Journal of Scientific and Technical Research
11 (2) December 2021, 09-16
http://www.publishingindia.com/jstr

Design and Optimization of Irrigation Water Distribution System in Northern Nigeria

Mohammed Rabiu Musa, Muhammad Isa Abdurrahman and Gaurav Saini*
Department of Civil Engineering, School of Engineering and Technology, Sharda University,
Greater Noida, Uttar Pradesh, India
*Corresponding Author: gaurav.saini@sharda.ac.in

Abstract: Most farmers in Northern Nigeria rely on conventional irrigation channels to transfer water from rivers, dams, lakes, or streams to their respective farmlands for irrigation. However, this method of water distribution is not without problems; seepage, evaporation, and transpiration are difficult to prevent, construction and maintenance of these channels take a significant amount of time, and maintaining a steady fall is relatively difficult. In general, the channel distribution system is much less efficient than a system based on pipes. Nonetheless, pipes are relatively expensive and often inaccessible for the riparian and other small-scale farmers in Northern Nigeria. This study aims to propose an alternative water distribution approach that will minimize water loss and deliver the water at a higher level using new (less expensive and readily available) material, which has been used to line water channels. After assessing different materials, a distribution system with a plastic envelope suspended from a taut wire was used, making it possible to accept water at a position, about 2 m, above ground level, and carry it over appropriate distances at minimum fall rates without losses. A means of discharging water from the envelope and distributing it over a cropped area was also developed, thus rendering the system resistant to problems associated with flooding of small basins.

Keywords: Nigeria, Riparian, Seepage, Shadouf, Water channel, Water loss.

I. INTRODUCTION

The traditional distribution channels, used in conjunction with the shadouf, have the major advantage of not requiring anything other than labor to construct them. They are generally made as close to a contour line as possible [1]. These channels also have disadvantages; construction and maintenance take up considerable time, and it is also difficult to ensure that the channels have a steady fall. In general, the distance covered by these systems is not as great as if pipes had been used and, unlike pipes, they do not deliver as much water as they receive [2]. Seepage and, to a lesser degree, evaporation and transpiration losses occur that are difficult to prevent (Mila, 2010). Seepage refers to water movement in or out of earthen irrigation channels through pores in the bed, and bank material has been identified as a seepage in irrigated agriculture. There are several factors influencing channel seepage; soil texture in the channel bed and banks, changes in water temperature, siltation conditions, changes in bank storage, soil chemicals, water velocity, microbiological activity, adjacent field irrigation, and variations in water [3].

Another inevitable consequence of this traditional distribution system is that water arrives at its destination at more-or-less ground level, so the only possibility is for either flood or furrow irrigation; the one exception is when water is deposited in a sump and then, in a separate operation, taken out with a watering can [4]. In some situations, the channel near the shadouf may be formed on top of a rounded ridge. This is done to extend the length of the channel and hence the area to be irrigated. At the start of the channel, where the calabash is emptied, it is usual to line the sides of the channel for the first two or three meters of the slope to prevent erosion and to slope it slightly to prevent water spilling back into the source [5].

The rate of water losses will depend not only on the soil, but also on factors such as temperature, wind speed, humidity and the age and type of vegetation surrounding the channels [3] [6]. In small channels, it has been estimated that evaporation losses are low, often less than 1%, a level that gives little cause for concern [7]. In contrast, the losses through seepage and transpiration can be considerable; up to about 50-70% losses [8]. These levels are so high they are almost unbelievable, but it must be accepted that under certain circumstances they can occur.

The same sources of loss are encountered in large distribution channels, and if flows are high, concrete, stone or some other lining materials will be required to prevent erosion and also reduce seepage [9] [10]. A study on soil infiltration rates of some 40 sites in North Carolina, United States found an average infiltration rate of about 5 cm/hr [11]. They inferred that soils with such rates of infiltration have moderately high infiltration levels and that distribution channels should be lined if plants are to be irrigated via channels. A study compared different lining materials and concluded that clay lining coupled with compacted channel bed provides the best anti-seepage performance, followed by compacted channel bed only, then pebble and concrete lining [12]. Another study investigated the infiltration rates of unlined channels and channels lined with a mixture of clay and bentonite in Nigeria [13]. They found that about 83% of irrigation water could be saved if channels are lined with the combination of clay and bentonite. Another research group conducted the same study in India using low density polyethylene (LPDE), overlaid with 15 cm soil cover, as the lining material [14]. They recorded infiltration rates of 0.011 cm/hr and 3.28 cm/hr for the lined and unlined channels, respectively, thus saving more than 99% of the irrigation water which would have been lost through seepage.

