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ON THE EFFECTS OF GEOLOGICAL AND HYDROMETEOROLOGICAL FACTORS ON FAILURES AND DISTRESSES OF EARTH DAMS IN NORTH EASTERN NIGERIA

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ABSTRACT

Forty two earth dams were randomly selected and investigated in North-Eastern Nigeria to determine the geological and hydrometeorological factors responsible for their failures and distresses. The Association of State Dam Safety Officials (ASDO) method was used to ass's failures, distresses and functionality following a collection of data from Upper Benue River Basin Development Authority, States Ministries of Water Resources and the Nigerian Meteorological Agency. Site visits to randomly selected dams in the study area was done for observations and measurements. The geology of the study area is composed of Basement complex, Alluvium, Tertiary to recent Volcanics, Bima and Gombe Sandstones, Pindiga and Yolde formations, Granites and Igneous rocks among others. Of the dams sited on the Basement complex, 61, 27 and 11% were functional, failed and distressed respectively. The dams on Younger granites have an even number of failures and functionality. All the dams on Gombe sandstones and Pindiga formations are functional. The status of the dams were affected by two opposing scenarios, viz; the peak rainy season of August to September with monthly total rainfall ranging from 327.1mm to 478.8mm which recorded 75% of failures and distresses due to erosion, siltation and subsequent flooding. The dry season spanning October to February with monthly evaporation ranging from 354.6mm to 409.7mm and high temperatures in the range 39 - 43^{0}C witnessed 20% of dam failures with excessive loss of reservoir water by evaporation.

It is suggested that adequate geological and hydrometreological studies be conducted and data used to guide construction and reservoir operations. Grouting, Impervious blanket, incorporation of cut-off wall and some form of soil stabilisation of earth dams is necessary to enhance stability and minimise seepage.

KEYWORDS: Dam Failures, Geology, Hydrometeorology, North-Eastern Nigeria

INTRODUCTION

A dam is a barrier that blocks the flow of water and produces a reservoir. Artificial dams are built for water storage, flood control, electricity generation (Jackson, 2008) and as major source of irrigation water (Husnain and Tsugiyuki, 2009).

When designing a building or other structure on land, it is important to take into consideration the structural properties of the ground that supports the project. Adequate knowledge of ground conditions is very essential for analysis, design and construction of geotechnical systems (Adejumo *et al*., 2012). Project delays, failures and cost over-run are the results of inadequate and inappropriate sub-soil investigations. Thus, geotechnical investigation is an integral component of any civil engineering project.

It might be expected that progressive advances in dam design and construction techniques would result in lower incidence of failures. However, there may be some unforeseen factors that can produce unexpected problems. Added to this is the fact that most of the easy dam sites around the world have been utilized. Thus, some dam constructions have been done on progressively more difficult and geologically complex sites, which increases the probability of failure incidents (Wrechein and Mambretti, 2009). Despite the increasing safety of dams due to improved engineering knowledge and better construction quality, a full non-risk guarantee is not possible and an accident can occur, triggered by natural hazards, human actions, construction deficiencies and age.

Between 1900 and 1965, about 1% of the 9000 large dams in service throughout the world failed, while another 2% suffered serious accidents (Wrechein and Mambretti, 2009). Thandaveswara, (2007) and Wikipedia, (2012) have presented a comprehensive list of notable dam failures around the world spanning 1889 to 2012. Hope, (2003), Etiosa, (2006), Daily Triumphs, (2011), Lukman *et al*, (2011) and Ezugwu, (2013) have mentioned some dam failures in Nigeria.

There is paucity of data on the causes of earth dam's failures and distresses in north-eastern Nigeria. This study attempts to investigate the geological and hydrometeorological factors that influenced failure and distress of earth dams in north-eastern part of Nigeria and come up with engineering solutions capable of minimising failures and remedy distresses.

MATERIALS AND METHODS

The study was conducted using the Association of State Dam Safety Officials (ASDO, 2011) method. The method details dam failure investigation guidelines as recommended by the Dam Failure Investigation Committee.

