitations of the storage capacity. However, the studies have shown that these challenges can be addressed through appropriate design, implementation, and maintenance strategies.

Keywords: Rainwater Harvesting, Rainwater Quality, Large Public Institutions, Water Quality.

1. Introduction

Access to safe drinking water is still remains a significant challenge for a large population. According to estimates by WHO/UNICEF, around 1.1 billion population do not have good water to drink. The unavailability of safe drinking water is a major public health issue, leading to waterborne diseases and relatedsocio-economic challenges.Efforts to improve access to safe drinking water must be prioritized to address this global challenge [1].Governments around the world are providing financial incentives to encourage the adoption of rainwater harvestingsystems.Developed nations such as Germany, Denmark, Australia, and New Zealand have implemented rainwater utilization programs that employ pipe-bound systems in private residences, public facilities, and industrial sites. These initiatives aim to conserve precious drinking water by substituting it with collected roof runoff, rather than using it for non-potable purposes like toilet flushing[2].Many researchers worldwide have recently attempted to assess the quality of roof runoff. However, most of these studies focus on urban areas of developed countries, investigating the role of roof runoff in urban stormwater pollution rather than the

utilization of harvested roof runoff. This paper, on the other hand, examines the quality of water collected from roof catchments in relation to its use as a harvested water source.

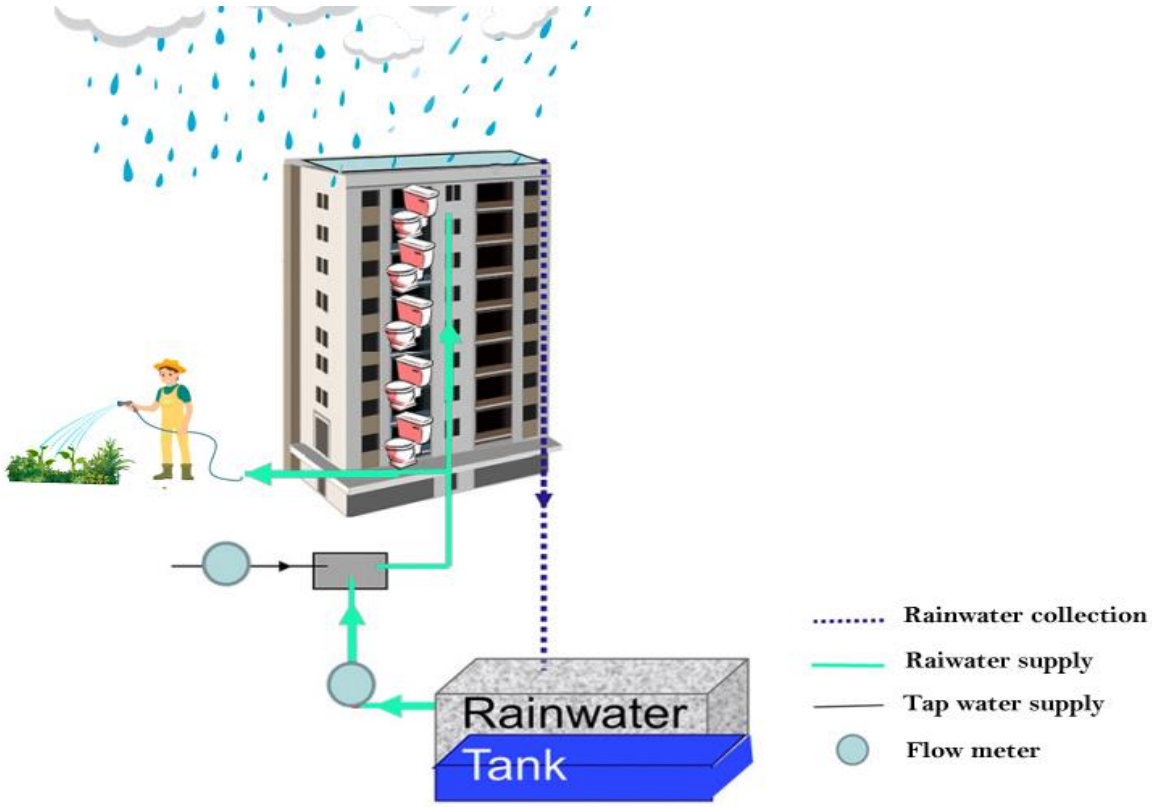


Figure of rain water harvesting.

