EUROPEAN ACADEMIC RESEARCH
Vol. IV, Issue 11/ February 2017

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

ISSN 2286-4822
www.euacademic.org

The Effects of Inadequate Urban Drainage System on Pavement Performance in Ethiopia

KOKEB ZENA BESHA
Lecturer
Department of Civil Engineering
College of Engineering
Assosa University, South Western Ethiopia

Abstract:

In urban areas, networks of roads are constructed to support human and vehicular traffic. In complement, drainage facilities are provided to ensure timely disposal of surface water runoff generated from impermeable surfaces and surrounding areas. Inadequate drainage maintenance has a significant part on pavement performance. To keep the performance of the road pavement, it is important to provide adequate drainage system with a timely maintenance activity. For this reason, the main objective of this study was to investigate the impacts of poor drainage on urban road pavement performance. The descriptive cross-sectional study was done by selecting 200 respondents at the study area. The primary data was collected through interview, questionnaires survey and field observation, whereas the secondary data source was related literature reviews. The result of the investigation shows that most of the roads at the study area are highly suffered due to poor drainage infrastructure. The finding of study indicates that inadequate/absence of drainage system and poor maintenance are responsible for urban road pavement performance at the study area. The study suggest that upgrading urban drainage infrastructure service by preparing sustainable plan and feasibility study, improving existing drainage maintenance and effectively manage of existing drainage infrastructures can keep the road pavement in good performance.

Key words: Poor Drainage, Impacts of Drainage, Road Performance, Urban Road

1. INTRODUCTION

Water (as a runoff) has a number of unhelpful effects on road pavements when not controlled properly. Water entering a pavement structure migrates as moisture through the structure. The amount of water penetrating the pavement is dependent on rainfall, drainage, design of the road structure, type and condition of the surface layer (cracks, joints, etc) and shoulders and the materials in the pavement, sub-grade and subsoil. An excess of water can cause a lower bearing capacity of the pavement structure and reduces pavement service life. It has many adverse effects like reduction in shear strength, pumping of file particles, stripping of asphalt in flexible pavements, etc.

In the built up areas, networks of roads are constructed to support human and vehicular traffic. In complement, drainage facilities are provided to ensure timely disposal of sewage and surface water runoff generated from impermeable surfaces and surrounding areas. Poor drainage will reduce the life of the pavement and have serious environmental impacts if left unchecked. There are many approaches to reduce erosion of exposed surfaces associated with urban roads, such as side drains, and better slopes and maintenance of existing drains. Any road will readily concentrate runoff, so there is a need to design and construct roads to allow for frequent and safe discharge.

The conveyance of a drain is facilitated if the ground surface or its invert has sufficient slope. An area or drain invert is said to be sufficiently sloped where the grade is greater than 2% (J. A. van Dort and M. G. Bos, 1980). However due to municipal activities these drains may be blocked with refuse,

grit, yard or construction materials (C. O. Owuama, 2012). As reported by Rokade S.et.al. (2012) that water related damage to pavement can cause one or more of the following forms of deteriorations: a) reduction of base, sub base and sub grade strength, b) differential swelling in expansive sub-grade soils, c) stripping of asphalt in flexible pavements, d) frost heave and reduction of strength during frost melt, and e) movement of fine particles into base or sub base materials resulting in a reduction of the hydraulic conductivity considerably. The damage to the road can be reduced if the flow of water is controlled. Minor damages can easily be repaired as part of the regular maintenance provided to the road and its structures. If the flow of water is not properly managed, the deterioration of the road will be more serious and occur more rapidly. This will lead to higher maintenance demands and in the worst cases result in serious damage which may obstruct the traffic flow.

Poor drainage and road integration has also facilitated the flooding of urban areas. Dagnachew Adugna Belete (2011) reported that due to inadequate integration between road and urban storm water drainage infrastructure provision, many areas are exposed to flooding problems. In other words, urbanization and modernization in Ethiopia results in higher rainfall intensity and consequently accelerated and concentrated runoff in the urban areas.

In Ethiopia, the pattern of urbanization and modernization has meant increase densification along with urban infrastructure development. This has led to deforestation, use of corrugated roofs and paved surfaces (ibid). The combined effect of this results in higher rainfall intensity and consequently accelerated and concentrated runoff in the urban areas. Because of inadequate drainage, poor maintenance and lack of sufficient road profile, a significant part of the water accumulated on road pavement and causes pavement distress (Kokeb Zena Besha & Addisu Adamu Alemayehu, 2016). They stated that the surface water from the

carriageway and shoulder should not be drained off, and runoff water from the adjoining land easily enters to the roadway because of poor drainage provision.