Desktop research was used to establish a holistic database on the Geology and Hydrometeorology of the study area as well as relevant information on the earth dams. The Nigerian register of dams and past reports (archives) were consulted. The geological and hydrometeorological data related to dam failures, distresses and functionality were obtained from Upper Benue River Basin Development Authority, States Ministries of Water Resources and the Nigerian Meteorological Agency. Reports on past dam incidents was sourced from relevant organizations and a Geologic map was generated using arc GIS 9.3 version. Field work was conducted in form of visits to randomly selected dams in the study area for observations and measurements. The 42 dams investigated cut across North Eastern Nigeria with 25, 10 and 7 in Adamawa, Gombe and Bauchi states respectively.

RESULTS AND DISCUSSIONS

Geology Vs Dam Status

The status of the dams in the study area is detailed in Table 1.

Table 1; Status of Dams in the Study Area

Status	Number
Functional	21
Failed	11
Distressed	5
Under Construction	5
Total	**42**

In Figure 1 is presented the geological map of the study area as well as dam locations and status

The geology of the study area is composed of Basement complex, Alluvium, Tertiary to recent Volcanics, Bima and Gombe Sandstones, Yolde, Pindiga, Gombe and Kerri-kerri formations, Igneous rocks, Recent sediments, Younger sedimentary rocks and Younger granites. The GPS indicated that the dams in the study area are located on all these geological formations. Each of these geological formations poses the question of stability, water tightness and sound foundation for dams and reservoirs in the study area. Of the dams sited on the Basement complex, 61, 27 and 11% were functional, failed and distressed respectively.

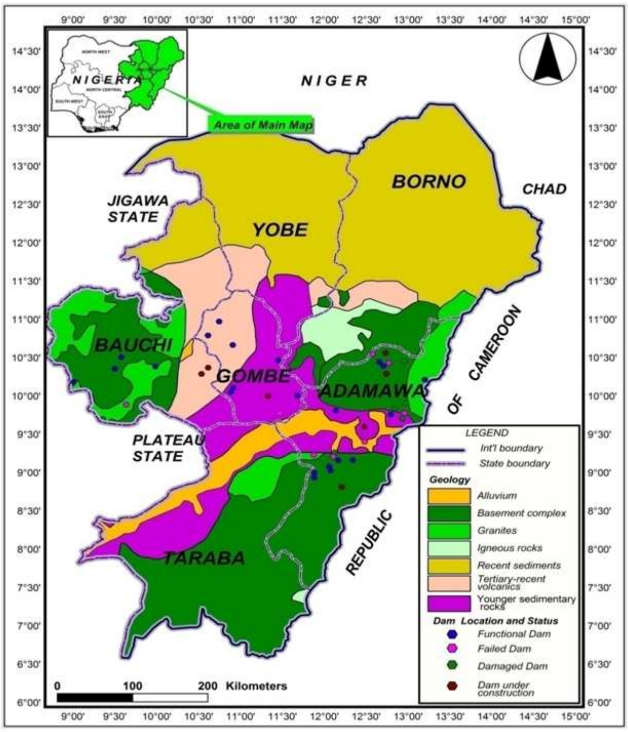

Figure 1

Table 2: Dams Locations on Geological Formations and Their Status

Geologic Formation	Status			
	Functional	**Failed**	**Distressed**	**Under Construction**
Basement Complex	10	6	2	1
Alluvium	-	1	-	1
Tertiary to Recent Volcanics	2	3	3	-
Bima Sandstone and Yolde formations	2	-	-	1
Gombe Sandstone	1	-	-	-
Pindiga formations	2	-	-	-
Kerri-kerri formations	3	-	-	2
Younger granites	1	1	-	-
Total	**21**	**11**	**5**	**5**

The characteristics of the basement complex as outlined by Adefila (1975) gave it the ability to be strong as a foundation material. Thus, it can support dams with little risk of failure. The nearly impermeable nature of the formation also allows it to retain water.

As reported by Offodile, (1992) the older and younger granite are hard, with low permeability and generally not water bearing. The high runoff and low infiltration rate encourage water retention and stability of the dams on these formations. For the dams on Younger granites, 50% failure and 50% functionality were recorded.