2. Factors Affecting Roof Runoff Water Quality

The water quality is influenced through several factors, including the source of water, the risk of pollutants on the time of collection of rain water, treatment of rainwater, and storage of rainwater, and the potential for contamination when the water is consumed [3].Contamination of water can happen at any stage like on the roof, gutters or pipes, and in storage tank.Contamination of rainwater in a rooftop harvesting system may start when it lands on the roof, where it can pick up dirt and dissolve heavy metals, especially on metal surfaces, before flowing into storage. Further changes to the water quality can occur during storage, which may depend on the type of materials used in the storage system.

It is widely recognized that many substances exhibit a "firstflush effect," in which their concentrations are initially very high during first few minutes of a rain event after that it gradually dropand attained a constant value [4].Typically, these dynamic effects occur during the first 2 mm of runoff height. Firstflush effect can combination of the following three processes [5]:

- First, material that accumulated on roof at the time of the previous dry period can be run off by rain.
- Second, weathering and corrosion products from the roof can be washed off.

- Finally, the concentration of substances in rain may decrease with rising rainfall depth, as particles, spray, and gases are scavenged by rain drops.

Implementing a firstflush device which is well-maintained can significantly enhance the rainwater quality.Generally, rainwater collected from metal roofs exhibits a good amount of bacteriological quality compared to other types of roofs [6].According to a study [6] contamination of rainwater tends to increase when the dry periods extended between rainfall events due to higher collection on roofs. The researchers also discovered that the runoff quality is influenced by the intensity of the rainfall.

A study [7] that found some types of bacteria were capable of growing from low to higher concentrations levelon the time of the storage of harvested rainwater.In other research [8] on the long-term storage of rainwater found that certain bacterial strains did not decrease in levels despite extended storage periods.Specifically, smaller tanks exhibited high levels of contaminated bacteria as compared to larger tanks. The absence of mechanical devices to protect water quality in all tanks further compounded the issue, as tanks with lower capacities received a disproportionately larger share of contaminating microorganisms. Additionally, smaller tanks were more likely to accumulate sludge at the bottom, which could mix with standing water, further deteriorating the water quality. The study suggests that installing first-flush instrument alone can result in a significant enhancement in the quality of microbiological rainwater.

3. Physical-Chemical Quality

Various studies have been conducted on the physical-chemical characteristics of roof-collected rainwater, which have been reported in the scientific literature. Some research, which have been conducted in different regions of the world, generally indicate that the physical-chemical quality of roof-collected rainwater meets the regulationsof drinking water quality. However, it should be noted that someresearch have found that the pH of roofcollected rainwater is an exception to this general trend [10].Therainwater pH comes in the range of 4.5 to 6.5, but studies have shown that it may rise slightly after passing over the roof and during storage in tanks.It's worth noting that the pH value of roof-collected rainwater may decline over time due to the age of the storage tank and the length of time that the water has been stored.