If a riparian farmer were to install a single bucket lifter to simply replace his shadouf and deliver at the shadouf level, the farmer would have the potential to lift water at an increased rate. Alternatively, the farmer could lift it to a higher level at a reduced rate. A higher discharge point would enable him to adopt a different distribution system since it is usually not possible to make channels that are raised substantially above ground level. Such a change would have the potential to send the water further than a system based on conventional channels: an investigation of the possible alternatives was indicated.

To cope with this higher discharge point, the first option considered was, of course, the use of the many types of pipe available - various plastics, rubber, fabrics, steel, asbestos and lead have all been used. Unfortunately, the cost of these materials tends to put them out of reach of riparian farmers [15]. One drawback with pipes, other than the lay-flat types, is that they are bulky to transport to remote areas; the lay-flats, unfortunately, tend to be rather expensive because they are fabric reinforced and they are only suitable for conveying water under pressure, otherwise they tend to stay collapsed.

Due to the limited available water supply and ever-increasing demand for water, appropriate design and construction of conveyance systems are important to reduce infiltration. Not only is seepage a waste of water, but it can also contribute to other issues, such as waterlogging and agricultural land salinization.

This work aims to examine the application of new materials, with the view to replacing pipes. Intuitively, the starting point for a developing country is polythene sheet, a relatively cheap and readily available material; which has been used to line water channels, although less satisfactorily than when the more expensive butyl rubber is used [14]. Water is also known to move freely through the subsoil, as was shown by the fact that the five wells maintained their level during the lifting tests carried out by [16] in the same area, so it was thought that it would be worthwhile to conduct seepage tests in the study area.

II. STUDY AREA

A. Geographical Location

Nigeria is one of the largest countries in Africa. It comprises an area of about 923,768 Km^2 and is situated in the tropics between latitudes 4° and 14° north of the equator [15]. Nigeria's neighbours are, in the north, the Republic of Niger, in the north-east, the Chad Republic, in the east, the Republic of Cameroon and the Peoples Republic of Benin in the west (Fig. 1). The country is divided into three unequal parts by the rivers Benue and Niger, the Benue flowing from the east and the Niger from the north-west. The rivers meet at Lokoja near the federal capital of Nigeria, Abuja, and then flow south into the Atlantic Ocean (see Fig. 1).

Fig. 1: Political Map of Nigeria

Three sites were chosen, at distances of 30,300 and 600 m from the Kano River and investigations were done at each site.The Kano River basin, like most areas in Northern Nigeria, lies on the Precambrian basement complex [17] generally known as the basement complex. To the north-east of the old Kano State, now Kano and Jigawa States, is a continuous hydrological boundary separating this formation from the Chad formation, the latter being covered by a thick succession of sedimentary rocks. The north-west part of this boundary in the State runs from longitude 8° 30 E to longitude 10° 00 E at its south-eastern extremity [17]. The basin is roughly rectangular in shape and it all lies in the western part of the Lake Chad basin. The basin was estimated to cover 7770 km^2, to be 152 km long and 56 km wide. The Kano River joins the Challawa river to form the Hadejia river near Tamburawa village, which is about 20 km from Kano City [18].

The terrain through which the Kano River flows is generally higher than that found in the south of the country, the altitude varying from 300 - 1500 m. It rises in the Jos plateau, which is centrally situated in Nigeria and which has extensive plains and broad valleys [19]. This plateau and the high ground around its north-west edge form the escarpment of the Kano River. The

Kano River scheme draws its water supply from the Tiga dam by gravity, through an 18 km long main channel. It is currently one of the largest schemes not only in Nigeria but in the whole of West Africa [20].

B. Climatic Condition

Nigeria has a typical tropical climate which is characterized by dry and wet seasons. The dominant factor influencing the climate is the presence of two air masses - the tropical continental air mass and the equatorial maritime air mass. The latter is characterized by south-westerly winds associated with cool and moist monsoon winds from the Atlantic [21]. The tropical continental air mass, on the other hand, produces dry north-easterly winds and these are associated with the dusty harmattan from the Sahara Desert [22].