The Bima Sandstone which is found in parts of Gombe, consist of essentially feldspathic sandstones, grits, pebble beds and clays. It is highly crystalline and cemented. Under this condition, it presents the hydrogeological characteristics of Basement complex rock with secondary permeability only developed by means of fracturing, weathering and solution (Okafo, 1982). It is generally a good foundation material due to its poor permeability. About 70% of the dams located on Bima sandstone and Yolde formations are functional while the remaining 30% are under construction.

The overlaying Kerri-Kerri formation is a sequence of fine grained sandstones, clays and silts with some thin coal bands. The lithology changes rapidly both vertically and laterally as observed by Okafo (1982). Due to its looseness and coarseness, the Kerri-Kerri formation is stable with good bearing capacity. Sixty percent of the dams on Kerri-kerri formation were found to be fuctional while the remaining 40% are under construction.

The Gombe sandstone consists of a series of brownish well-bedded fine to medium grained sandstones, sandy and silty micaceous shales and mudstone (Okafo, 1982). The formation is generally impervious to some extent and fairly stable under loading. The dominant argillaceous materials further reduce the permeability considerably. All the dams on Gombe sandstones and Pindiga formations are functional.

The only completed dam sited on Alluvium has failed. Seventy-five percent of the dams found on Tertiary to recent Volcanics have either failed or are distressed, while the remaining 25% are functional.

Hydrometeorology Vs Dam Status

Table 3 highlights the period of failures and distressnes of the dams. Most of the dam failures and distress occur during peak rainfall months as a result of flooding, erosion, siltation and overtopping, while a few happen during peak dry season months due to excessive dryness coupled with high evaporation losses.

Table 3: Period of Failures and Distresses

Dam Name	Month of Incidence	Embankment Type	Status
Girei Dam	April	HE	Failed
GGR Dam2	March	HE	Failed
GGR Dam4	August	HE	Distressed
GGR Dam5	September	HE	Failed
Nzuzu Dam	September	HE	Failed
NGGR Dam1	April	HE	Distressed
NGGR Dam2	August	HE	Failed
Nasarawo Dam	September	HE	Failed
SBGR Dam1	September	HE	Distressed
SBGR Dam2	August	HE	Failed
SBGR Dam3	September	HE	Distressed
SBGR Dam4	September	HE	Distressed
Cham Dam	August	ZE	Failed
Bambam Dam	August	HE	Failed
Waya Dam	August and September	ZE	Repeated Failure but Rehabilitated
Dull Dam	August	HE	Failed

Key; GGR = Guyaku Grazing Reserve, NGGR = Nasarawo Gongoshi Grazing Reserve, SBGR = Sarau Belel Grazing Reserve, HE = Homogeneous Embankment, ZE = Zoned Embankment

Rainfall Factors

The main characteristics of rainfall in the study area are its seasonal nature and its variability from year to year. Similar studies (Ishaku et al., 2010, 2011 and 2013) in different parts of Nigeria show different rainfall patterns and variability. Change and variability in rainfall are important determinants of the need for dam construction, reason for construction and period of construction. This also suggest likely flooding seasons and therefore the risk of failure or distress when the reservoirs are being threatened by excess water from floods resulting from heavy storm events.

Table 4 shows a statistical summary of monthly rainfall for Adamawa from 1982 to 2010. Similar summary for Bauchi and Gombe are detailed in Umaru (2014). It was observed that rainfall in the study area sets in properly in March and ends in October/November of each year. The peak of rainfall occurs in the months of July and September. The dry season starts in October/November and spread to February of the following year. These observations agree with Offodile (1992), Adebayo and Umar (1999) and Lukman *et al.*, (2011).

Most of the dams under investigation exploit runoff from surrounding hills and seasonal streams in the reservoir catchment. Construction of earth dams in the study area helps to conserve excess water that is obtained during peak rainy season to be utilized during lean periods. The short period of rainy season calls for proper harnessing of the water resource by damming, while the long dry period allows for convenient construction on the sites. Construction during peak seasons is very difficult and expensive. Most of the dam failures occur during the period of peak rainfall due to excess flooding (Table 3). The status of the dams were affected by peak rainy periods with monthly rainfall ranging from 327.1 to 478 mm where about 75% of dam failures and distresses were recorded due to erosion, siltation and subsequent flooding.