In most towns of Ethiopia, side drains did not have sufficient capacity and longitudinal slopes to carry away all the surface water collected from the surrounding catchment areas. This improper drainage system causes the failure of road pavements by increase in moisture content, decrease in strength, mud pumping, formation of waves and corrugations, stripping of bitumen, cutting of edges of pavement and so on (Kokeb Zena Besha et.al., 2016).

The aim of this study is to evaluate the impacts of poor drainage on road pavement performance in Assosa town. To achieve our goals we conduct a thorough investigation on the road and drainage infrastructures of the town. The remainder of this paper is organized as follows: A brief description of the literature review gives as a clear background and gaps in the area followed by materials and methods. The next section of the paper gives us the detailed parts of result and discussion and finally, the conclusion and recommendations are given.

1.2. The Study Area

The study area is Assosa town, Ethiopia. It is the capital city of Benishangul Gumz Regional State. The study of poor drainage system is important to analyze its impacts on road performance, which is vitally important in terms of social and economic aspects. The total catchment area of the town is about 24km2. Assosa is a home of nearly 46,200 people (CSA, 2015). The population density of the town is estimated to be more than 1925 inhabitants per km2.

Figure 1: The Study Area (Google earth, 2016)

1.3. Study Objectives

The main objective of this paper was to investigate the impacts of inadequate drainage system on the performance of road pavement. The specific objectives derived from this are

- To assess the existing drainage channels at the study area
- To evaluate the impacts of poor drainage on road pavement performance
- To identify the causes of poor drainage system at the study area
- To suggest some mitigation measures

2. RELATED STUDIES

Urban storm water is a system both above and underground for carrying away storm water or waste water. Land drainage is the process of releasing running water through supply ditches allowing it to flow over land through supply ditches to furrows between blocks of land (Ndiwalana, R., 200). Raj Vir Singh, (1991) identified water logging as one of the causes of poor drainage. The causes of water logging are both natural and artificial. The natural causes include poor drainage of the sub-soil under favourable geological existence of hard pan below the surface, sub-mergence of land under floods and deep percolation from rainfall as well as the artificial causes are excessive seepage from unlined ditches and distributaries, hydraulic

pressure from upper saturated areas located at higher elevations, and poor maintenance of natural drainage or blocking of natural drainage by roads and railways. He further stated it that land drainage problems occur in flat areas of even land surface with depressions or ridges preventing natural runoff and in areas without any provision of outlet.

The increasing population concentrations associated with the urbanization process also resulted in increases in waste generation. Household wastewater was connected (disposed off in the nearest open channel) and in turn created problems of smell. As a result, the open channels constructed to alleviate flooding were covered creating combined sewer systems (Smission, R.P.M, 1980). In most developing countries, solid waste disposal is closely linked with urban wastewater drainage in that open sewers and drainage channels often end up also being receptacles for solid wastes generated in the community. This leads to blockages, reductions in capacity and an exacerbation of flooding problems (Ajayi, J.O.K, 1993).

World Bank Report as listed in (World Bank, 1996) indicated that poor drainage conditions in developing countries are a result of weak institutional capacity, inadequate regulatory policies, inadequate governance, and generally lack of public Education / awareness /participation. The resolution of problems associated with infrastructural provision in most developing countries currently follows along the traditions of the developed countries. Often, this is not appropriate for the locality. Urban drainage practice shows that in the past, the philosophy has been based on conveying peak flows of municipal waste water and storm runoff away from the urban areas as quickly as possible (Sonuga F, 1993). This has resulted in downstream flooding and heavy pollution of receiving waters. But it should not be forgotten that in some developing countries especially where the above mentioned qualities exist, still drainage problems especially those related to weather conditions do still occur (ibid). The problems of poor drainage

are adverse in developing countries. According to Clarence in many African countries sewage systems and disposal habits especially in urban areas rely upon storm water drainage and this is the major cause of health problems (Clarence, J. V, 1984). Raven Johnson (1993) points out that storm runoff quality is often worse off than that of sewerage. Storm runoff carries salts, oils, untreated garbage, construction sediments and traffic emissions through rain which washes pollutants out of the air. This normally contains asbestos, chloride, lead, organic wastes, sulphuric acid and zinc. The provision and management of urban drainage system is a challenging problem in most cities/towns of Ethiopia and the situation in Assosa town is not different from this (Kokeb Zena, 2016). There are also literatures which stated that poor drainage causes early pavement distresses lead to driving problems and structural failures of road. To prevent or minimize premature pavement failures and to enhance the road performance, it is imperative to provide adequate drainage (Magdi M.E, 2014).