The boundary between these two air masses is known as the inter-tropical front or inter-tropical convergence zone (ITCZ) and it runs approximately from east to west. The retreat of the ITCZ to the north during the summer months, under the influence of a low pressure zone over the Sahara desert, allows the maritime air mass to enter the area and this marks the beginning of the rainy season. At the end of this season, the southward movement of the boundary occurs and once more the continental air mass from the Sahara is brought back into the area; this marks the onset of hotter, less humid conditions [21].

As a result of climatic differences between the north and south, there is a large corresponding variation in vegetation in the country [22]. The tropical, humid south, with its natural forests, supports trees such as cocoa, rubber, coffee and a variety of long growing seasonal plants like cocoyam and cowpea. In contrast, parts of extreme north are desert but the bulk is savanna of one type or another.

Northern Nigeria has high temperatures, low humidity and long periods of uninterrupted sunshine, reduced only by the cloud cover (normally from mid July to September) and the dust from the Sahara during the harmattan which reduces the duration of the sunlight and its brightness of the sunshine to 75-80% of the maximum possible [23] El Niño. The combined effect of these factors is that water evaporation rates are particularly high throughout the region [22].

III. METHODOLOGY

A. Infiltration Rates Determination

A double ring infiltrometer was used for initial investigations. The inner cylinder of the set was 30 cm in diameter and had a scale attached, the outer one was 40 cm in diameter and they were used in the method detailed by [24]. Essentially the process involved pressing the cylinders firmly into the ground and then, while maintaining a depth of water in the annular space between the two cylinders of 6 cm, determining the rate at which water had to be added to the inner area to maintain a similar depth of water cover. The purpose of the outer ring is to provide a zone which minimizes the lateral spread of water below the inner ring.

Water was added to the inner area in amounts of 1 liter at a time dictated by the level indicated on the scale. The frequency of these additions was being recorded: when the intervals became more or less constant the determination was complete.

B. Wire Load-Carrying Capacity Determination

There is a scarcity of information on the behavior and load-carrying capacity of taut wires, so it was necessary to set up an experimental rig to measure the influence of factors such as wire tension, gradient and the distance between supports on sag, at flow rates that could be achieved by the single bucket lifter operated under ideal conditions. The aim was to produce a system with as few supports as possible, with thin (therefore cheap) wire and with the minimum gradient.

The first step taken was to fix a horizontal 12 gauge galvanized mild steel (GMS) wire, supported at 6 m centers and tensioned by hanging 1, 2 or 3 steel weights (27 kg each) on it, and to attach to it a 500-gauge x 40 cm wide polythene envelope, sealed at both ends, which was then progressively filled with water. The arrangement is as shown in Fig. 2, the aims being to decide whether clothes pegs could be used to fasten the film to the wire, to measure the sag at different loads and to gain some indication on the required spacing of the supports.

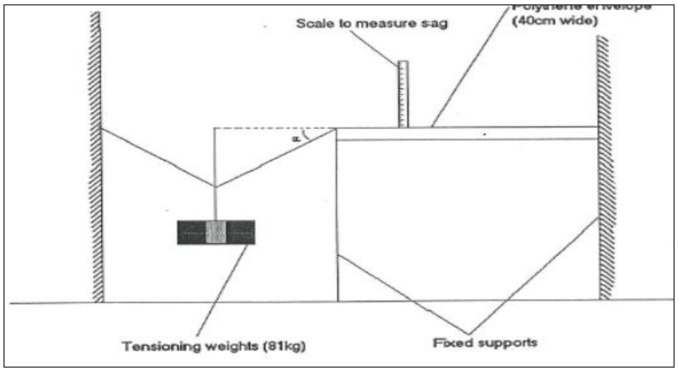

Fig. 2: I2 g GMS Wire Tensioned by Hanging on the Three Weights

C. Distribution Experiments to Determine Tension/Sag/Flow

A calibrated diaphragm load cell was then acquired to enable further tension/sag/flow experiments to be conducted, where an improved rig was set up in the workshop. The wire was attached at one end to a fixed point, using the technique described for the tensile tests. The height of the anchor point at the other end could be varied to achieve a predetermined gradient, with the load cell mounted in line. The required wire tension (not to exceed 2 kN) was set by tightening or loosening a nut on a threaded tensioning bolt.

The load cell and its meter can be seen in Fig. 3, together with the water tank and valve which gave a discharge rate of approximately 1.8 ls^{-1} when fully opened. During a test, previously drawn buckets of water were continuously tipped into the tank to give a run of over 1-minute duration; this provided ample time in which to take the necessary readings.