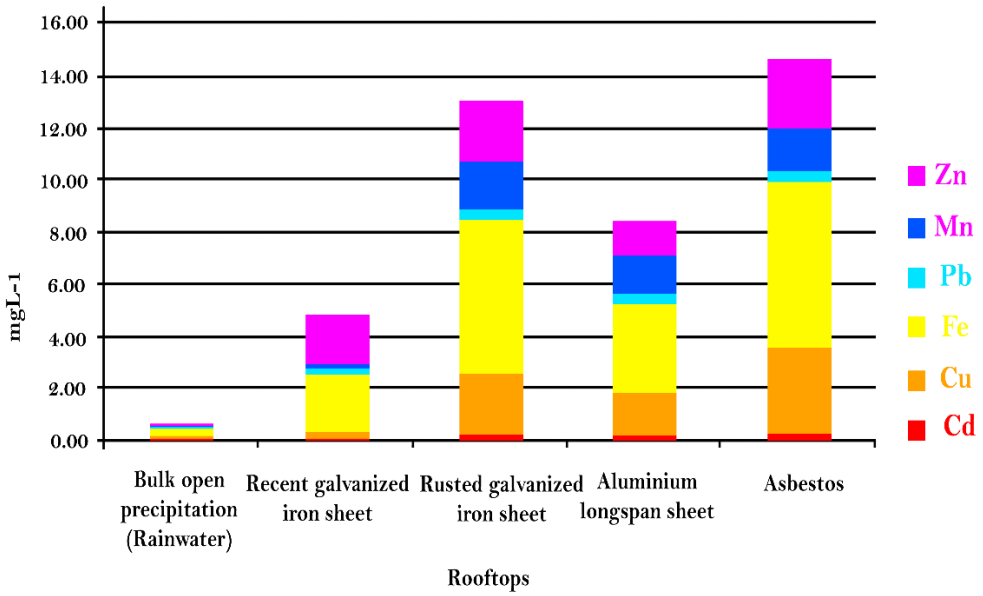
The cracks of wood roof can trap the water, creating an environment that is conducive to the growth of wood rotting organisms, as well as the growth of plants and the decay of organic matter.

3.1. Heavy Metals

Heavy metals are a significant concern in rainwater harvesting due to their toxicity, widespread occurrence, and the difficulty of removing them through simple treatment processes [11].Although rooftops are effective at collecting atmospheric particles, the roofs themselves can also be a source of heavy metals due to the leaching and degradation of roofing materials [12]. Over time, roofing materials may deteriorate and release heavy metals into rainwater, particularly in areas with high levels of atmospheric pollution or acid rain. In a study [13] the concentration of zinc and copper were found in roof water, to the extent that they constituted an environmental hazard and also affected the quality of water [14]. Lead and cadmium are also commonly

reported in rainwater harvesting studies. In particular, lead has been observed in runoff from a variety of roofing materials, including polyester [15], slate, galvanized iron [16], and asphalt shingle roofs [17]. Similarly, cadmium has been found in runoff from zinc and tarfelt roofs. These heavy metals can pose a risk to human health and the environment [18].

It's crucial to monitor water quality for heavy metals when using harvested rainwater for direct drinking purposes, particularly if the water is collected from metal roofs [19]. This is especially important in developing countries where rainwater harvesting is a common practice but monitoring and regulation of water quality may be limited [20]. However, there are relatively few studies on heavy metal contamination in roof runoff from developing regions of the world, and it's expected that the collected rainwater quality may differ in these regions due to differences in climatic conditions and roofing materials [21]. Below Graph showing heavy metal concentration in rooftop runoffs.



Here is the table of heavy metals that are found in many study of rain water harvesting.

Collection Of Sampling From	**No. Of Samples Analyzed**	**Heavy Metal Found**
Roof catchment	14 rain events	Fe, Mn, Cr, Cd, Pb, Zn, Cu
Roof catchment	31 rain events	Zn, Pb, Cu, Cd
Roof catchment	125 rain events	Pb, Cd, Zn, Cu
Roof catchment	31 storms	Al, Mg, Zn, Pb, Mn, Cu
Roof catchment	12 rain events	Zn, Pb, Ni, Hg, Cu, Cr, Cd, As

3.2. Trace Organics

Trace organic compounds, such as pesticides, are frequently detected in roof runoff and are among the most common groups of pollutants found in harvested rainwater [22]. These compounds can pose a risk to people life and inour surroundings, and can accumulate in harvested rainwater over time.The level of trace organic compounds in roof runoff can be affected by both the property of the roof and the pollutants chemical property [23]. Polkowska [24] found that toluene hydrocarbons, were more abundant in roof runoff from a roof which is covered of tar paper. Organic carbon was found to be high in runoff from a polyester roof [13]. Zobrist also observed that a polyester roof was a conduit for pesticides, whereas roof tiles and gravel tended to keep pesticides [18]. Although there were some cases where a roof acted as a sink for pollutants, the predominant function of roofs was found to be as a source of pollution.
Here is the table of trace organics that were found in many study of rain water harvesting.