3. RESEARCH METHODOLOGY

In this study, the required data was obtained from two sources which include: Primary and secondary sources.

A. Primary Sources

i) Interview: An in-depth interview was conducted in the field with the community. Oral questions were administered in the four kebeles of Assosa town namely, Assosa 01, 02, 03 and 04 to yield the information required on poor drainage impacts on road performance, effects and the proposed solutions to the problem.

ii) Administering of Questionnaires: The questionnaires designed respects the rights and anonymity of the respondents thereby ensuring confidentiality of the respondents.

A total of 200 questionnaires addressing the most likely causes, effect of water drainage challenges as well as environmental challenges relating to the improper utilization of the drainage systems in the chosen locations were distributed using stratified random sampling method to the four (4) kebeles of Assosa (50 each) and 100% recovery was recorded.

iii) Field Observations: For this study, pictures of different scenario as it relates to different drainage issues were taken to show the true state of things in the study area. Observations and discussion with residents were also made and recorded. This also gave an insight to the major challenges encountered within these areas of study.

B. Secondary Sources

Secondary sources of information that was used in the study include publications, journals, books, unpublished documents, conference proceedings etc.

Finally, data analysis began with editing data collected from the field. Data was analysed on the information about the respondents, existing drainage system in Assosa town, factors responsible for poor drainage and the effects of poor drainage. This is important, for it guaranteed accuracy and consistence which was vital for reasonable analysis. The numerical data generated was systematically assembled in tables because they offer orderly placement of data and subsequent computations.

4. RESULTS AND DISCUSSION

4.1 Existing Drainage Channel of the Town

Existing drainage channels in Assosa town are rectangular, circular and trapezoidal by shape. In addition to this, open,

semi-open and fully buried types of drainage channels were observed.

Table 1: Drainage dimensions and existing condition analysis summary

S/N	*Drainage Type*	*Average Length(m)*	*% in Good Condition*	*% in Fair Condition*	*% in Poor Condition*
1	Circular	18.1	9.2km (24%)	0.404km (1.1%)	8.5km (22.2%)
2	Rectangular	15.72	5.7km (14.9%)	2.7km (7.1%)	7.4km (19.3%)
3	Trapezoidal	4.3	4.3km (11.2%)	--	--
	Total	***38.3km***	***50.1%***	***8.2%***	***41.5%***

Source: *Primary data, 2016*

A. Circular/pipe Drains: According to the data of table 1, the total length of the circular drains is about 18.1km. Of this, 24% the circular drains are in good condition, 1.1% of them are in fair condition whereas about 22.2% of the circular drains are in poor condition.

B. Rectangular Shaped Drains: As per the data of table 1, the total length of rectangular drains is about 15.72km. Of this, 14.9% is in good condition, 7.1% is in fair condition and about 19.3% is in a poor condition.

C. Trapezoidal Drains: According to the data of table 1, the total length of trapezoidal shaped drains is around 4.3km. Of this, 11.2% is in good condition from the total drainage channel length.

During the field observation time, it is observed that all the circular drains are closed (buried) type, the rectangular drains are open and semi-open type and the trapezoidal drains are also open and semi-open to the environment. In general, considering the above table 50.1% of the drainage system is in good condition, about 8.2% is in fair condition that needs maintenance and 41.5% of the drainage system of the town is at a poor condition that needs rehabilitation.

4.2 Impacts of Poor Drainage on Road Pavement Performance

If not properly controlled water is a cancer for road pavements. Many pavement failures are the direct result of water entering the pavement courses and/or the sub-grade. Water entry in the compacted unsaturated material will increase water pressure or decrease suction, and in turn, reduce the effective stress. Hence, the strength and the elastic and plastic stiffnesses of the pavement material and the sub-grade will be reduced. The rate of traffic-induced deterioration of the road will increase during this time. Based on the field observation conducted from May to December 2016 at the study area, the following effects of poor drainage on pavement performance were identified:

Inadequate Drain Size: Most of the drains are with small cross section of about 0.4m width and not more than 1m depth. Such types of drains are incapable to discharge the storm water safely and cause street flooding during the rainy seasons rather over flowing. These challenges do not only retard storm water flow in the drain, but they also increase overflow and street flooding conditions.