Fig. 3: The Load Cell and its Meter Together with the Water Supply Tank, Showing the Discharge Valve and Delivery Pipe

D. Discharge Hole in the Envelope

Before taking the rig out into the field, consideration was given to methods of releasing the water from the system. It could obviously be allowed to run out of the end of the envelope; but for convenience, some rapid method by which it could be taken out through an aperture and then the aperture be closed was required. It was thought that to have a complete break in the envelope which could then be joined would not be satisfactory so a different approach was tried. This involved cutting a 20 mm circular hole in the base of envelope through which was threaded string; the string passed through a 25 mm polystyrene sphere and round a stone weight (approximately 50 g) as shown in Fig. 4. Pulling the string upwards allowed water to pass through the uncovered hole.

It was thought that several of these holes would be required to let the flow out; this arrangement worked reasonably well but it leaked slightly. In the next step, the balls were replaced by a "sausage" - a sand-filled polythene sleeve (38 mm diameter, 2 m long) to which two strings were attached.

At this time straight pins were used instead of pegs to fasten the envelope to the wire. The former was considerably cheaper than the pegs but soon rusted (stainless steel ones would be a better alternative) but yet another device was also tried which promised to be better than either of the others. This was a plastic kwiklok bag closure clip of the type used to close plastic bags containing sliced bread or sandwiches. Unfortunately, it was not possible to obtain supplies of these, so the remaining work was done using stainless steel pins.

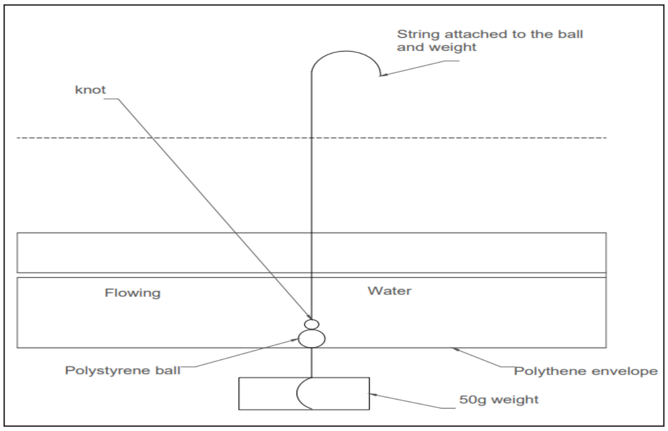

Fig. 4: The First Attempt to Make A System of Closing a Discharge Hole in the Envelope

It was then considered time to move into the field to get practical experience of supports and other features of the system, bearing in mind the materials available in the study area. At the lower end, the wire was tied round a tree, whilst at the water supply end it passed round a short length of timber held behind twin stayed posts (Fig. 5).

Fig. 5: The First Field Distribution Rig

Also shown in these Figures are the tensioning weights, the water supply tank and the envelope, pinned to wire which itself is supported by polypropylene twine tied around a grooved horizontal bar nailed to the tops of two slim vertical wooden posts. Levels were set up using an open hose pipe filled with water, then it was an easy process to adjust the twine length to give a steady fall.

Later, when the water lifter had been developed, an elevated tensioned wire was required, in this case, the supports were provided by wooden fencing posts, driven firmly into the ground, to which were nailed two pieces of timber (Fig. 6).

In another location, a 50 m run of envelope was supported by slinging the wire from light horizontal timber supports nailed to the uprights of a field fence.

Fig. 6: The Polythene Envelope Directly Joined to the Single Bucket Lifter: Water Can be Seen Flowing Out of the End of the Envelope

E. Direction-Changing Device

A device was constructed which provides an opportunity for changing the direction of water flow when needed. In a pipe-based system, tee-pieces can be used, but no such fittings are available for envelopes, so steps were taken to make one in such a way that copies could be made in the study area. The device was cast in concrete; it measured 31 cm x 31 cm x 23 cm and cast into its upper surface was a plastic plant pot (13 cm diameter, 15 cm deep), the base of which coincided with the ends of four 6 cm diameter plastic pipes cast diagonally in the block. It can be seen that elastoplast was wrapped around the pipes to provide a grip to which the envelopes could be tied by twine. Grooves were also cast into the top of the block to locate the wires and into two sides of the block to fit round fencing posts; the block rested on two pieces of timber nailed to the posts as shown (Fig. 7).