Collection Of Sampling From	**No. Of Samples Analyzed**	**Parameters Tested**
Roof catchment	45 rain events	Pesticides, Petroleum Hydro-carbons,
Roof catchment	14 rain events	Pesticides
Roof catchment	33 rain events	Aliphatic Carbon

4. Conclusions

There are many factors which is going to reduce the quality of the collected rainwater like the different type of roof material, the amount of the rain fall intensity, trace organics such as pesticides, toxic heavy metal which is difficult to remove from collected rain water, the rise in the pH value of rain water when it falls on the roof and after the collection of it in the tank. So to insure the quality of collected rain water we should focus on the factors that actually affect the water quality like material of roof, rain fall intensity, toxic heavy metal, etc. Proper collection and maintenance practices are crucial in maintaining the quality of roof-collected rainwater, as poor practices can significantly reduce its quality.

References:

[1] WHO/UNICEF 2000 In Global Water Supply and Sanitation Assessment 2000 Report. World Health Association and United Nations Children's Fund, Geneva, Switzerland and New York.

[2] Hermann, T. & Schmida, U. 1999 Rainwater utilisation in Germany: efficiency, dimensioning, hydralulic and environmental aspects. Urban Water 1, 307–316.

[3] Heijnen, H. 2001 Towards water quality guidance for collected rainwater. In Proceedings of 10th International Rainwater Catchment Systems Conference,Weikersheim, Germany. International Rainwater Catchment Systems Association, pp. 133–136.

[4] Martinson, D. B. & Thomas, T. 2005 Quantifying the first-flush phenomenon. In Proceedings of 12th International Rainwater Catchment Systems Conference, New Delhi, India. International Rainwater Catchment Systems Association, pp. 1–7.

[5] Zinder, B., Schuman, T. & Waldvogel, A. 1998 Aerosol and hydrometer concentration and their chemical composition during winter precipitation along a mountain slope II. enhancement of below-cloud scavenging in a stably stratified atmosphere. Atmos. Environ. 22(12), 2741–2750.

[6] Yaziz, M. I., Gunting, H., Sapari, N. & Ghazali, A. W. 1989 Variations in rainwater quality from roof catchments. Wat. Res. 23(6), 761–765.

[7] Lye, D. J. 1989 Virulence characteristics of bacteria isolated from cistern water systems in rural Northern Kentucky, USA. In Proceedings of 4th International Conference on Rainwater Cistern Systems, Manila, Philippines. International Rainwater Catchment Systems Association, pp. 1–6.

[8] S Rani, S Sharma, M Bansal, R Garg, R Garg, Enhanced Zn (II) adsorption by chemically modified sawdust based biosorbents, Environmental Science and Pollution Research, 1-16, 2022

[9] Lye, D. J. 1991 Microbial levels in cistern systems: acceptable or unacceptable? In Proceedings of 5th International Conference on Rainwater Cistern Systems, Taiwan, Republic of China. International Rainwater Catchment Systems Association, pp. 1–7.

[10] T Gupta, K Ansari, D Lataye, M Kadu, MA Khan, NM Mubarak, R Garg, Adsorption of Indigo Carmine Dye by Acacia nilotica sawdust activated carbon in fixed bed column, Scientific Reports 12 (1), 15522, 2022

[11] Plazinska, A. 2001 Microbial quality of rainwater in selected indigenous communities in Central Australia. In Proceedings of 10th International Rainwater Catchment Systems Conference, Weikersheim, Germany. International Rainwater Catchment Systems Association, pp. 129–132.