Figure 2: inadequate drain size accompanied by water logging

***Mud Pumping*:** Water seeping through the pavement can also transport soil particles and cause erosion and mud pumping (i.e. transport) of fines as well as leaching of many materials. Moisture entry can also affect the performance of the surface course by causing stripping of bitumen from aggregate, layer separation between bound courses, and pothole formation.

Structural Failure: As a result of poor maintenance, workmanship, material quality and poor supervision, existing drains and its structures is collapsed before design life. This situation affects the road pavement by diverting the storm water and soil & sediments towards the road ways. Figure 3 shows a collapsed drain which is unable to perform its intended purpose. As we observed in this drain, weeds & grass are growing, sediments are accumulated.

Figure 3: Collapsed & vegetated concrete drains

The soils deposited in the drains provide substrate for the growth of vegetation which further restricts drainage down slope. Following the vegetal growth in the drain, debris collected by the road wash is wedged in it thereby compounding the flow situation.

Blocked Drains: in most areas of the town, the manholes and culverts are blocked with silt and sand accumulation. Culverts and manholes are converted to dumpy place and subsequently obstructed the storm water flow. In figure below (right), the cover of the manhole is submerged inside the hole & water flows over pavement which erodes the edge.

Figure 4: Failed manholes of side drain due to poor maintenance

In addition, the drain is often used as refuse disposal channel by residents, creating very poor sanitary condition. It was observed that the side drains were full of dirty water and refuse dumps. The inlets on the curb were blocked with soil & silt accumulation as shown in figure 5. No regular maintenance for the drains was observed throughout the year.

Figure 5: Blocked drains at Dead Ends

Formation of Potholes: Structurally, most of the side drains are at bad condition and the resultant effect of this critical situation causes serious distresses and damages on pavement. The road edges suffered from detachment of asphalt layer due to continuous contact of water leading to stripping of asphalt from aggregates resulting in severe pavement distresses like potholes, washed pavement and edges failure (figure 6).

Figure 6: Severely failed edges and formation of potholes

The construction of drainages will be a waste when not properly maintained. The performance of a drain is attributed not only to how effective it is utilized, but also to the conditions therein. These conditions include the presence of waste, the presence of growing plants, weeds and siltation.

Some of the drains have dead ends such that transflow hardly occurs. As a result, sustained flooding of the area after a torrential rainfall is common. This provides breeding ground for mosquitoes which thrive on stagnant water, introduces other water associated health risks, and promotes structural failure of the adjacent road pavement.

Silt & Sediment Accumulation: Even after a little rainfall there is a formation and transportation of mud, silt and soil on the pavement and its edges. These unwanted materials are coming from failed, deteriorated and poorly maintained side drains & their structures. Pavement failures like potholes, ravelling, depressions, and silt sedimentation on depressions were followed as shown in figure 7.

Figure 7: Silt & mud pumping on road pavements

4.3 Investigating the Causes of Poor Drainage System

As per the interview and the researchers' field observation, the following main causes of poor drainage infrastructures are identified:

i) Design Problems: In general, most of the side drains provided to roads in Assosa town are observed and they built from earth materials, stones & concrete materials. Some of them are open to the environment; others are covered with concrete slab or blocks. Failures of built drains like collapse of bed, side walls and/or covers caused by improper design and construction, settlement may lead to the development of cracks and subsequent failure. Most of the drains channels are

designed by the engineers of the ministry of infrastructure or by consultants who have no experience of the drainage work. This leads to a situation where preliminary studies that will help the design and construction decisions are not done. This leads to poor understanding of the drainage which subsequently leads to poor design and construction of drainage system.

ii). Quality of Construction Materials: Use of low quality construction materials such as stone, concrete, adversely affects the quality of the drains and its structures. This sometimes occurs in the form of the improper concrete mixture for construction of drain channels. It is investigated that the use of soil of low bearing capacity as foundation bed, use of poor quality of concrete components and poor standards of stones leads to the failure of the drains and culverts. It is observed that concrete works are easily cracked and stone masonry works are simply crashed on the finished works/products.