Evaporation Factors

Evaporation in the study area is generally high. A statistical summary of evaporation in Dadinkowa area between 1982 and 2010 is presented in Table 5. The data and statistical summary for Yola and Bauchi is detailed in Umaru (2014). In general, evaporation outweighs rainfall. The mean daily evaporation values are slightly high for the dry season months of November - April with the highest values occurring between February and April. This is when the influence of the moisture laden south-westerlies is greatest.

This scenario results in high losses of water from the reservoirs by evaporation with consequent dam failures around the catchments. Twenty percent of dam failures and distresses occurred during the dry season months. This agrees with Ishaku and Majid, (2010).

Table 4: Statistical Summary of Monthly Total Rainfall (Mm) in Yola over a Period of 1982-2010

Rainfall	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average	-	-	19.0	36.8	112.5	128.8	244.2	202.3	182.4	59	7.4	-
Maximum	3.9	-	54.0	89.3	217.0	246.9	1991.1	437.8	355.2	192.6	15.4	-
Minimum	3.9	-	1.7	0.3	34.6	21.2	93.6	83.3	78.7	5.7	0.3	-
Median	3.9	-	14.9	37.6	115.3	115.1	193.4	199.7	183.2	49.9	6.95	-
SD	-	-	18.69	23.75	48.19	49.47	340.50	64.07	68.22	47.31	7.34	-
Skewness	-	-	1.15	0.58	0.27	0.65	5.15	1.44	0.57	1.68	0.15	-
Kurtosis	-	-	1.05	-0.09	-0.75	0.44	27.31	5.88	0.13	2.80	-4.56	-
Variance	-	-	349.66	564.19	2322.80	2447.39	115941.2	4106.17	4654.77	2238.55	53.95	-

Table 5: Statistical Summary of Monthly Total Evaporation (Mm) in Dadinkowa over a Period of 1982-2010

Evaporation	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average	226.6	257.5	314.3	303.1	317.6	227.1	201.9	180.6	244.2	164.1	210.0	210.2
Maximum	295.2	295.4	409.7	404.0	374.0	334.6	333.7	395.5	1995.6	233.5	329.6	291.7
Minimum	151.6	179.0	200.8	191.6	182.1	158.3	108.8	115.6	129.1	62.0	115.9	161.3
Median	231.0	267.6	316.0	310.8	305.9	212.9	189.1	165.8	163.3	162.2	208.5	215.3
Kurtosis	0.166	1.03	-0.05	-0.05	13.76	0.01	1.42	5.73	24.52	1.06	1.64	0.87
Skewness	-0.347	-1.192	-0.394	-0.203	3.654	0.759	1.044	2.096	4.932	-0.544	0.425	4.63
SD	34.96	30.15	56.31	51.75	81.09	45.29	48.60	61.48	366.41	39.86	47.19	333.22
Variance	1222.67	909.22	3171.93	2679.06	6576.99	2051.80	2362.74	3780.68	1342.61	1589.13	2227.71	1110.42

Table 6: Statistical Summary of Monthly Mean Maximum Temperature (^{O}c) in Bauchi over a Period of 1980-2010

Temperature	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average	30.8	33.7	36.8	37.7	35.8	32.9	30.6	29.6	30.8	32.7	33.3	31.4
Maximum	34	38.1	38.5	40	38.4	34.9	33	32.2	33.2	34	34.7	33.7
Minimum	24.9	30	34.5	29	32.2	29	28.8	28	29.8	31	30.8	28.9
Median	30.9	33.6	36.7	38.0	35.9	32.7	30.3	29.6	30.6	32.9	33.3	31.4
SD	2.23	1.96	0.98	1.84	1.28	1.17	1.03	0.86	0.78	0.78	1.03	1.25
Skewness	-0.743	0.001	-0.340	-3.659	-0.374	-0.815	0.527	0.652	1.312	-0.803	-0.663	-0.069
Kurtosis	0.121	-0.320	0.013	17.618	1.137	3.017	0.076	1.385	1.996	0.158	0.018	-0.895
Variance	4.96	3.82	0.95	3.38	1.63	1.37	1.06	0.74	0.61	0.61	1.05	1.55

Temperature Factors

The temperature in the study area is relatively high. The temperature recorded from Bauchi has been subjected to statistical analysis and is presented in Table 6. The mean daily maximum is close to 40^{o}C in March/April in Bauchi and rises to 43^{o}C within the same period in Yola. The minimum temperature for the study area is recorded in Dadinkowa with about 25^{o}C in December/January.