[12] NO Eddy, RA Ukpe, P Ameh, R Ogbodo, R Garg, R Garg, Theoretical and experimental studies on photocatalytic removal of methylene blue (MetB) from aqueous solution using oyster shell synthesized CaO nanoparticles (CaONP-O), Environmental Science and Pollution Research, 1-16, 2022

[13] Ghanayem, M. 2001 Environmental considerations with respect to rainwater harvesting. In Proceedings of 10th International Rainwater Catchment Systems Conference, Weikersheim, Germany. International Rainwater Catchment Systems Association, pp. 167–171.

[14] R Garg, R Garg, MA Khan, M Bansal, VK Garg, Utilization of biosynthesized silica-supported iron oxide nanocomposites for the adsorptive removal of heavy metal ions from aqueous solutions, Environmental Science and Pollution Research, 1-14, 2022

[15] Davis, A. P., Shokouhian, M. & Ni, S. 2001 Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. Chemosphere 44, 997–1009.

[16] Manjeet Bansal, Rajni Garg, V.K. Garg, Rishav Garg, Sequestration of heavy metal ions from multi-metal simulated wastewater systems using processed agricultural biomass, Chemosphere 296 (133966), 2022

[17] Chang, M., McBroom, M. W. & Beasley, R. S. 2004 Roofing as a source of nonpoint water pollution. J. Environ. Mngmnt. 73, 307–315.

[18] Zobrist, J., Muller, S. R., Ammann, A., Bucheli, T. D., Mottier, V., Ochs, M., Schoenenberger, R., Eugster, J. & Boller, M. 2000 Quality of roof runoff for ground water infiltration. Wat. Res. 34(5), 1455–1462.

[19] SA Odoemelam, EO Oji, NO Eddy, R Garg, R Garg, S Islam, MA Khan, Zinc oxide nanoparticles adsorb emerging pollutants (glyphosate pesticide) from aqueous solutions, Environmental Monitoring and Assessment 195 (6), 658, 2023

[20] R Garg, R Garg, M Sillanpää, MA Khan, NM Mubarak, YH Tan, Rapid adsorptive removal of chromium from wastewater using walnut-derived biosorbents, Scientific Reports 13 (1), 6859, 2023

[21] Gromaire, M. C., Garnaud, S., Saad, M. & Chebbo, G. 2001 Contribution of different sources to the pollution of wet weather flows in combined sewers. Wat. Res. 35(5), 521–533.

[22] Simmons, G., Hope, V., Lewis, G., Whitmore, J. & Gao, W. 2001 Contamination of roof-collected rainwater in Auckland, New Zealand. Wat. Res. 35, 1518–1524.

[23] Moilleron, R., Gonzalez, A., Chebbo, G. & Thevenot, D. R. 2002 Determination of Aliphatic hydrocarbons, in urban run off samples from the 'Le Marais' experimental catchment in Paris. Wat. Res. 36, 1275–1285.

[24] Polkowska, Z., Gorecki, T. & Namiesnik, J. 2002 Quality of roof run off waters from an urban region (Gdansk Poland). Chemosphere 49, 1275–1283.

[25] Santhosh, N., B. A. Praveena, Reema Jain, Mohd Abul Hasan, Saiful Islam, Mohammad Amir Khan, Abdul Razak, and Md Daniyal. "Analysis of friction and wear of aluminium AA 5083/WC composites for building applications using advanced machine learning models." Ain Shams Engineering Journal (2022): 102090.

[26] Alharbi, Raied Saad, Shaminee Nath, O. Mohammed Faizan, Mohd Sayeed Ul Hasan, Shamshad Alam, Mohammad Amir Khan, Sayantan Bakshi, Mehebub Sahana, and Mufti Mohammad Saif. "Assessment of Drought vulnerability through an integrated approach using AHP and Geoinformatics in the Kangsabati River Basin." Journal of King Saud University-Science 34, no. 8 (2022): 102332.