iii). Solid Waste Dumping: The attitude of residents in communities under which these drainage channels are constructed and located is negative. From the investigation conducted and as seen in the photographs which taken from the drains sites during the field survey clearly shows that residents have converted the drains and the culverts into refuse dump places. This results in blockage of drains and its subsequent failures which in turn does negatively affect conditions of the road pavement.

iv). Effects of Poor Maintenance: Whenever the drains and their structures are well built they need adequate maintenance for sustainability. One of the main problems of drainage development in Assosa town is maintenance. The drains and culverts are rarely maintained and whenever maintenance is attempted it is done randomly. The financing of the maintenance, rehabilitation and conservation of the drainage

network had always been left to the government at the state and local levels who because of their lack of maintenance culture do not release funds for drainage maintenance at the appropriate time. The drainage network was therefore left to deteriorate.

v) Inadequate Drain Size: The dimensions of the drainage systems are not satisfactory for the respondents and the researchers as well. The width of the drains is less than 0.4m, and the depth is below 1m at some observation points. Many problems of diverse dimensions have been observed in association with the incidence of drainage problems in Assosa, and these are as follows. First, about 86(43%) of the respondents are of the view that one of the effects of drainage channel problem is the incidence of temporary street flooding due to size problems. Secondly, 67(33.5%) of the respondents have the view that the development of environmental deterioration consequent upon waste materials that spilled away from the drainage channels onto the land surfaces. Finally, 47(23.5 %) of the respondents are of the view that the problem of water being splashed on pedestrians or road users due to either drains blockage or non-existence of drainage channel.

vi). Poorly Executed Construction Jobs: In Ethiopia, it is not new that poorly executed construction jobs are to be the major factor which contributes to poor drainage and road pavement conditions. Some project contractors and consultants do not adhere strictly on the working drawings and the resultant effect of this negligence is poorly executed jobs. From the investigation conducted, it is noticed that the manholes and culverts are unfit in dimension, either greater or lesser than holes, widths vary within a meter length of drains, and the same is true for depths. The resultant long term effect of this condition if not checked will be a total collapse or failure of the

facility. To prevent this condition from occurring, it is highly advised that engineers handling construction jobs should executed them with strict adherence on the working drawings of that specific job. 127 (63.5%) of the respondents agreed that the dimensions of the drains have some problems that needs due considerations in the future.

4.4 Mitigation Measures to Control the Problem

In view of the above issues proposed and by combining with the local actual situation, effective, rational, economic and feasible corrective measures are to be developed to tackle the problems. In general, the following main points should be considered:

A) Improved Facility Management Service: facility maintenance service is the integrated management to enhance the performance of the infrastructure. Facility maintenance is often seen as an annoyance or as a "necessary evil." This is partially due to the assumption that facility maintenance generates costs but does not give much in return. What is not understood is that high-quality maintenance has many positive, mostly indirect, effects on the infrastructure performance. In most towns of Ethiopia, asset management practice is poor; most infrastructures are maintained if there is some ceremonies. The situation here in Assosa is not different from this, which needs improvement by the concerned bodies.

B) Maintenance of Existing Drains: As we observed and reinforced by 131 (65.5%) of the interviewers, cleaning up and maintenance before the rainy season should be done in all the channels to avoid sedimentation and siltation which are one of the main causes of poor drainage. The respondents confirmed that if this is put in place it will mitigate the problem of stagnant water and flooding problems significantly in the town.

C) Construction of Additional Drains: As there are areas without storm water drains (like new settlements, some parts of kebele 03 and most of the outreach areas), the construction of additional drainage infrastructure is a must at the study area. Considering the slope of the area and runoff condition, it is recommended that provide drainage system the victim area. There are also local earth roads which have no drainage system at all. These roads are unwalkable during the rainy season because of mud accumulation. So these unpaved roads should be reconsidered without any precondition.

D) Sustainable Urban Drainage Systems (SUDS): The current drainage system is conventional drainage type at the study area. But it is better to develop sustainable urban drainage systems (SUDS) to improve drainage and reduce the volume of surface at the study area. The use of green space in the design of SUDS allows water to be controlled using trees and vegetation, green roofs, ponds and wetlands. Green roofs can especially be implemented in order to increase interception, storm water storage and evaporation in highly urbanised areas where the space to introduce green infrastructure is restricted.