The high temperatures encourage the loss of water from the reservoirs through evaporation. This is highly disadvantageous and makes situation difficult for reservoirs to conserve water well into the drier seasons. This contributed to the failure of some dams in the study area with reservoir water drying up before the year runs out.

Relative Humidity (RH) Factors

Mean monthly relative humidity is generally low with no month experiencing values greater than 90% (Table 7). The mean monthly relative humidity is slightly high in the wet season of June to October. The maximum recorded in Yola is in the range of 82 to 90% in the months of June/July while the minimum for same station was 14% in February. Bauchi has a maximum RH of 88% in August and a minimum of 15% in February. The maximum for Gombe was 81% in August and minimum of 15% in February. This phenomenon is controlled by the influence of the moisture-laden south westerlies and moisture deficient north-easterlies. Offodile (1992) reported a similar trend of events for the country.This phenomenon again, subject the reservoirs to water losses especially during the dry season when the recharging rains and seasonal streams contribute little or nothing to reservoir storage. Low relative humidity encourages evaporation. This, coupled with high temperatures is responsible for some dam failures in the study area.

Table 7: Statistical Summary of Monthly Relative Humidity (%) in Yola over a Period of 1982-2010

Relative Humidity (RH)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Average	30	26	32	45	58	68	73	75	77	67	40	32
Maximum	45	44	76	88	79	90	82	86	87	80	52	53
Minimum	18	15	14	27	46	48	58	37	63	48	18	25
Median	28	23.5	30.5	44.5	60	68	75	79	78	69	39	30.5
Mode	27	21	33	47	49	68	76	79	77	70	39	26
SD	7.12	8.53	13.45	14.08	8.86	8.24	5.45	9.63	5.40	8.51	8.48	7.03
Skewness	0.30	0.84	1.33	1.23	0.30	0.06	-1.11	-2.80	-1.13	-1.01	-0.76	1.43
Variance	50.74	72.80	181.14	198.52	78.53	67.91	29.72	92.88	29.25	72.42	71.92	49.47
Kurtosis	-0.509	-0.427	2.914	2.264	-0.303	1.920	1.499	10.056	1.632	0.568	0.729	2.237

CONCLUSIONS

The study concludes that;

- There is paucity of data on failures and distresses of earth dams in North eastern Nigeria.
- The variants of Basement complex formations posses stability as well as water tightness for sound foundation of dams and their reservoirs.
- Younger granites formation present an equal chance of failure and functionality for dams built on them.
- Most of the dams located on Bima sandstone and Yolde formations are functional due to stability, water tightness and good load bearing nature of the formations.
- Majority of the dams found on the Kerri-Kerri formation are functional as a result of the stability and good bearing capacity of the formation.
- All the dams on Gombe sandstones and Pindiga formations are functional hence the formations are good as foundations for dams and reservoirs.
- Majority of the dam failures and distresses occur during the period of peak rainfall as a result of erosion, siltation and flooding by heavy storms.
- High losses of water from the reservoirs by evaporation driven by high temperatures and low relative humidity contributed to some dam failures in the dry seasons.
- The findings suggest that adequate analysis of geological and hydrometreological data be conducted before dam construction and reservoir operation.
- To maximise stability and minimise seepage, grouting, use of impervious blanket, incorporation of cut-off wall and other forms of soil stabilisation should be applied.
- Erosion should be minimised with adequate compaction, use of riprap and application of turfing sod on the embankment crest, upstream and downstream slopes.