Fig. 7: The Block Supported by the Two Pieces of Timber Nailed to the Posts

IV. Results and Discussion

A. Infiltration Tests

The raw data of the soil infiltration tests for the three sites was used to calculate infiltration rates during the determination and the parameters and regression co-efficient for both the Kostiakov and Phillips equations. The mean final infiltration rates were 8.79 cm hr^{-1} at the site closest to the river, 19.09 cm hr^{-1} at site 2 and, furthest from the river, 4.65 cm hr^{-1}. These values are higher than the optimal rates of infiltration which is between 0.7 to 3.5 cm hr^{-1} for Nigerian soils (Oruk *et al.,* 2011). Even though it is not realistic to compare large and small channels, nevertheless the test results indicate that the topsoil in the sample area tends to be extremely permeable. The results of the final infiltration rates are presented in Table I.

Table I: Final Infiltration Rates (cm hr^{-1})

Location	*Site 1*	*Site 2*	*Site 3*
1	11.32	17.56	4.53
2	8.37	16.17	4.70
3	7.19	23.54	4.78
Mean	8.79	19.09	4.65
Standard Deviation	2.18	5.33	0.06
Coefficient of variation of mean	24.3%	28.8%	1.3%

If one takes a channel length of 40 m, at the highest measurement of soil permeability (19.09 cm hr^{-1}), and assumes a channel width of 0.25 m, then the wetted area of channel is 10 m^2 and the seepage loss will be 1.91 m^3 hr^{-1}. When compared with the rate of water lifted by the five shadoufs used in this area in the study undertaken by Musa *et al.* (2020), this seepage rate amounts to between 26% and 41% of the amount lifted. This can be regarded as a 'worst case' scenario; however, if one takes a shorter channel, say 20 m, on the least permeable soil, the comparable losses are 23 m^3 hr^{-1} - some 3% and 5% of the amounts lifted by the highest and lowest output shadoufs.

In some soils, it might be possible to reduce seepage by consolidating, or even puddlingthe soil through which the channels are made, but the soils in the study area are, almost without exception, of a type that do not lend themselves to this kind of treatment. Lining with a waterproof film might also be considered, but as far as is known this is not a common practice, although it might be done if the level of seepage losses was appreciated by those who lift the water.

One practice that is quite common is to grow perennial crops along the edges of the main channels, which in fact run in the same path year after year [5]. In this way some benefit may be obtained from the water which would otherwise be wasted.

B. Determination of Wire Load-Carrying Capacity

In each run, water was introduced in 0.5 liters amounts into the centre of the envelope; the first run used one 27 kg tensioning weight, the second two and the third all three weights. The results are as shown in Table II.

TABLE II: THE EFFECTS OF WATER LOAD ON WIRE SAG AT THREE LEVELS OF WIRE TENSION

Water Added (Liters)	*Sags (cm)*		
	1 Weight	*2 Weight*	*3 Weight*
0	2.5	1.9	1.5
0.5	4.5,	2.5	2.1
1.0	6.5	3.5	2.8
1.5	8.5	5.0	3.0
2.0	11.5	6.0	4.0
2.5	12.5	7.0	5.0
3.0	14.5	8.0	5.5
3.5	16.5	9.0	6.0
4.0	17.0	10.0	6.5
4.5	18.5	**	7.5
5.0	**		8.3
			***

** Pegs holding envelope slipped, water discharged.
*** And the water started to run out of ends of envelope.

The actual wire tension was not determined, although it could have been calculated had the angle of the wire to the horizontal in the weight-supporting section been measured. e.g. when x = 20° the tension would be 0.387, 0.774 and 1.16 KN with 1, 2 and 3 weights, respectively.

C. Ultimate Tensile Strength Determination

This preliminary run emphasized the key role of the wire's initial tension and so steps were taken to obtain different types of wire and to determine their ultimate tensile strength (UTS). Samples of 2.50 mm and 3.13 mm diameter (12 and 10 gauge) GMS and 3.13 mm diameter high tensile steel (HTS) wire were used.

The tensile tests were carried out on an Instron 1195 machine. The main problem was to devise a means of clamping the sample without damaging it - this was done by wrapping it four times around a circular member before it reached the clamping point. The ultimate tensile strengths for the 10 gauge, 12 gauge and the HTS wires were determined to be 441.86, 473.20 and 1196.8 KN/m^2, respectively.