E) Awareness Creation at Community Level: It is observed and supported by 104 (52%) respondents that the attitude of some urban communities is poor towards drainage system. A paradigm shift of the behavioural pattern of the urban community (with respect to indiscriminate dumping of refuse, building without leaving appropriate setbacks, etc) is very crucial to the mitigation of flooding in the study area. This can be done by formulating a wide campaign on public awareness and sensitization through seminars and workshops concerning environmental protection.

F) Dust Bins: 109(54.5%) of the respondents requested that garbage containers should be provided at central and selected

place. Therefore, by providing garbage containers on arterial and collector roads or by encouraging small enterprises it is better to reduce the dumping of solid waste in the open drains, manholes and culverts.

5. CONCLUSION AND RECOMMENDATIONS

Based on the study conducted to assess the impacts of poor drainage on the performance of road pavement, the following conclusions can be made: the impacts of poor drainage on the performance of road pavement is adverse, improper and inefficient drainage system and poor maintenance of existing drains highly reduced the performance of road pavement and its service life, proper planning and implementation is not observed at the study area. From the data of the study, the following recommendations are suggested for Ethiopia:

- Regular maintenance of drainage systems should be considered as an important part of maintaining and managing road infrastructures at the study area
- Any times, the improvement of drainage infrastructures should be considered as part of the road surface maintenance and improvement activities
- Not only the coverage but also the quality of the urban drainage infrastructure should be considered in the future, as drains are collapsed and failed before their design life.
- Making a scientific and reasonable plan as soon as possible and integrate the drain network construction, in order to improve the dirt holding rate
- Improve drainage systems towards better separation between rainwater and sewage collection to avoid illicit connections in some residential areas
- In general, upgrading urban drainage infrastructure service by preparing sustainable plan and feasibility study, improving existing drainage maintenance and effectively

manage of existing drainage infrastructures can keep the road pavement in good performance.

ACKNOWLEDGEMENT

The financial support from Assosa University is highly acknowledged by the author. In addition, the author is thankful to all the editors and reviewers of the manuscript from the Department of Civil Engineering of Assosa University.

REFERENCES

1. Ajayi, J.O.K. (1993). Managing the Lagos metropolitan storm water runoff problems under structural adjustment. Published by African world press, Nigeria.
2. Central Statistical Agency, CSA, (2015), Addis Ababa, Ethiopia
3. Clarence, J. V. (1984). Applied stream sanitation, John Wiley and Sons New York.
4. Dagnachew Adugna Belete. (2011). Road and urban storm drainage network integration in Addis Ababa, Journal of Engineering and technology research, Vol 3: 217-225.
5. J. A. van Dort and M. G. Bos, (1980). Main drainage systems, Design and Management of Drainage Systems, Wageningen: ILRI press, 161–171.
6. Kokeb Zena. (2016). Challenges of Urban Drainage System in the Emerging Towns of Ethiopia: the Case Study of Assosa Town. International Journal of Science and Research (IJSR) Vol 5, issue 7, 301 – 306.
7. Kokeb Zena Besha & Addisu Adamu Alemayehu. (2016). Assessment of Road and Surface Water Drainage Condition in Urban Ethiopia with Special Reference of Assosa Town. European Academic Research, 4(2): 1966 -1991.

8. Magdi M.E. (2014). The Impacts of Poor Drainage on Road Performance in Khartoum. International Journal of Multidisciplinary and Scientific Emerging Research 3(1).
9. Ndiwalana, R. The challenges of surface water Drainage in Kampala District, Second Edition , Kampala 200, Claredon; oxford.
10. Raj Vir Singh, (1991). Drainage and salinity control. First Edition, Humanshu Publications Lagos Nigeria.
11. Raven Johnson Berg, (1993).Municipal waste water pollution, unpublished document
12. Rokade S., Agarwal P.K. and Shrivastava R. (2012). Study on drainage related performance of flexible highway pavements. International Journal of Advanced Engineering Technology, 3: 334-337.
13. Smission, R.P.M. (1980). The single pipe system for storm water management. Wat. Tech. 13, 203-214.
14. Sonuga F. (1993). Challenges of the drainage in the developing countries, in proc, 6th international Sounders College publishers.
15. World Bank Publications, (1996). Sanitation in developing countries, urban management, World Bank-Washington DC.