[27] Gupta, Tripti, Khalid Ansari, Dilip Lataye, Mahendra Kadu, Mohammad Amir Khan, Nabisab Mujawar Mubarak, Rishav Garg, and Rama Rao Karri. "Adsorption of Indigo Carmine Dye by Acacia nilotica sawdust activated carbon in fixed bed column." Scientific Reports 12, no. 1 (2022): 15522.

[28] Khan, Mohammad Amir, Nayan Sharma, Giuseppe Francesco Cesare Lama, Murtaza Hasan, Rishav Garg, Gianluigi Busico, and Raied Saad Alharbi. "Three-Dimensional Hole Size (3DHS) approach for water flow turbulence analysis over emerging sand bars: Flume-scale experiments." Water 14, no. 12 (2022): 1889.

[29] Pandey, Manish, Jaan H. Pu, Hanif Pourshahbaz, and Mohammad Amir Khan. "Reduction of scour around circular piers using collars." Journal of Flood Risk Management 15, no. 3 (2022): e12812.

[30] Hasan, Mohd Sayeed Ul, Abhishek Kumar Rai, Zeesam Ahmad, Faisal M. Alfaisal, Mohammad Amir Khan, Shamshad Alam, and Mehebub Sahana. "Hydrometeorological

consequences on the water balance in the ganga river system under changing climatic conditions using land surface model." Journal of King Saud University-Science 34, no. 5 (2022): 102065.

[31] Deb, Plaban, Barnali Debnath, Murtaza Hasan, Ali S. Alqarni, Abdulaziz Alaskar, Abdullah H. Alsabhan, Mohammad Amir Khan, Shamshad Alam, and Khalid S. Hashim. "Development of eco-friendly concrete mix using recycled aggregates: Structural performance and pore feature study using image analysis." Materials 15, no. 8 (2022): 2953.

[32] Kumar, Arun, Parveen Berwal, Abdullah I. Al-Mansour, Mohammad Amir Khan, Shamshad Alam, Seongkwan Mark Lee, Akash Malik, and Amjad Iqbal. "Impact of Crumb Rubber Concentration and Plastic Coated Aggregates on the Rheological Performance of Modified Bitumen Asphalt." Sustainability 14, no. 7 (2022): 3907.

[33] Qamar, Mohd Obaid, Izharul Haq Farooqi, Faris M. Munshi, Abdullah H. Alsabhan, Mohab Amin Kamal, Mohd Amir Khan, and Aisha Saleh Alwadai. "Performance of full-scale slaughterhouse effluent treatment plant (SETP)." Journal of King Saud University-Science 34, no. 3 (2022): 101891.

[34] Khan, Mohammad Amir, Nayan Sharma, Jaan H. Pu, Faisal M. Alfaisal, Shamshad Alam, Rishav Garg, and Mohammad Obaid Qamar. "Mid-Channel Braid-Bar-Induced Turbulent Bursts: Analysis Using Octant Events Approach." Water 14, no. 3 (2022): 450.

[35] Hasan, Murtaza, Mehboob Anwer Khan, Abdullah H. Alsabhan, Abdullah A. Almajid, Shamshad Alam, Mohammad Amir Khan, Tinku Biswas, and Jaan Pu. "Geotechnical Behaviour of Fly Ash–Bentonite Used in Layers." Applied Sciences 12, no. 3 (2022): 1421.

[36] Khan, Md Amir, Nayan Sharma, Jaan Pu, Faisal M. Alfaisal, Shamshad Alam, and Wahaj Ahmad Khan. "Analysis of Turbulent Flow Structure with Its Fluvial Processes around Mid-Channel Bar." Sustainability 14, no. 1 (2021): 392.

[37] Khan, Md Amir, Nayan Sharma, and Jacob Odgaard. "Experimental and Numerical Studies of Velocity and Turbulence Intensities for Mid-Channel Bar." Water Resources 48 (2021): 746-762.