REFERENCES

1. Adefila, S. F (1975); Decline in Pressure Head of "Middle Zone" Aquifer of the Chad Basin in parts of Southeastern Niger and Northeastern Nigeria. *Journal of Mining and Geology*. Vol. 12 No; 1& 2. P23
2. Adejumo T. W, Alhassan M. and Boiko I. L. (2012); Physico-mechanical Properties of Some Major Weak Soils in Nigeria. *Electronic Journal of Geotechnical Engineering*. Vol. 17 pp 2435-2441Retrieved 10thMay, 2013from EJGE.
3. Adebayo A. A and Umar S. A (1999); Hydrology and Water Resources. In: Adebayo A. A. and Tukur, A. L. (eds.) *Adamawa State in Maps.* Paraclete publishers, Yola, Nigeria pp 101-123.
4. ADSO (2011); Association of State Dam Safety Officials. *Dam Failure Investigation Guideline*. Dam Failure Investigation Committee.
5. Daily Triumph (2011); Enhancing Dams Operation in Nigeria. Daily Triumph News Paper of 4th March, 2011. Nigerian Newspers.com. Retrieved 4th Dec, 2011.
6. Etiosa, U. (2006): Dams are Unrenewable. *A Discussion Paper. Community Research and Development Centre, Nigeria* ; A Paper Submitted to Federal Ministry of Water Resources, Abuja, Nigeria.
7. Ezugwu C. N. (2013). Dam Development and Disasters in Nigeria. International Journal of Engineering Research and Technology Vol. 21 No. 9 pp 960 - 977
8. Hope, E.O (2003): Damned to be Dammed? A Case Study of Ojirami Dam in Southern Nigeria. *Society for Water and Public HealthProtection*. www.swaphep.virtualactivism.net (2003)
9. Husnain, T. W. and Tsugiyuki, M. (2009), Dissolved silica dynamics and phytoplankton population in Citarum watershed, Indonesia. Journal of Food, Agricultural and Environment, Vol. 7 No. 3 and 4 pp 655-661.
10. Ishaku H. T and Majid M. R. (2010). X-Raying Rainfall Pattern and Variability in North-eastern Nigeria: Impacts on Access to Water Supply. *Journal of Water Resources and Protection*. Vol. 2 No. 11 pp 952-959.
11. Ishaku H. T, Mohammed A. H, Fabian M. D, Ambros A. Z. and Ajayi A. P. (2010). Planning for Sustainable Water Supply through Partnership Approach in Wukari Town, Taraba State of Nigeria. *Journal of Water Resources and Protection*. Vol. 2 No. 10 pp 916-922.
12. Ishaku H. T, Majid R. M, Ajayi A. P. and Haruna A. (2011). Water Supply Dilemma in Nigerian Rural Communities: Looking towards the sky for an Answer. *Journal of Water Resources and Protection*. Vol. 3 No. 8 pp. 598-606.
13. Ishaku H. T, Ajayi P. A, Abdurrahman A. S. and Fabian M. D. (2013). Complementing Water Supply through Rainwater Harvesting in some Selected Villages of Sahel Savannah Ecological Zone in Borno State Northeastern Nigeria. *Journal of Water Resources and Protection*. Vol. 5, No. 2, pp. 200-207.
14. Jackson, D. C. (2008), "Dam" Microsoft Encarta (DVD). Redmond, W. A. Microsoft Corporation.
15. Lukman S, Otun J. A, Adie D. B, Ismail A and Oke I. A (2011). A Brief Assesement of a Dam and its Failure Prevention. *Journal of Failure Analysis and Prevention*. Vol. 11 pp97-109
16. Offodile, M.E (1992); An Approach to Ground Water Study and Development in Nigeria. Mecon Services, Jos

Nigeria.

17. Okafo, B.J.O (1982); Notes on Gravity Profile between Bauchi and Gombe across the Kerri-Kerri Formation. *Nig. Journal of Mining & Geology*. Vol. 19 No. 1 pp 278 – 279.
18. Thandaveswara B. S (2007); Hydraulics. *Indian Institute of Technology Mdras*
19. Umaru, A. B. (2014); Influence of Engineering Properties of the Soil, Geological and Hydrometerology factors on Failures and Distress of Earth Dams in North-eastern Nigeria. Unpublished Ph.D Thesis, Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan Nigeria.
20. Wikipedia Free Encyclopedia (2012). *Dam History*. Retrieved Apr. 27th, 2007 from http://en.wikipedia.org/wiki/Dam History.
21. Wrechien D. and Mambretti (2009). Dam-break Problems, Solutions and Case Studies. *WIT eLibrary*. WITpress Southampton, Boston USA.