As expected, the UTS value for the HTS wire was more than twice that for the GMS; unfortunately, the yield points, which are probably more relevant to the application than UTS, were not distinct, but there was some indication that they occurred at approximately 80% of the failure load (FL). The corresponding failure loads were found to be 3.4, 3.4 and 9.2 KN for the 10 gauge, 12 gauge and the HTS wires.

Although the HTS wire was examined, it was not the intention to use it unless the other two wires were completely inadequate, because the former is difficult to work with and it could not be guaranteed to be available in the study area.

D. Distribution System Experiments

Distribution System Experiment 1: In this experiment 12-gauge wire was used, a gradient of 1 in 140 imposed, flow rate was 1.8 l/s and support spacing was either 3 or 4 m. The results are shown in Table III.

TABLE III: OUTCOME OF THE DISTRIBUTION SYSTEM EXPERIMENT

	Support Spacing	
Wire Tension (KN)	3 m	4 m
1.2	Satisfactory	1.2
1.5	Satisfactory	1.5
1.8	Wire Stretched	1.8

The flow rate chosen for this experiment (1.8 ls^{-1}) was somewhat higher than that established with the single bucket lifter in the field of Sutton Bonington. This was a deliberate move because it was thought that with a lower lift than that used in the field (4.3 m), the extraction rate would increase, in fact in the Garu Study area the rate sometimes exceeded 2 ls^{-1}. It was clear from this experiment that wire of the size used was only marginally capable of meeting the required duty, and that supports every 3 m or closer would be required, so it was decided to carry out a similar experiment using a heavier duty wire.

Distribution System Experiment 2: This was again carried out in the workshop and it used l0 gauge wire which was more highly tensioned. The 1:140 gradient was retained and three distances between supports were used. The results are summarized in Table IV.

TABLE IV: OUTCOME OF THE SECOND DISTRIBUTION SYSTEM EXPERIMENT

Wire Tension (KN)	*3 m*	*4 m*	*5 m*
1.8	√	√	X
	√	√	
2.1	√	√	X
	√	√	
2.4	√	√	**XX**

√:Satisfactory; X: Envelope overfull; XX: Envelope overfull and wire stretched

Distribution System Experiment 3: Following the 2nd experiment, it was decided that the 5 m spacing was too wide, so 3 and 4 m spacing were tried at a lower gradient (1 in 280). The results of this experiment (Experiment 3) are summarized in Table V.

Table V: Outcome of the Third Distribution System Experiment

Wire Tension (KN)	*3 m*	*4 m*
1.8	√	√ X
2.1	√	√
2.4	√	√

From this experiment it can be seen that at a tension well below the yield point of the wire and supports 4 m apart, the envelope was able to carry water at the required rate with an acceptable amount of sag and without the envelope tearing.

E. Direction Changing Device

A limitation of using a taut wire to carry the water-conveying material is that it can only run in a straight line, unless a substantial support, capable of resisting side forces is installed wherever a change of direction is required. The direction-changing device constructed provided a means of changing the direction of water when required. The pipes provided the means of attaching the polythene envelopes to the device.

F. Distribution After the Envelope

A feature of this approach to water distribution, which the shadouf - based system does not have, is that the water may arrive at the place where it is to be used above ground level. This then opens up the possibility of a more sophisticated distribution system than flooding, and this could lead to more accurate distribution of water within a basin. It could also mean that much larger basins might be used which itself could be of some benefit to the farmers; it might even be possible to dispense with basins altogether [26].

Fig. 8: The Flow Splitter Discharging Water at the Brook

It was thought that relatively few runs of envelope would be required, then some means of taking water to individual basins would be needed. This could be by earth channels, but then some of the above benefits would be forfeited, so some means of transferring the water from the envelope to a pipe or portable channel was sought. This might then terminate by feeding the water into a pipe/flow splitter device (of the type shown under test in Fig. 8), making it possible to distribute water to various points in the crops. The best solution produced for transferring the water from the envelope to a pipe involved the use of one quarter of an old car tyre mounted on a small wooden stand; the tyre acted as a catching trough and it was fitted with a 50 mm diameter steel outlet pipe forced into a hole cut in the tyre wall.