[38] Khan, Mohammad Amir, Nayan Sharma, Jaan Pu, Mohammad Aamir, and Manish Pandey. "Two-dimensional turbulent burst examination and angle ratio utilization to detect scouring/sedimentation around mid-channel bar." Acta Geophysica 69, no. 4 (2021): 1335-1348.

[39] Khan, Md Amir, Nayan Sharma, Jaan H. Pu, Manish Pandey, and Hazi Azamathulla. "Experimental observation of turbulent structure at region surrounding the mid-channel braid bar." Marine Georesources & Geotechnology 40, no. 4 (2022): 448-461.

[40] Pandey, Manish, Mohammad Zakwan, Mohammad Amir Khan, and Swati Bhave. "Development of scour around a circular pier and its modelling using genetic algorithm." Water Supply 20, no. 8 (2020): 3358-3367.

[41] Amir Khan, Md, Nayan Sharma, Manish Pandey, and Obaid Qamar. "Turbulent characteristics of flow in the vicinity of mid-channel braid bar." Canadian Journal of Civil Engineering 48, no. 7 (2021): 879-887.

[42] Amir Khan, Md, and Nayan Sharma. "Study of bursting events and effect of hole-size on turbulent bursts triggered by the fluid and mid-channel bar interaction." Water Supply 20, no. 6 (2020): 2428-2439.

[43] Khan, Mohd Amir, and Nayan Sharma. "Investigation of coherent flow turbulence in the proximity of mid-channel bar." KSCE Journal of Civil Engineering 23 (2019): 5098-5108.

[44] Pandey, Manish, Wei Haur Lam, Yonggang Cui, Mohammad Amir Khan, Umesh Kumar Singh, and Zulfequar Ahmad. "Scour around spur dike in sand–gravel mixture bed." Water 11, no. 7 (2019): 1417.

[45] Khan, Md Amir, and Nayan Sharma. "Turbulence study around bar in a braided river model." Water Resources 46 (2019): 353-366.

[46] Khan, Md Amir, and Nayan Sharma. "Study of depth-wise profiles of velocity and turbulence parameters in the proximity of mid-channel bar." ISH Journal of Hydraulic Engineering 27, no. sup1 (2021): 1-10.

[47] Khan, Md Amir, and Nayan Sharma. "Analysis of turbulent flow characteristics around bar using the conditional bursting technique for varying discharge conditions." KSCE Journal of Civil Engineering 22, no. 7 (2018): 2315-2324.

[48] Khan, Md Amir, and Nayan Sharma. "Study of turbulent characteristics of flow around island in a braided river model using quadrant technique." ISH Journal of Hydraulic Engineering 24, no. 1 (2018): 1-8.

[49] Khan, Md Amir, Nayan Sharma, and Gopal Das Singhal. "Experimental study on bursting events around a bar in physical model of a braided channel." ISH Journal of Hydraulic Engineering 23, no. 1 (2017): 63-70.

[50] Parveen Berwal, Ajay Bansal " Experimental Study on Strength Characteristics of Concrete Mix in 28 Days by Using Polyester Fibre with Super plasticizer" International Journal of Enhanced Research in Science, Technology & Engineering, ISSN: 2319-7463, Vol. 5 Issue 8, August-2016

[51] Parveen Berwal, Amit " An Accidental Study and Safety Measures of Hisar-Rohtak National Highway" Imperial Journal of Interdisciplinary Research (IJIR) Vol-2, Issue- 10, 2016,ISSN : 2454 -1362.

[52] Parveen Berwal, Sandeep Dalaal "Study the Strength Characteristics of Concrete using Waste Material" International Journal of Engineering, Applied and Management Sciences Paradigms, Vol. 39, Issue 01, Publishing Month: September 2016 , An Indexed and Referred Journal ISSN (Online): 2320-6608

[53] Parveen Berwal, Sombir "A Laboratory Study on Use of Waste Glass Powder as Partial Replacement of Cement in Concrete Production" International Journal of Advanced Research, Idea and Innovation in Technology, ISSN: 2454-132X, (Volume3, Issue1) 2017.