V. Conclusion

The minimization of losses through seepage and evaporation from wetted soil surfaces is an area that has great potential in terms of saving water. Pipes, or even envelopes, could reduce seepage, but possibly a greater contribution could be made by changing the application method from one that is based on flooding basins. An examination of the infiltration rate of the soil in the sample area showed that it was high, which suggests that water loss during distribution to the cropped area can be significant. The high cost of pipe in the area prompted the development of an alternative means of distribution, consisting of a plastic film envelope suspended from a taut wire; with this it is possible to accept water at a position two metres or so above ground level and carry it over appropriate distances at minimal rates of fall without loss. Means of discharging water from the envelope and distributing it over a cropped area were also developed, making it possible to avoid some of the utilization problems associated with the flooding of small basins.

Water is precious in the area, therefore there is need for effective control of the amount of water utilized for both irrigation and human consumption. Although modest amounts of money have been invested in irrigation research and advice, and in training farmers in good water management, much more effort is required and additional technical and financial resources need to be made available to improve the efficiency with which water is used to grow high quality crops.

References

[1] R. H. Y. Fu, S. S. Abe, T. Wakatsuki, and M. Maruyama, “Traditional farmer-managed irrigation system in Central Nigeria,” *Jpn. Agric. Res. Q. JARQ*, vol. 44, pp. 53-60, 2010, doi: https://doi.org/10.6090/jarq.44.53.

[2] T. Saeed, “Impact of water losses and maintenance of canal irrigation system on agriculture (Case study: Urmar minor of Warsak Gravity Canal Pakistan),” *Am. J. Exp. Agric.*, vol. 4, pp. 550-562, 2014, doi: https://doi.org/10.9734/AJEA/2014/6352.

[3] Z. Iqbal, R. T. MacLean, B. D. Taylor, F. J. Hecker, and D. R. Bennett, “Seepage losses from irrigation canals in Southern Alberta,” *Can. Biosyst. Eng. / Le Genie des Biosyst. au Canada,* vol. 44, no. 1, pp. 21-27, 2002.

[4] J. A. Burney, R. L. Naylor, and S. L. Postel, “The case for distributed irrigation as a development priority in Sub-Saharan Africa,” *Proc. Natl. Acad. Sci.*, vol. 110, no. 31,

pp. 12513-12517, 2013, doi: https://doi.org/10.1073/pnas.1203597110.

[5] A. N. Angelakis, D. Zaccaria, J. Krasilnikoff, M. Salgot, M. Bazza, ……. and E. Fereres, "Irrigation of world agricultural lands: Evolution through the Millennia," *Water (Switzerland)*, vol. 12, no. 5, 2020, doi: https://doi.org/10.3390/w12051285.

[6] M. A. Kahlown, and W. D. Kemper, "Seepage losses as affected by condition and composition of channel banks," *Agric. Water Manag.*, vol. 65, no. 2, pp. 145-153, 2004, doi: https://doi.org/10.1016/j.agwat.2003.07.006.

[7] P. K. Swamee, G. C. Mishra, and B. R. Chahar, "Design of minimum water-loss canal sections," *J. Hydraul. Res.*, vol. 40, pp. 215-220, 2002, doi: https://doi.org/10.1080/00221680209499864.

[8] K. D. Uchdadiya, and J. N. Patel, "Seepage losses through unlined and lined canals," *International Journal of Advances in Applied Mathematics and Mechanics*, vol. 2, no. 2, pp. 88-91, 2014.

[9] Z. Shah, H. Gabriel, S. Haider, and T. Jafri, "Analysis of seepage loss from concrete lined irrigation canals in Punjab, Pakistan," *Irrig. Drain.*, vol. 69, no. 4, pp. 668-681, 2020, doi: https://doi.org/10.1002/ird.2474.

[10] B. Saha, "A critical study of water loss in canals and its reduction measures," *International Journal of Engineering Research and Applications*, vol. 5, no. 3, pp. 53-56, 2015. [Online]. Available: www.ijera.com

[11] E. Z. Bean, W. F. Hunt, and D. A. Bidelspach, "Field survey of permeable pavement surface infiltration rates," *Journal of Irrigation and Drainage Engineering*, vol. 133, no. 3, pp. 249-255, 2007, doi: https://doi.org/10.1061/(ASCE)0733-9437(2007)133:3(249).

[12] L. Yao, S. Feng, X. Mao, Z. Huo, S. Kang, and D. A. Barry, "Coupled effects of canal lining and multi-layered soil structure on canal seepage and soil water dynamics," *J. Hydrol.*, vol. 430-431, pp. 91-102, 2012, doi: 10.1016/j.jhydrol.2012.02.004.

[13] I. Israel, I. Etim, and E. Etim, "Evaluation of seepage losses in an earth lined canal: A case study of University of Uyo Farm, Uyo, Nigeria," *International Journal of Engineering Sciences & Management Research*, vol. 2, no. 2, pp. 14-25, 2015.

[14] A. Kumar, and R. Singh, "Plastic lining for water storage structures," *Technical Bulletin*, 2010. [Online]. Available: http://www.dwm.res.in/pdf/bulletin_50.pdf

[15] I. B. Yamusa, Y. B. Yamusa, U. A. Danbatta, and T. Najime, "Geological and structural analysis using remote sensing for lineament and lithological mapping," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 169, no. 1, 2018, doi: https://doi.org/10.1088/1755-1315/169/1/012082.

[16] M. R. Musa, M. I. Abdurrahman, S. Arora, and G. Saini, "Design optimization of water lifting device in Kano, Nigeria," *International Journal of Advanced Research in Engineering and Technology*, vol. 11, no. 11, pp. 679-690, 2021, doi: 10.34218/IJARET.11.11.2020.065.

[17] A. K. Abdullahi, "An economic analysis of a settlement model for Fulani pastoralists in Sokoto state, Nigeria," PhD Thesis, School of Agriculture, University of Nottingham, Leicestershire, 1985. Accessed: Jun. 17, 2022. [Online]. Available: https://ottawariver.ca/terms-and-policies/

[18] M. T. Ahmad, and N. Haie, "Assessing the impacts of population growth and climate change on performance of water use systems and water allocation in Kano river basin, Nigeria," *Water (Switzerland)*, vol. 10, no. 12, p. 1766, 2018, doi: https://doi.org/10.3390/w10121766.

[19] S. Odunuga, and G. Badru, "Landcover change, land surface temperature, surface albedo and topography in the plateau region of North-Central Nigeria," *Land*, vol. 4, pp. 300-324, 2015, doi: https://doi.org/10.3390/land4020300.

[20] D. Sangari, "An evaluation of water and land uses in the Kano river project, phase I, Kano state," *J. Appl. Sci. Environ. Manag.*, vol. 11, 2010, doi: https://doi.org/10.4314/jasem.v11i2.55002.

[21] H. Haider, "Climate change in Nigeria: Impacts and responses," *K4D Help. Rep.,* pp. 1-38, 2019. [Online]. Available: http://www.rockfound.org/initiatives/climate/climate_change.shtml%0Awww.iied.org/HS/publications.html.%0AHOW%0Ahttps://assets.publishing.service.gov.uk/media/5dcd7a1aed915d0719bf4542/675_Climate_Change_in_Nigeria.pdf

[22] O. M. Eludoyin, and I. O. Adelekan, "The physiologic climate of Nigeria," *Int. J. Biometeorol.*, vol. 57, no. 2, pp. 241-264, 2013, doi: https://doi.org/10.1007/s00484-012-0549-3.

[23] O. R. Salau, A. Fasuba, K. A. Aduloju, G. E. Adesakin, and A. T. Fatigun, "Effects of changes in ENSO on seasonal mean temperature and rainfall in Nigeria," *Climate*, vol. 4, no. 1, pp. 1-12, 2016, doi: https://doi.org/10.3390/cli4010005.

[24] T. J. Marshall, and J. W. Holmes, Soil physics. Cambridge: Cambridge University Press. x + 345. *Educ. Psychol. Meas.*, vol. 28, no. 3, pp. 951-951, 1979, doi: 10.1177/001316446802800332.

[25] O. Egbai, U. Samuel, E. J. Ndik, U. Uquetan, and O. O. Francis, "Infiltration rate assessment of coastal plain (Ultisols) soils for sustainable crop production in the frontiers of Calabar-Nigeria," *Journal of Sustainable Development*, vol. 4, no. 4, pp. 222-229, 2011, doi: https://doi.org/10.5539/jsd.v4n4p222.

[26] G. P. Mengü, and E. Akkuzu, "Impact of irrigation management transfer on land and water productivity and water supply in the Gediz Basin, Turkey," *J. Irrig. Drain. Eng.*, vol. 136, no. 5, pp. 300-308, 2010, doi: https://doi.org/10.1061/(ASCE)IR.1943-4774.0000191.